Advances in Multimedia and Simulation. Human-Machine-Interface Implications

Proceedings of the Europe Chapter of the

Human Factors and Ergonomics Society

Annual Conference in Bochum,

November 1997

Klaus-Peter Holzhausen (Ed.)

Fachhochschule Bochum, University of Applied Sciences

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Advances in Multimedia and Simulation. Human-Machine-Interface Implications

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Klaus-Peter Holzhausen (Ed.)

Advances in Multimedia and Simulation. Human-Machine-Interface Implications – Klaus-Peter Holzhausen (Ed.) – Fachhochschule Bochum, University of Applied Sciences.

Proceedings of the Human Factors and Ergonomics Society Europe Chapter 1997 Annual Conference in Bochum, November 1997.

Keywords: ergonomics, human factors, multimedia, simulation, management of enterprises

Contents

HM-Human-Machine-Interface

DS- Defense System

AT1- Automotive and Traffic Applications 1

AT2- Automotive and Traffic Applications 2

AT3- Automotive and Traffic Applications 3

MS- Medical Systems

Acknowledgements

Prof.-Dr.-Ing. Klaus-Peter Holzhausen
Fachhochschule Bochum, University of Applied Sciences

The focus of the *Human Factors and Ergonomics Society Europe Chapter 1997 Annual Conference* in Bochum is on *Advances in Multimedia and Simulation* from the viewpoint of *Human-Machine-Interface Implications.* This very important and modern topic attracted more than 50 scientific papers. The conference enjoys contributions from important universities, research establishment as well as associations and firms.

I am grateful and proud that a major contribution was given by the *European Office of Advanced Research and Development (EOARD)* of the United States Air Force. This donation confirms the growing importance of our Chapter not only in Europe but also in the United States.

Another major contribution is given by the *ARAL AG.* We are especially grateful for this one, because the ARAL AG is one of the most important companies in our city of Bochum, a major employer in the Ruhr Region, and a leading German enterprise in the field of energy.

The host of this conference is the *Gesellschaft der Förderer der Fachhochschule Bochum e.V. (Fachhochschule Bochum Alumni Association).* The Alumni Association and my institute are responsible as local hosts for the organization and realization. The symposium would not have been possible without the support of our higher education institution, the Fachhochschule Bochum, University of Applied Sciences. The Fachhochschule Bochum is co-organizer of this scientific event. The President of our University, Rektor Prof. Dr. Martin Grote, is taking the opportunity to open the conference with a greeting address. Mrs. Gabriele Schäfer, *Mayor of the City of Bochum,* is going to convey the greetings of the City.

Dr. Harold van Cott, President of the Human Factors and Ergonomics Society in the United States, sent us a greeting address, which is in our proceedings.

I would like to thank Dr. h. c. Klaus Steilmann, Member of the Club of Rome, President and C.E.O. of the Bochum based Steilmann Group, for his keynote speech on *Multimedia and Management of Enterprises* that he is going to give on the conference.

My personal thanks are to all the contributors to this conference, the speakers, members of the organizing and the program committees, for their work and advice. I want to mention my colleagues of the Fachhochschule Bochum, who made this event happen, and I am very grateful to the many students and staff in my *Laboratory for Artificial Intelligence, Computer Graphics, and System Software (kiss-lab).*

Message to the Europe Chapter

Harold van Cott, Ph.D., President
Human Factors and Ergonomics Society

Professor Cavonius, Ladies and Gentlemen: Greetings to all of you here in Bochum at this meeting of the Europe Chapter of the Human Factors and Ergonomics Society. I had hoped to be here with you today, but an unavoidable, personal scheduling conflict prevented it. None-the-less, on behalf of the Society's Executive Council, I would like to wish you well for a successful conference.

In September, I attended the 1997 41st Annual Meeting of the HFES in Albuquerque, a small, historic city in central New Mexico. It was a busy week of renewed friendships, symposia, papers, posters, receptions, banquets, and tours. Late September is a good time to be in Albuquerque. Seeing the awesome Sandia mountain range emerge from morning twilight into a pure blue sky invigorates the soul for the day ahead. The days were long but gratifying. Evening meals with green chili stew, ostrich and buffalo steak were a novelty to tastes formed in the Eastern U.S.

In 1956, the HFES had its first meeting in Tulsa, Oklahoma. About 150 charter members, who had organized what was then called the Human Factors Society of America, were there. I was among them: green but enthusiastic. This year over 1.200 members from all over the world attended the Albuquerque meeting. I was there and became the 41st President of the Society. Today, I'm gray but still roaring to go. This is an exiting time to be a member of HFES. It will become more exiting as the society's strategic plan continues to unfold. As members assume society leadership roles and take on program activities, the accomplishments of the long-range plan will be increasingly felt, the society will flourish, and our profession will grow. This strong European Chapter is but one proof of the growing global human factors and ergonomics community. We are delighted that distinguished colleagues such as you are members.

Today I would like to tell you about the accomplishments in 1997 and the plans for 1998 of the Human Factors and Ergonomics Society.

A lot was accomplished in 1996/7. Our Web Site was running smoothly and was used extensively. The directory of graduate programs in human factors education and the author's guide to preparing manuscripts for publication were put on the Web Site.

Informing others outside the field of the benefits of applying human factors data and principles has always been a problem. Last year, an illustrated report, *Good Ergonomics is good Economics*, was published as a removable insert in our magazine, *Engineering in Design*. These case histories drawn from around the world, on the costs and benefits of human factors and ergonomics interventions, are available in either paper or electronic format from the Society's email address (hfes@compuserve.com). Slides and text of these stories may also be obtained from the Central Office for use in giving presentations. The success stories will be expanded and updated as members augment the current file of stories and pictures with material form their own experiences. I invite you to do so.

Feedback from focus groups and from a survey of all members showed that HFES should put more effort into reaching out to government and industry with education and information. In the past year, and with the combined strength derived from teaming with the Federation of Behavioral and Cognitive Sciences and the American Psychological Association, the HFES participated in programs to educate staff of the U.S. Congress on the value of the discipline and the importance of supporting funding for research and applications. Presentations and an exhibit were made at the Medical Device and Manufacturing Show. A policy and guidelines for conducting advocacy and outreach efforts was being developed.

Given that more of our members are moving into small business and independent consulting, we decided to give workshops on forming and managing efforts in these areas for the first time in Albuquerque. Enrollment and participant enthusiasm was high, and similar workshops are contemplated for 1998.

With funding in hand from two founding partner companies- Sun Microsystems, Inc. And the Eastman Kodak Company- the HFES Institute became a dream turned in reality. The Institute will provide a badly needed mechanism for procuring research data needed to fill critical data gaps in new industry standards, guidelines and best practices.

Volunteers are the life-blood of HFES. More are needed if we are to enhance, strengthen and extend our efforts. But good training is required for volunteers to become truly effective. This year, again for the first time, a Leadership Day for local and student chapter presidents and technical group chairs was held. Over 80 enthusiastic participants shared experiences, identified common problems, and started to build plans for solutions to them. Many of those present had not met before and formed ties. It was a good start on the way to our goal of amplifying the capability of the Executive Council to plan and manage our many new initiatives.

Here are some examples of new efforts scheduled for 1997-98:

Two new collections of papers from the *Proceedings* will be published on topics of high current professional and public interest. One will be on design for the aging population. The other will cover papers on musculosceletal disorders and manual handling.

Two important surveys are planned for 1998. One will be a survey of member needs and preferences for the electronic delivery of mail. The other will be a detailed survey of salaries.

If your arms ached or your wallet shrunk from carrying or mailing home the two volumes of annual meeting proceedings, be of good cheer. Relief form transporting the growing bulk of the *Proceedings* is in sight Next year, they will be available on CD-ROM in a searchable format, as well as in traditional hard copy. In addition, a portion of cumulative index of our journal may be included on a trial basis on CD-ROM.

Students are always broke. Next year, student members will be able to receive a 50% discount off full member dues. For the first time two years following graduation while they are getting professionally established.

Next year the Executive Council will continue strategic planning, monitor current programs, plan new initiatives, and invite feedback and ideas from all members. To do all of these things well, the Council will meet quarterly. Additional outreach efforts, leadership forums, practitioner workshops and issues of membership recruitment and retention will be given high priority at these meetings.

As for my own agenda as President, I plan to revive the dormant Technical Advisory Group to advise the Council on emerging opportunities for the application of our science and technology, and for the actions that HFES can take to be proactive in the pursuit of these opportunities. After learning about the struggles of our chapters simply to survive, to hold meetings and to communicate with members, I plan to explore ways to help chapters and the technical groups to establish listservers to enhance communication among their members and with other chapters and HFES. I also plan to visit local and student chapters. I will continue to support HFES' standards activities and the new HFES Institute, and I will work with the Council of Technical Groups on a plan to create a "NewsletterDigest", a publication drawing from the best, most interesting and useful articles in the newsletters published by the Technical Groups.

In concluding, I invite you, the members of the Europe Chapter, to send me suggestions and ideas about how to strengthen the Society and advance the science and practice of human factors and ergonomics. Your perspectives as colleagues who live and work outside of North America, will provide us with insights on new research methods and applications that will enrich our common endeavors. My email address is HPVANCOTT@AOL.COM.

Thank you for inviting me to attend this meeting. I am sorry that I can not be with you. I trust that you will find his to be a worth while conference. Have fun as well!

Multimedia and Management of Enterprises

Dr. h. c. Klaus Steilmann
Member Club of Rome
President and C.E.O. of the Steilmann Group, Bochum-Wattenscheid

Introduction

The speed of technical development in the area of new information and communication technologies can hardly be correctly estimated. For trend researchers, politicians, and "economic gurus" Multimedia when associated with terms such as information society, data highway and digital era promises solutions for the greatest problems of the 21st century: worldwide peace, global growth and unemployment. Technical opportunities that are concealed behind the shimmering term, Multimedia, are definitely impressive. The combination of communication systems, telephone, data networks, and communication satellites with other means of communication such as television, computer, fax machine, and radio offers users the perspective of worldwide interactive connection. In addition to real corporations, more and more virtual firms will be developed, creating a so called "cyber industry". These virtual corporations are agile, global, "cybernetic", and fast learning companies, which will expedite the evolution of the business worlds in a decisive manner. Cyber corporations are part of modern economic systems, which show similar behavioral patterns to biological ecosystems. They connect multiple industries and compete for synergetic effects and predominance in the jungle of competition. James Martin distinguishes three kinds of intelligent Darwinist-like evolution (Martin, 1997a). The primary type of evolution relates to the modification of a product or service while maintaining a predefined manufacturing process and a fixed structure of the corporation. The secondary type of evolution refers to the modification of the production process, the methodology or the workflow. In this context the structure of the corporation can be adapted appropriately. The tertiary type of evolution investigates factors outside of the company, termed the framing condition, i.e. relations to other companies.

My long standing experiences as an entrepreneur proved these evolutions not only to be typical for cyber enterprises but also necessary for the development of corporations today. Yet, the concentration on the tertiary type of evolution will be considerably increased as more cyber corporations emerge. Multimedia is literally the combined use of different media, more precisely, use of such media that utilizes different human senses such as the visual and the auditory systems. So far, Multimedia has had several different effects. Multimedia is not only comprised of multiple modes of information, but also computer integration and/or computer support. The overall effect is a computer supported media integration process. The user has time-independent access on information, digital processing, storage and proliferation of this data and also the option to interact and communicate at any time (Hermanns; Suckrow, 1993. Gräbner; Lang 1992. Stippel, 1992).

For my subsequent explanations and arguments, I would like to use the term Multimedia synonymously with Multimedia techniques for new information and communication technologies. I choose to do this because there are a great number of different interpretations and definitions for Multimedia, even if these compose a more complex scope than original sense. For reflections on changes in business and management this definition is very useful. I do not want to concern myself with all technical parameters at this time.

Many authors have dealt with Multimedia definitions under the viewpoint of assessing social aspects of new technologies. Many more authors have described social aspects of new technology without even mentioning Multimedia. The reason for is that Multimedia is a comparatively new term, though selected elements of it have long existed, subsumed under terms like new techniques, computer networking, hypermedia etc. Many books included in the bibliography therefore do not explicitly address Multimedia but nevertheless contribute significantly to social aspects of computer applications, the influence of computer networking to management and the consequences of connecting enterprises worldwide.

Unfortunately I cannot cite and evaluate the literature covering these topics in detail. Yet a number of books or studies will be mentioned and cited in brief throughout this paper if necessary to further clarify my statements.

Multimedia in the Sociological Evolution

The protagonists of new technology address Multimedia as the most important revolution since the invention of fire (Spiegel Spezial, 1996a). The term Information Society is frequently used here without analyzing the true content of the term. The following basic understanding which is of crucial importance is frequently forgotten: "Society cannot be reduced to information. Economical, ecological, social, and psychological conditions form the foundation of life and not only information (Höfling, 1996).

There are currently four extreme views of Multimedia. They are:

- A warning that Multimedia destabilizes established sound structures in all areas,
- The tendency to expect a great "hausse" (boom or bull-market) for society, economics, and consumer, a true thrill,
- The expectation of a "baisse" (fall or bear-market), a doomsday-like situation,
- The belief that the world will not change despite technical innovations.

Probably none of the four statements can truly characterize the consequences of this new technology alone. During a study initiated by the Office of Research on Consequences of Technology from the German Parliament in Bonn, different application areas of Multimedia technologies were covered, including the following:

- Multimedia in Business Applications
- New Media worlds in private households
- Multimedia in the public domain, i.e. for citizens and community
- Learning by Multimedia
- The new Multimedia vocabulary
- Computer support for radio

The study comprises nearly ten pages of consequences and suggestions (Riem; Wingert, 1996), that make clear that Multimedia greatly influences all areas of life and will result in profound changes in commercial activity. I do not want to restrict my analysis to the business and management processes as companies are embedded in sociological framing conditions, especially since the tertiary evolution constitutes the greatest challenges.

Changes in the social attitudes of people with respect to behavior while buying, relaxing or vacationing have a direct economic effect on values in the ecological situation. This is a very important issue for me. I am interested to see how people will take the challenge of Multimedia, how they will use their chances, see its risks and understand the innovative development of the information- and communication technologies that will become part of new organizational structures in business. I am eager to see new concepts of marketing and sales in certain aspects of principal policies. Learning will develop to be a complex challenge. From my understanding this challenge will not only relate to "learning with Multimedia", but to learning for and because of Multimedia. It cannot be overseen that in the public and in management on many different levels there is already a certain level of knowledge regarding the existence of Multimedia applications. Society on the other hand possesses only partial competence to use these new opportunities. Moreover, the risks of multimedia technologies are perceived very differently in practical work, everyday use, and by small and medium sized companies even though the theoretical aspects are well defined. There is still very little routine skill, know-how, and user experience available in these technologies on a broad scale. It is not only a requirement of school education to further develop these skills, but it is also an essential task for the management in businesses. This point I will further elaborate on later in this paper. Moreover, we will need a realistic calculation of national economy and business administration related facts to assess the ever accelerating physical and moral deterioration of new information- and communication technologies and software.

Only in the evolutionary context of society, a clearer understanding of Multimedia can be developed which is neither euphoric nor apocalyptic, but realistic. Businesses will be forced to approach these new technologies with a much stronger emphasis. They should do this on the basis of their critical engagement.

New Challenges to Democracy and Participatory Leadership in Industry

General access to information has a basic and profound sociological importance and is an important prerequisite for a democratic society and participatory leadership on the business level.

In conjunction with the possibilities to spread out new multimedia techniques, numerous new formats to democratize, monopolize, globalize, and respectively regionalize society and management will result. The jurisdictional framework for the new information and communication services has not yet been defined. Germany is one the first countries in the world to have developed such a framework. These new established standards focus on the principle of extensive deregulation, which promises free access, responsibility, and data protection specific to different areas. Yet, present laws are not fully accepted by the German economy. The main criticism exist against the following split governmental responsibility for different electronic services:

- German federal states are responsible for TV-shopping and Videotext,
- Internet and telebanking are under the sovereignty of the Federal Government.

There are no regulations within corporations regarding management.

The Federal Association of German Industry expects an increase in uncertainty with respect to legal problems and investment policies. They are also afraid that many businesses will leave the country, because increased requirements of data protection will highly influence the flow of data within the corporation. The further development of the legal framework is of crucial importance to the full use of labor potentials as documented by a study of the Council of Economic Advisors to the United States of America. According to the study, a significant increase in return from investment could be achieved by reduction of legal uncertainties, the elimination of restrictive regulations and the promotion of competition in telecommunication and in the telecommunication industry. Besides legal regulations, restrictions of access to use new technologies with respect to costs have to be taken into account. The new technologies presumably guarantee their users an equal access to global knowledge resources, information, and interactive participation in the opinion forming process in the corporation. It should be stressed that this is true only for potential users. Only those who have access and competence to use and exploit this information can derive benefits from these opportunities. Cost effectiveness plays a crucial role in the further development of management in the direction of participatory management.

There are no clear perspectives on the future price to use multimedia technologies. Many experts have the opinion that prices for information transfer will drastically decrease due to the complete liberalization of the telecommunication market. They predict that not only the promotion of mass access to technologies, such as the Internet and other new communication services, will be enforced. Mass access to information can be an opportunity for democratic processes in society and business. Right now the information highways are far too slow, unsafe, and too expensive for many potential users. In many companies the rules for the Intranet, the information and data exchange within the corporation, are just being defined. Whether or not more participation can really be achieved or whether fewer software moguls increase their power remains to be seen.

Even today Bill Gates is known as one of the most influential entrepreneurs in the world. He is in the position of acquiring the complete cultural inheritance of the world in negotiation with the great museums of all countries in the sense of buying the right to reproduce them. It is expected that access to Internet information, therefore use of Multimedia, will become more expensive the very minute when the integration of all business transactions, life experiences and educational processes of the majority of people is achieved. Experiences in the past show that we will have to expect additional fiscal and financial taxes in new dimensions.

Meanwhile powerful global multinational companies of information and communication technologies and media trusts have developed unknown amounts of power and political influence. National governments cannot practically oppose this power with appropriate countermeasures besides quarreling, as seen with TV-transmission times and communication channels. In this respect, there may arise new dangers to democracy. The influence of the national governments, as opposed by supranational organizations, regional interest groups and by competition of private firms, will be drastically reduced. Even data relating to individuals, their private consumption, shopping habits, preferences and liking will be ever more controlled by economic giants. The companies will be obliged to store and use personal data according to the technical state of the art with greatest possible care. This applies to the use of personal profiles and potential abuse of personal information.

The prominent German newspaper FAZ-Magazin predicts that democracy will be the great loser in the information society (FAZ-Magazin, 1996). Opinion polls via Internet will surely influence the work of governments and parliaments and thus undermine their ability to govern responsibly. Each individual, who is wealthy, educated and has Internet access becomes the winners. On the other side are millions and millions of illiterates with respect to computer technologies. Five billion social losers currently have no chance to access the net. Members of the industrial society look down contemptuously on "digital illiterates" or "homeless in cyberspace".

Even though globalization is a major trend now, there is also a trend towards regionalization. The "technocratic digitalos" and an increasing number of people turn to traditional structures to find their identity in small regional units. At the same time there can be seen another trend towards isolation and crisis through the lack of information. The reason for this trend is the power and financial influence of managers and owners of information. The same trend is obvious for the management and the participatory inclusion of coworkers in the corporation. The development of democratic processes globally, regionally in a country and in industry will be an important prerequisite in order to take countermeasures against possible negative tendencies and to intensify the use of positive impacts that new technologies may offer.

Opportunities and Challenges for Multimedia in Business

Technological innovations change products, production procedures, organizations, materials, and markets. In the clothing industry measuring equipment will be used increasingly to scan a human body in three dimensions and to produce scans in true color. These scans are used to show the final result and to cut the cloth appropriately. A day later the customer will receive his clothes perfectly made-to-measure by a direct delivery service. The scanned anthropomorphic data will be written to a Personal Body Card by the customer and the salesman for later use. The advent of high tech in the world of sales and the textile industry requires new solutions from cyberspace. The Textile/Clothing Technology Corporation (TC**2), a 200 firm consortium, demonstrated how a designer in New York cooperates with a customer using video-teleconferencing to design clothing made-to-measure.

Today it is not a technical problem for the customer to select from huge computerized fashion collection, the fashion pattern, the fabric, colors and texture, even the buttons and to display the customer dressed in his personal composition of clothing on a digital photograph. There will arise a threatening competition for those businesses selling clothing not made-to-order and it will be necessary for my company to take this new development of made-to-measure clothing with great attention.

The philosophy of buying will play an important role for the customer buying his clothing. Shopping will be an entertainment, trying on and rummaging will be a means of joy and reduce efforts to find the right clothes to a minimum. The greatest challenges for industry and management resulting from closer links between industry, trade, and the customer will be soon visible. The processes in and around enterprise are becoming more and more complex. A special situation attained by the direct connection that is now possible not only between trader and customer but also between producer and customer. For many production tasks basic strategic questions arise for businesses.

Opportunities for the industry are in an increase of efficiency with respect to internal communication and informational processes. These opportunities can be enhanced using data exchange, videoconferencing, tele supply samplings, and education. Even external communication is an important future application area of multimedia. Offers can be made using online services, consumers can be attracted using CD-ROM catalogues, and direct exchange of information can be possible using e-mail or automatic exchange of documents. Decentralized firms based on telecommuting have the advantage to produce specific to the customer's needs on schedule and be cost efficient. The market position of small and medium firms can be increased using state-of-the-art information and communication media.

The members of the "New Media" study group, amongst whose members were delegates of the Federal Government of Germany, defined these particular requirements for the business:

- More customer orientation by increasing the quality of offers,
- Increased fulfillment of global market opportunities (e.g. by marketing using the internet),
- Increase of the ability for innovation and readiness for new services and better performance orientation through more efficient use of technological potentials and new forms of cooperation in networks,
- Adaptation of the corporate identity to new technological opportunities such as decentralized organization, a stronger orientation of staff towards corporate identity, reduced number of management levels in the company management, lean and flat hierarchies, continuing education and qualification of staff in "learning enterprises".

Currently, the highest priority use of Multimedia is within the market-oriented management, a tendency called marketing-communication.

In America, 25% of the biggest corporations are represented on the Internet. Online, each company has the same market opportunities. New service providers can effectively compete against established firms, if they are smart, innovative and offer their clientele interesting presentations. Using multimedia technologies, e.g. the Internet, results in many advantages for all parts of a company and many opportunities for the management:

- Time effective processing of routine tasks,
- Increase of productivity and at the same time reduction of staff,
- More efficient use of resources and time saving,
- Improvement of the basis of planning and decision taking through better access to external information, early warning when trends change, retrieval of market research data, knowledge of different industries and economic trends,
- Enhancements in production by well-aimed selection of suppliers worldwide, direct communication with these suppliers, and online synchronization to reduce stock,
- Changed aspects of corporations using global access to electronic business, open communications channels, and increased customer contacts,
- More skillful product design using closer connections to designers and design consultants, cooperation with research establishments, continuous inclusion of new global trends,
- Using expanded marketing or micro-marketing oriented strategies according to indi-

vidual requirements and preferences, fast feedback, market research data, and continuous sales forecasts of trade companies worldwide,

- Better customer orientation, customer following precise orders and deliveries using faster access of skilled knowledge, problem solutions and product information,
- New chances for humanization of the world of labor,
- Improvements in the field of personnel management, using electronic curricula vitae, access to differentiated education, self-learning, information about jobs and careers in the corporations, hiring of self employed at-home workers and project oriented teams,
- More flexibility and at the same time more socially adequate organization of working time,
- Reformed information handling,
- Better and more cost effective communication, with new potential customers worldwide,
- Increase of professional knowledge offering chances for continuous exchange of experience,

and others.

Many corporations are starting to use the opportunities of the Internet by offering to their staff the chance to use this new medium, applying their own strategies and thus opening the net for important business processes.

As soon as corporations become more flexible and smaller, the importance of alliances for the success of the corporation will rise. Information management will develop as a key factor. Everybody who wants to initiate alliances successfully needs frictionless, properly timed and unhindered flow of information and communication. Corporations require international presence, "global sourcing". They also need development teams to cooperate worldwide using time differences to be innovative and creative 24 hours a day. There is an urgent need to define and optimize management information and information structures that are crucial for the business purpose and to reform process and informational structures as well as data architecture. To guarantee efficiency in management of information there are further requirements than simply technological competence. Virtuosity will be required for those who find synergies in knowledge resources with respect to a specific problem to derive innovative developments for the corporation.

This means drastic changes for the top management as well as the employees. It also requires continuous learning and a lot of intuitive selecting of information. The Internet is not only a source of relevant information but also a huge ocean of banalities with singularities of great value (Martin, 1997b).

Using Multimedia on the level of a corporation is more crucial to solving application problems than to technical aspects. In this respect, there are numerous new challenges for companies. Requirements relate to the development of worldwide new information sources, but also in designing a network of development and production stages. New virtual structures in organization and labor will develop in combination with new industrial processes that today cannot even be imagined. Integrated document management, diagnosis of technical systems using remote access and analysis systems will be even more effective using many new internal applications. Even now, there is definitely a fast reduction of hierarchies and a much faster flow of information using multimedia techniques. Management can be developed more efficiently and in a more process-oriented manner offering completely new possibilities in connection with multimedia customer service. Not only the introduction of computer oriented manufacturing, but especially computer supported, customer oriented, and interactive mass production-to-measure, will lead to the establishment of numerous new task areas. These applications within the corporation require permanent learning processes within industry. At the same time the development of intra-networks and changes in the overall communication structure require new efforts. The aim is to react in a timely, quality oriented, and predetermined way that is flexible to customer requirements. At the same time customers should be included in interactive design processes. This idea is already in preparation in the field of industrial mass confection made-to-measure. We can predict, especially in this professional area, most of the revolutionary consequences. At the same time there are new problems with security. These problems do not only relate to the increasing use of virtual money and digital signatures but also to new dangers of industry espionage and the potential breakdown of complete information systems and databases. In response to this I would like to study the problem of computer viruses and hackers. I would also like to study the problems of the intelligent theft encouraged by high tech systems that are not completely safe, especially since our industry is one of the most affected branches.

Changes in Management Processes due to Communication and Information Technologies

The possibilities for representing corporations and products on the Internet are plentiful and diverse. Company information and brands can be displayed and put forth. There are advertisements for many brands including promotional actions such as sponsored events, games, and price opportunities to attract customers. New ways of promotion are being developed using virtual showcases, Multimedia shops, video entertainment and shop radio. Shopping will become an "adventure journey", parts of the selection will be connected to product worlds or can be reorganized in new worlds by the customer himself. The Internet has received a degree of user-friendliness by its new graphical user interface, the World Wide Web.

Entrepreneurs and top management have to ask themselves whether the corporation shall be developed to a virtual corporation, a cyber-enterprise, and whether it is possible. They will also need to decide whether there is a profound strategic vision and whether there are qualifications and skills – or competence in the enterprise altogether- to face these new challenges.

New developments in information and communication technologies result in necessary changes for the corporation such as:

- Fast reaction to events and – if necessary- to take a favorable turn into a new direction of corporate strategy,
- Continuous improvement of products and services and introduction of new products,
- Ongoing development of applied strategies to permanently enhance and change products.

Speed of reaction in many situations will become a crucial factor in competition for:

- Recognizing requirements of new products,
- Bringing new products to market,
- Establishing new services,
- Improving products,
- Reacting to trends in fashion,
- Satisfying customer requirements,
- Controlling stock and distribution of goods.

Technical information and communication processes will put forth a significant contribution in these areas. We must be even more conscious of the fact that human communication is a decisive part of our culture that will be critically influenced especially by the new information and communication techniques and the use of multimedia. Using the new media there is a completely different form of communication between individuals. The digital age is understood by many people as birth of a new confidence that is based on digital principles. The completely new cultural aspects of life in our so called "global village", the new Internet culture, has not yet been researched sufficiently as of yet. In the "First Annual Report to the European Commission from the Information Society Forum" of June 1996 there was an introduction of 128 members of the Forum who were elected by the commission. Their background can be subsumed under five groups:

- users of the new technologies: industry (banks, retail, maritime etc.), public services, consumer groups, small and medium-sized enterprises and the professions
- social groups: academics, employers organizations, trade unions, youth groups, regional and city representatives
- content and service providers: publishers and authors, film and TV producers, broadcasters, computer software producers and information service providers
- network operators: telecommunications repair technicians, cable TV, mobile and satellite operators
- Institutions: members for Parliament, of the Economic and Social Committee of the Committee of the Regions and the data protection Commissioner.

In six working groups they dealt with the following questions

- the impact on the economy and employment
- basic social and democratic values in the „virtual community"
- the influence on public services
- education, training and learning in the Information Society
- the cultural dimension and the future of the media
- sustainable development, technology and infrastructure

These tasks are probably correct. Yet it is not clear whether they address the really decisive question in appropriate depth: the evaluation of information and knowledge.

Filtering the growing flood of information individually and converting information into applicable useful knowledge is, from my point of view, the primary purpose and presents the greatest challenge for today's managers. New multimedia systems should not only offer information, but also explain complex contexts in an acceptable manner. At the same time any information of any content should be able to be produced and offered globally.

From my understanding it is a fatal error to believe that more information also improves the quality of information. We all know from our practical experience that more information guarantees by no means a qualitatively new level of being informed. Even in the information age we must not oversee that useless information, redundant information, false information, misinformation, and catastrophic information serve no purpose as people are frequently flooded by data and are still hungry for the right information. Evaluation of information is therefore frequently more important than the information itself. This subject is a task that cannot be easily formalized on the corporate level. In how far multimedia information processing enhances and facilitates the adoption of knowledge by offering a better emotional access to our brain or whether it hampers knowledge acquisition by sacrificing resources to redundant information, will be a question of continuous learning within the corporation.

Consequences of Multimedia for Employment

The political consequences with respect to the task of new multimedia developments are many and complex. There is hardly an industry that will not be influenced by new technical innovations. The change of existing professions and the development of new ones will determine the organization of work. It will also be determined by changes of forms of cooperation within the corporations, between corporations, and in industry. Nevertheless, the potential for improved labor efficiency and effectiveness is highly controversial. One group understands Multimedia as the greatest hope for new workplaces, others define it as a "job-killer". As seen historically both sides are correct. Increases in production have lead to more growth and new jobs in the long run. Yet it is not clear how long it will take until production relevant increases of incomes will lead to a higher request for goods and as such compensate for prior effects of rationalization. Nobody can tell today which and where new products and services will develop and lead to a higher level of employment. Fourastié (Fourastié, 1954) based his theories on his so called 3-sector-model in which he predicted employment and technical development in agriculture and forestry, industry, and services related to employment as 10:10:80. Initiated by the OECD in the 70's, there was a reorganization of statistical measures taking a fourth sector, the information sector, into account. This sector was defined using a very wide scope. It included all administrational professions, the complete educational world, even foresters and inn keepers, and other "information processing" professions.

Multimedia inspires the imagination of many but for most of it is still in a state of experimentation. The most important purpose of the new information and communication technologies is to divert routine jobs to machines and then eliminate them. Computer technologies serve the purpose of increasing efficiency and quality in the corporation. Unskilled typists and low ranking managers who only conduct routine tasks can easily be replaced by cheap and reliable software products. The consequence of this is fear because finding a new job within the corporation is not likely. Everywhere, in production, in administration, or in the office, knowledge is used productively in a systematic way. Opportunities for effecting change are used in an optimal way, and cost will be reduced. Many experts talk about a new ethic of efficiency that is applied to all branches of the business and which are directly or indirectly linked with modern information- and communication technology.

Studies of the University of Würzburg, Germany, prove that more than 6.7 million jobs of the current 22 million jobs in this country could be cleared away by introducing the new information and communication technology. One example for the amount of potential workplace reduction is set out in the following table:

Professional Domain	**Employees 1996** (not part of the study)	**Estimated unemployed people** (after introduction of IT technologies)
Banking	771.667	473.718
Consulting	844.000	293.200
Education	914.233	249.426
Office	1.465.000	806.000
Health Services	839.192	293.941
Commerce	3.382.192	1.726.961
Public Administration	2.604.000	1.199.769
Planning	194.000	63.950
Cleaning	835.000	138.150
Others	1.609.000	304.430
Transport/Logistics	897.100	666.860
Renting	236.000	118.030
Insurance	660.400	390.400
Sales Promotion	80.000	15.150
Total	15.331.784	6.739.985

This relates especially to branches such as banks and insurance companies, consulting, health services, commerce, public services, transport, logistics, and simple service professions such as in renting offices, which are subject to rationalization even more. The already mentioned "First Annual Report to the European Commission from the Information Society Forum" underlines the findings from the point of view of the consequences with respect to employment using the following thesis:

"In order to maximize the job-creating benefits of the new technologies as quickly as possible, it is essential and urgent for companies and organizations of all sizes to adapt their organizations and structures. Until this process is well underway, the Information Society looks likely to destroy more jobs than it creates".

This strengthens the so-called "job-killing-thesis".

In the future the adapted principle of lifelong employment will be an unrealistic ideal. Outsourcing of processes in enterprise will increase. More and more work will be converted to self employed, free lancing and temporary jobs. A new highly competitive market will develop. Not only will telecommuting become more popular, but also improved flows of information will make work processes more flexible. It will become easier for firms to acquire external workers. The consequence will be that the corporations can work more effectively, be more decentralized, and can decrease in size. Telecommuting, teleservice, telecooperation, telecommunication, and even telefeeling will no doubt reduce personal and direct human contact even more. It will depend a great deal on the management how far the personality of a human employee and his chance for creativity and self-development will be dealt with. And it will also depend on the management for which positive or negative consequences the increasing number of virtual enterprises will bring about, that can be transferred from one location to another and easily seize and start operation.

A study of the German Institute for Work and Technology (Institut für Arbeit und Technik, 1997) shows that telecommuting or telework has a growing importance in combination with major shortcomings. Especially for women telecommuting offer new job opportunities but it does result in some disdvantages. Housework and professional work have to be performed at the same time increasing workload. Telecommuting also tends to reduce chances of a career because career is closely linked to presence in the enterprise.

Now I would like to talk about another consequence of Multimedia with respect to labor, which is the global competition for the company location. This is not only a competition between products and services but also a struggle for work places. Self-employed persons must be prepared for an intensified competition with respect to accomplishment and price for their products. Even developing countries possess highly specialized experts, who can access global markets without restrictions. From all these examples it is clear that the concern about the degree of employment is very justified.

After talking in detail about the negative aspects of the employment situation I would like to contribute to the position of "Promising Multimedia". We must not forget the positive employment tendencies. These tendencies promise to maintain employment and even define new workplaces using increased efficiency. Everything depends on the ability of structural change in the corporations and the position in the international competition. The optimistic attitude of many is based on the macroeconomic assumption, that earnings with respect to productivity cannot simply be ignored with respect to employment. Increased buying power in different areas will strengthen demand and help to develop new workplaces. But it is only speculation as to what extent this will happen.

Another thesis in the first annual report is the following:

„Telecommuting offers many job-creating possibilities and attractive improvements in working lifestyles, although, it raises many important issues for labor laws and collective bargaining. Public policy must facilitate, not obstruct, the development of telecommuting. Promoting a mix of home and office telecommuting is an effective way of handling fears that telecommuting exclusively in the home may be too isolating."

These sentences make clear that even the protagonists of Multimedia cannot contribute concretely to the blessings of new information and communication technologies.

The brief effect of rationalization cannot be avoided because the corporations are forced to produce as cost effectively and efficiently as possible to withstand international competition. Corporations must reduce product cycles and at the same time increase the variety of products and models. They must also reduce development and delivery times, increase product quality and invent customer oriented system solutions. Currently, there is no reasonable alternative to the new technologies, or else all workplaces would be endangered. In how far information technologies are used for the development of new products or to improve these products is also dependent on management and motivation as well as skill of the employees. Discovery of new problem areas will be an important challenge for the management.

To guarantee a good future standing of Germany as a major industrial player, the already mentioned working group "New Media" was founded. In this working group delegates of the German Federal Government and those organizations were represented that are "members of the inner circle of the Bundeskanzler", the Chancellor of the Federal Republic of Germany. In this working group positive influences with respect to the level of employment were identified, especially in the information and communication markets. Despite the uncertainty of the prognoses in a series of different studies, quantitative effects of employment were analyzed that could be initiated using new media. Results of an analysis of Prognos/DIW in Germany came to the conclusion that about 180.000 workplaces in economical branches could develop that belong to the media- and communication sector until the year 2010. The highest potentials are with so called "content-providers" and in the area of computer software as well as computer services. A study of the METIER- consortium for the European Union calculates that by expansion of new information and communication technologies up by year 2010 six million additional workplaces could be generated. From these six million workplaces –on a calculated basis- 1.5 million could be established in Germany. Such estimates suffer from a lot of methodological problems. As there are no concrete prognoses at the present time, we should concentrate on the fact that only the creation of mass markets will develop employment effectively. The potential of technical innovations can only be fully utilized if they are accompanied by complementary organizational changes in work and production. Information society alone cannot solve the problem of employment. The solution of that problem will by no means be possible without lifelong education and social innovation.

Electronic Shopping and Cybercash Unlimited

A completely new challenge for the future is the increasing use of electronic shopping for all enterprises. All business transactions will radically change, not only from use of electronic commerce and interactive data exchange, but even more by new digital worldwide shopping possibilities.

Buying habits will drastically change. We do not yet know which will be the "killer applications" of information society. To identify these killer applications, pilot projects should be conducted in sample population as much as possible. Not only the technical aspects of transaction must be tested, but also the readiness of the customer to buy and to pay.

What will the achievements of online shopping be? Once a customer has developed a need for a particular item they may search online for that item that best matches the price range and specifications they desire. The order could then be taken and acknowledged online. The customer would receive immediate acknowledgement of purchase. Using direct data entry checked by the customers themselves, transaction errors could be reduced and orders can be processed in a cost-effective way. The customer could make purchases easily and efficiently, without being restricted by business hours. Buying is made virtually stress free. In this way the customers needs are best served.

Presently single enterprises in industry and commerce estimate the future of multimedia shopping very differently. Still it is very probable that radical changes of the structure of commerce will happen in the next decade. This change requires a timely orientation towards these new buying procedures. The basic credo of the information society is that everything is available everywhere and any time.

Home shopping is not new to people. Mail order houses have guaranteed comfortable shopping for a long time. Yet, teleshopping will fundamentally change the presentation and display of the whole portfolio of goods. Buying will be possible 24 hours a day and worldwide. The inherent loss of sensual pleasure especially in fashion will establish some barriers but not change the basic trend. Until recently it could not be estimated what consequences this would have on small retail establishments or the larger commercial chains. However, with the development of online shopping, many chances emerge for commerce to manipulate consumer behavior. Individual shopping habits can be recorded, analyzed, and stored in databases able to generate complete buyer profiles for use in subsequent marketing decisions. With regards to global competition, borders between producers and commerce will change under the influence of these new technologies. Many producers plan to utilize direct sales, factory outlets, and new forms of electronic warehousing to boost sales.

New procedures in management such as efficient "consumer response" or "category management" are predecessors of this development. International regulations on product liability, advertisement, and consumer protection are becoming more and more necessary in a world of increasing electronic shopping.

Multimedia and Simulation: Human Machine Interface Implications

There is still another facet of Multimedia that I have not yet discussed. This aspect of Multimedia does not utilize this technology as an instrument for shopping or as a tool for today's managers to operate their enterprise. Instead, it is the aspect of Multimedia that makes work at a complex technical plant acceptable, makes modern systems controllable and guarantees safe and efficient operation of complex systems. This facet includes the aspects of leisurely use, entertainment, and both useful and joyful implications for humans.

Many aspects of our everyday life can only be accommodated through the use of technical support. As those supporting systems become more and more sophisticated, they will require increasingly complex technical equipment. More complex technical systems require an increase in the skills of the human operator to guarantee their safe and efficient use. Many studies with respect to reliability of human operators prove the great influence of the human factor. Reports of commissions to clear up accidents and malfunctions of complex technical systems contribute a great deal to these studies. Later in this chapter I'll try to develop a systematic approach to clarify in what areas of life and work such technical support is undeniable and something nobody should do without. More and more sophisticated technical support thus calls for a carefully optimized control station to reliably operate complex systems. As this optimization is not just a technical optimization, but has to include the human operator as well, it will be an iterative design process comprising both the technical system components and the human factor. The human factor can be optimized by developing refined and adapted methods of training. Thus even a sub-optimal system can still be controllable. The far better approach, though, is the adaptation of the technical system to the requirements and characteristics of the human operator.

There is a new term called "Paradox of the Information Technology" (Brödner, 1997). This paradox explains the divergence of technical functions and human-machine performance. The more complex technical systems are, the more performance would be expected. Frequently the contrary is happening. Making users believe that technical systems are intelligent may result in inadequate confidence into those systems. Therefore it is crucially important that complex systems explain the way of their decision making to the human operator. Here again an important aspect of the human-machine interface is described.

Adaptation of the system to man requires a careful analysis of human abilities and limitations. Multimedia is a more recent approach to displaying information at a control station in a more acceptable and multisensual manner. It is thus better suited to inform the responsible person(s) about the state of the technical system. Multimedia can also be a technology to broaden the channel of operator input to the system and thus facilitate interaction between human and technical systems components.

There is a new term for the interaction of complex technical systems using Multimedia support at a control station for safe and efficient operation. This term is the "Human Machine Interface" for the control of human machine systems. As already mentioned, optimized Human Machine Interfaces will use techniques available to make system operation more efficient, safer, and more acceptable to human operators. Traditional interfaces predominantly use the human visual sense for information display. This is the historical technique because craftsmen have during all times in history judged their work processes by looking at their work. Today the display is mostly an electronic display, a screen display offering graphics output rather than columns of figures. There are cyber helmets available today that literally offer a far closer view of remote or simulated environments. Using these Multimedia system components, a deeper navigation in the world of the

Human Machine Interface is supported. A new term to describe these aspects of human control of technical systems is "immersion" into the controlled process with the consequence of an ever more perfected "telepresence" wherever required. Many modern approaches offer auditory information in addition to visual data. From simple warning horns in the past, to stereo headsets for pilots offering voice warnings from the direction in which a malfunction is located. Vestibular clues are presented to pilots in a moving base flight simulator enhancing the fidelity of operation. There are even approaches using the haptic and olfactory senses of man. These multimedia information displays in conjunction with the data glove and other non traditional control devices complete the instrumentation of modern Human Machine Interfaces optimized from an ergonomic viewpoint operating with the support of Multimedia.

Multimedia and the Human Machine Interface are tightly linked. The optimization process is a topic for research establishments, universities, and ergonomic departments in industry to investigate. It is an interdisciplinary science including the disciplines of engineering, psychology, and work medicine. National and international organizations and associations are working in the field of Human Engineering or Human Factors Engineering in the research, development, and application as well as optimization and evaluation of Human Machine Interfaces. Beyond these are the Gesellschaft für Arbeitwissenschaft in Germany, the Ergonomics Society of Great Britain, the International Ergonomics Association (IEA) and the Human Factors and Ergonomics Society in the United States (HFES). For example, the HFES, more specifically its European Section, is organizing a conference on exactly the topic of "Multimedia and Simulation. Human Machine Interface Implications" in my city Bochum, Germany, in November 1997 (Holzhausen, 1997).

Now we know that Human Machine Interfaces are crucial to the interaction between a human and a complex technical system respectively its underlying process. Yet, multimedia Human Machine Interfaces do not only serve the purpose of controlling "real" physical processes. Frequently they are used to control "simulated" processes. Many people do not realize this, but simulations are very important today and very helpful. Experts can "model" a process even better if they know more about the process and describe it in a mathematical way. In this way the parameters influencing the processes will be recognized. The effect of these parameters and their changes on the process can then be determined. Important examples for such complex processes are the bloodflow in the human body, meteorology, or aerodynamic aircraft models.

Researchers, engineers and other experts can "use" the simulated system much like the real one, try to improve the model and afterwards use it for diagnosis, weather forecast or as basis for constructing a plane. Sometimes a simulation will be run at the same control station that is used to control the real process. One such example would be a traffic simulator connected with a real control system controlling traffic lights in a city in order to improve the community traffic flow.

One important criterion in a modern human engineered multimedia control station is the "factor time". The factor time can be very efficiently used to increase system performance, and safety. Real processes perform in "real time". All system components including the human operator must react in the real time frame. Simulation though can use time compression methods effectively to arrive at simulation results much faster than the real system. Meteorologists compute weather models independently of the real time, produce a weather forecast much faster, and distribute a gale warning in time. A simulation can also be conducted in "slow motion". This guarantees a much more detailed view for the human trying to understand turbulent effects of air behind an aircraft wing or in a blood vessel, especially if the Human Machine Interface offers adequate Multimedia support.

I hope I could make clear that Human Engineering and Multimedia promise great support to humans in a complicated world if it is properly designed and correctly applied.

Let me try to describe possible application areas to Multimedia in connection with Human Machine Interfaces through a short systematic approach. A lot of applications exist in traffic systems on land, in the water and in aeronautical applications. Many cockpit systems in modern cars, ships, and aircraft use multimedia support for navigation, diagnosis, and communication. The same is true in aerospace applications. The space shuttle requires many human engineered control systems to safeguard its operation.

Stationary control centers use Multimedia too. Examples are control of traffic systems, police forces or fire brigades, air traffic control and space systems. Operations of a space station, the Mars Rover, a Venus rocket, or the Hubble Telescope are unthinkable without simulation and Multimedia in the control room.

In logistics ever increasing demands require Multimedia for applications, such as management of truck fleets, the storage of goods in a warehouse or worldwide supply. Industry depends on Multimedia in all the well known "Computer Aided Technologies" such as CAD, CAE, CAD, and CAM or process control in a plant.

As already mentioned modern medicine makes use of Multimedia in diagnosis (Ultrasonic, tomography, data transmission between clinics and telepresentation of X-ray photographs), 3D man models and stereotactics in surgery and 3D endoscopy.

In research and development literature reviews using hypertext and hypermedia support are state of the art. Telelearning and Videoconferencing are widely adopted. New didactic concepts are being developed and applied in universities, home learning. Even virtual universities are coming into existence.

In architecture, applications such as urban development, reconstruction of antique sites, virtually real buildings are widely adopted. Navigation through such buildings as the famous Frauenkirche of Dresden, which was destroyed in World War II and now is under reconstruction, are possible.

Terrain models for ecological protection, seismographic measuring campaigns, or satellite image processing require Multimedia and human machine interface optimization.

Last but not least advertisement and entertainment are mass markets under heavy pressure and competition. Virtual reality, virtual actors, and tools for sophisticated merging of movies and computer graphics animation are practical examples for near perfect presentation of Multimedia techniques to humans.

What are the consequences and benefits of applying Multimedia to the design and operation of Human Machine Interfaces? First of all safety aspects require every possible effort. These safety aspects include both work safety with respect to employees and to the population living in the area. More productivity and more transactions per time and employee are achieved without increasing work strain or maybe even reducing it. Problem areas can be tackled that were never suited for man made solutions before. Employees can work with a higher degree of job satisfaction. They will be able to look upon their work as good, helpful, efficient, and ethical.

Modern Technology for Information and Communication, Pros and Cons of the Ecological Disaster

Information technology is also frequently sited as a core element in technical environmental protection. Computers in conjunction with sensors and actuators reduce the emission of vehicles, analyze dioxin concentrations, reduce power consumption of freezers, localize polluted areas, control heating systems, and detect illegal harvesting of the rain forest. Information networks help prevent environmental pollution and the abuse of valuable resources. Telecommuting delivers an important ecological contribution, by reducing the resources required for travelling and driving considerably, especially in the service sector. Construction of new roads will be unnecessary, the collapse of the traffic systems will be avoided. The people will not need to move, instead the data would travel. New information and communication techniques present an image that is ecologically acceptable: no malfunction, no air pollution and no exploitation of scarce resources.

But the ecological impact is not solely positive. Here are two different opinions: the first opinion states that the information and communication technologies give us hope to be delivered from the problem of environmental destruction and the second opinion argues that industrial processes and western ways of life are supported and reinforced by information technology. From this point of view the new technologies accelerate the consumption of ecological resources on earth. On one hand the networking of partners using screens, e-mails and modems can drastically reduce the use of resources and nature. On the other hand the development of these techniques from an ecological point of view show considerable disadvantages. The ecological balance of the new information and communication technologies is not as favorable as often pretended. According to calculations by the Institute for Climate Research, Environment and Energy based in Wuppertal, Germany, the "ecological package" of a 486 PC adds up to a total of 16 to 19 tons of resources. A state of the art production facility for semiconductor wafers consumes 240.000 KWh energy per day. Additionally, it requires 6.8 million liters of ionized water and 70.000 cubic meters of pure nitrogen per day. The so-called dematerialization using electronic processing and storage proves to be more and more a "green mythos". Thus the information market accelerates the waste of resources to a great extent. This can be shown even more drastically in connection with the use of paper. The paper consumption by a citizen of the Federal Republic of Germany increased from 126 kg in the year 1970 to 232 kg now. The Frankfurt, Germany based magazine "Öko Test" reports, that there would not be a single tree on earth once every Chinese person had the same paper consumption as a German. There are many other unsolved problems of ecology with respect to information and communication technology such as: emission of electro-smog, deposition and disposal of batteries, chassis and printed circuit boards, and the complete disposal of worn out computers. In this spirit I would like to state that the acceleration of technical and sociological developments initiated by the flow of information and communication on global scale contributes directly to the destruction of the environment and the creeping disintegration of society. As never before western ideals are distributed around the globe and lead to demands that revolutionize culture and way of life of other regions at a breathtaking speed. At the same time we recognize an increasing polarization of the rich and poor, especially with respect to information access. We must not overlook that today about 50% of mankind is not capable of using a telephone, even if they had access to one, much less, the capability of using an Internet account. A new ecology of media is required which would address the problem of disposal of the inevitable "information waste".

Effortless Learning or New Competition for Education

To receive or proliferate information, competence must be developed in the following areas: the „know-how" of information structure, the ability to evaluate information and to make it usable, the development of searching strategies, and the use of communication according to established rules. Multimedia development offers many new applications that require these qualifications: visualization of complex structures in science, new forms of work such as tele cooperation, telediagnosis in medicine and technical fields, telepublication, telelearning and –teaching.

There will be a global competition in the once national educational market. It is therefore important to start a comprehensive multimedia initiative for education and network oriented teaching. The competitiveness of single economies can only keep pace with global competition if network style thinking in school education and university teaching is established. In this manner, each economical location will be assessed as a scienctific site and as a place for information and communication. There will be a great new demand everyone to successfully export sufficient new knowledge into the global competition. This goal cannot be achieved by the industry alone. It requires a new and strategic cooperation between industry and communities, the state, and private or social educational institutions. Multimedia and network oriented education will enrich everyday learning in many ways. It will by no means be restricted to subjects such as computer science as it was in the past. More than ever, new media must be accepted and established as a tool in all subjects, including the complete course of all subjects beginning with the scientific/technical and ending with the musical/visual arts. The currently practiced format of multimedia learning using e-mail will be insufficient in the future. It is more important to acquire expertise in the practical application of multimedia communication techniques. A basic requirement for this is the education of teachers, professors, and university staff. Another requirement is the establishment of the necessary technical equipment. Taking into account all of the investment that is required for the reorganization of education using new multimedia learning there are considerable doubts that a fast implementation will be successful using public or community money alone. The universities are challenged at the same time to reconsider their present curricula from the viewpoint of Multimedia and to develop pedagogic didactic concepts. Focus must be on software for education and training. The development of "learning on demand" must be a subject for further research in order to understand its prerequisites and consequences better. One specific special danger is that, on different levels, at school, university, or administration, one waits for the other. A lot of time will be lost, as previously seen in many European states. Another challenge is the implementation of new technologies in the developing states, which requires even more effort. The 1996 initiative in Germany for "Internet access for all schools" must be further developed and fully implemented. The future costs for this initiative must also be taken into account. Along these lines, it should be pointed out again that transformation of our society into an information-based society should happen worldwide. On a global scope, there is a considerable lag in the developing countries, especially in the former Soviet Union and China. We clearly must see that in the next ten years more new knowledge will be processed and taught than in the previous 2500 years. The faster and the more comprehensively we address this task the greater the chances are that it will be successfully completed.

Using new information and communication technologies must become a general cultural tradition, including media education in professional education. Multimedia and network oriented education should not only be seen as only technical education but also as an opportunity to enrich learning playfully. Using these new technologies naturally, a new didactic and content-oriented creativity will be possible that allows more room for personal activities and individual learning. As the teacher acts only as a coach to help acquire knowledge, independence and responsibility of the student become more and more important. This proves once more that only easy access to Multimedia will help achieve acceptance of new technological development and helps promote these opportunities. Industry is also responsible for promotion of media education. The development of educational software should be designed for international use. As the problem of establishing multimedia techniques in industry is important in global competition, economics must maintain interest in encouraging educational initiatives so as not to fall behind the global standard.

Emotions and Virtual Reality

The ability to utilize new multimedia opportunities depends solely on the motivation of the end user. This motivation can be promoted using different strategies: the opportunity can be presented as entertainment or it can facilitate work. Only these capabilities will result in user acceptance, where the user explores each new interactive possibility step by step. Personal motivation is -from my understanding- the key around which all of us should design applications. We should use new techniques in ways that make them emotionally acceptable. Emotional relations will play a crucial role in the cyberspace era. Several studies prove that cyberspace will change emotional relations of humans at work. In addition, new emotions will be created to replace missing real contacts.

Traditional corporations very frequently ignore human feelings or even suppress them. But the work process is full of emotion. Enthusiasm, rage, fear, jealousy, pride, ambition, hatred, decisiveness, fury, and delight are all possible emotions generated by the prospect of a successfully completed project. Negative emotions support "work-to-rules" tendencies, positive emotions promote willingness to perform, productivity, quality, and finally customer satisfaction. It is important for companies to motivate their employees. To obtain this motivation, stimuli are required that are directly connected with customers' wishes, independent of the size of the office. Whether the cyber enterprise possesses better chances to develop its abilities in this area through more flexible structures has yet to be shown. We must remain aware that the customer will accept not everything that is technically practicable.

The integration of human thinking, acting, and decision processes is one of the greatest challenges for the future of multimedia. Neither nature nor human senses utilize "digitized" information. Nearly everything is "analog". It is not important to man that human feelings and sensual thrill such as smelling, tasting, viewing, listening, and loving can be implemented digitally. The effort of scientists to understand the human soul as an information processing system and to model it using mathematical equations may satisfy their ambition, but is of little help in eliminating human conflicts and contradictions of the presence. Not only the increasing number of religious, nationalistic, and racist wars support this thesis, but also the inherent conflicts in everyday human life. The new ideology of formalizing, digitizing, and generally making everything technically controllable sweeps the world, while defining power under the cover of multimedia democracy and plurality. Man can as such become dependent on new artificial/ technical worlds to replace the natural environment, forcing him to rely on new powers such as Bill Gates, Leo Kirch, Silvio Berlusconi and others. Along this line critics point out that Multimedia can lead to vicarious satisfaction and virtual reality without reference to the real world.

The resulting consequences of Multimedia on mankind and the possible increase of cultural differences cannot be predicted today. Human relations through electronic channels will serve to change emotions and an effect, which we may call "virtualization". Predecessors of "virtual children" are already available as toys and for those who do not want real children. A proof of this is the "Tamagochi"-cult from Japan. Its purpose is to feed and nurse an artificial computer egg like a living creature. The development and implementation of "soul-machines" as described in the previously cited article "Emo lebt" (Spiegel Spezial, 1996b) documents a possible trend. This trend makes me very thoughtful, it states that parents sooner or later may be satisfied with virtual children instead of real children. The blessings of Multimedia are Janus-faced. Even supporters of Multimedia must concede that in the end virtual conference dinners have no taste.

Change in Values by Multimedia

The transformation of our society into an information-based society requires not only state or private regulations worldwide, but also self-obligation and responsibility. The development of Multimedia technology will essentially change political systems in all countries. This has already been seen by the influence of media on the breakdown of communism. Consequently we are obliged to support reforming nations and not construct new electronic walls. Many new ethic and moral questions must be investigated due to this ongoing virtualization.

Because of conflict caused by lost values, changes of values, and inflation of values, personal attitudes and ways of thinking gain increasing weight. This creates great new challenges for politicians to establish regulations reaching much further than traditional laws which take morality absolutely seriously. The contradiction on all levels is that we mean well and hardly change our doings.

Using new information and communication technologies, people must be taught new aims for their life, learning, and work. Nobody's access to information must be hindered by another's monopoly on information. In conjunction with the increasing erosion of states' finances in all countries, a collapse would be inevitable because the planned developments could not be paid for. In this scenario new workplaces would not develop and social peace could not exist. The unity between nations would not be promoted but, as presently described by many authors, countries would be further differentiated in a global competition. In this case the technological revolution caused by Multimedia and data highways could become "man-eating" one day and eliminate their own children. This could happen in a way that we cannot foresee, as we could not foresee the catastrophes of the 20th century. On the other hand, the technological revolution could also produce new values promoting living or working together, international responsibility, family or traditional values, and regional affiliation in the best sense. An important question will be whether that the habits of man will change as quickly as media technologies and how many people will take part in this process. A pessimistic view on the development of the 21st century will not help to make the best out of the inevitable evolution. For that reason all business and management relevant questions should be viewed with critical optimism.

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Air Traffic Control Simulation and the Human Operator

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Abstract

Mobility is one of the great societal demands and air traffic is one mode of transport to serve this need. Substantial growth rates are predicted for future air traffic but the natural resources of real-estate, airspace, and human abilities required to accommodate much more air traffic become a limiting factor. A better utilization of given resources is needed, therefore, to increase air traffic capacity. One attempt in this direction is a more efficient air traffic management by the introduction of more automation and a better task sharing between the automated system elements and the human operator. A reconsideration of the role of the human operator, the develop-ment of an appropriate automation strategy and appropriate support tools, and the demonstration of concepts for a future air traffic management system are essential steps to achieve the goal. In this context the particular aspects of air traffic control simulation including human operators for the test and demonstration of air traffic control concepts are discussed and recent experiences are presented.

1. Introduction

Simulation in air traffic management research is one of the most used tools to achieve advances in air traffic management in Europe and world-wide. Different types of simulation exist. The fast-time simulation of air traffic, for instance, is an efficient means to assess future airspace and airport capacities, the expected flow of air traffic, and the delay of aircraft. Other topics are investigated best, however, in a real-time simulation of the respective air traffic scenario. These topics include - among others - the expected future demands on air traffic controllers and pilots or the performance and acceptability of advanced support tools onboard an aircraft and on the ground. Other areas are the use of a future air/ground data link and new procedures to control future air traffic more efficiently. Real-time simulation is the right choice in particular if human operators (air traffic controllers, pilots) take part in the simulation.

In the past these simulations have provided administrations, airport authorities, air traffic control authorities, and airlines with a realistic view and an interactive experience of future air traffic management tools and procedures. Experiences have shown that the availability of a high-performance real-time simulation not only is an efficient means for the design, development, assessment, and demonstration of future air traffic management and flight guidance systems and procedures. It is also a prerequisite for a successful acquisition of attractive new research contracts in air traffic management regarding automation and the future role of the human operator in air traffic management.

Air traffic control (ATC) is that element of air traffic management (ATM) which executes control over aircraft en-route and in the terminal area of airports. In the following recent experiences in ATC simulation with particular respect to the human operator are discussed.

2. *Current role of human factors/engineering in ATC*

As more and more functions of the human operator can be implemented by machines today the question is not how much can be automated but what degree of automation is acceptable responsibly. This, in turn, determines the role of the human operator and of its interfaces to the automated system. For instance, the Concept Document for the future European Air Traffic Management System (EATMS) lists as one of the principles for its development (EUROCONTROL, 1992):

> „The concept introduces new methods of task sharing between the automated system elements and the human operator. That development shall be carefully balanced in particular in relation to the responsibilities for traffic monitoring and decision making; this may set limits to the degree of automation. The man/machine interface is a key element of successful application of automation and of overall system performance."

The forecast of the potential future of the US Air Force (USAF, 1995) also lists among six identified essential capabilities „people" which includes things like modeling of the human operator, training, education, and human/machine interaction.

This much improved role of „people" and associated designs and developments of human/machine interactions and interfaces in comparison to the situation some years back cannot be overemphasized in times of severe cuts in funding and rearrangements of development priorities.

3. *Some fundamental considerations*

Human error will come, regardless of the quality of design and training. Suppressing human error is seen as a naive goal. A better approach would be to correct system ergonomics but keep the human in the loop (Amalberti, 1997). In recognition of this situation aviation research organizations, air traffic services and airport authorities are increasingly interested in real-time simulations and demonstrations of new developments in air traffic control automation before any final decision on their possible introduction is made. Questions of expected system performance, human operator workload and acceptance of a new system are to be answered.

Recent reviews and studies on the human operator and automation in ATC made or contracted by DLR are reported by Beyer (1996). According to the findings of Lenorovitz, Olason, Krois, and Tobey (1991) and Jackson (1989) the tasks of air traffic controllers can be summarized as follows:

- monitoring - what is the state of air traffic ?
- diagnosing - what happens and why ?
- planning - what options are available ?
- deciding - what option is optimum ?
- implementing - what implements an option best ?

A major issue of ATC automation is the transfer of cognitive functions from the human operator to machines. This approach to automation in ATC may lead to two self-contained lanes of functionality: one is present in the human operator and the other is implemented by the machine. Consequences are:

- From a functional and procedural point of view the machine must be able to handle the tactical control of air traffic and the strategic management of the flow of air traffic automatically.
- From an operational point of view there would be a partnership between the human operator and the machine: The human operator decides what type of machine support suits his momentary and foreseeable needs best and what tasks he can delegate to the machine for the time being.

This means in short: Automate as much as technically feasible but utilize machine functions only as far as responsibly acceptable. By this approach the human operator will be provided with a suite of tools to select from according to his needs and also with a chance to tune the tools in a way that their pace is matched to that of the human operator. Full authority is assumed by the human operator initially when new functions are introduced but this may change when the human operator gains better insight and more confidence into the new machine functions.

4. DLR's ATC simulation suite

The main target systems for air traffic management research and development are airports, aircraft, the airspace, and the air traffic. For obvious reasons it is next to impossible to utilize some of the target systems directly as an experimental platform to investigate new concepts of human/machine interaction in ATC and to evaluate new products and procedures. In 1970, therefore, the DLR began to establish virtual worlds of air traffic control and aircraft guidance by means of a simulation of these target systems with a high degree of realism. Major elements of the simulation are:

Airspace and air traffic simulation

A data base provides the infrastructure of the airspace of the Federal Republic of Germany and in particular of the extended terminal area of the airport of Frankfurt/Main. The data base includes all navigation data defined by ARINC specification 424, aircraft performance and weight data for a number of aircraft types as well as several different wind profiles. An air traffic generator uses the data base to create air traffic scenarios with a selectable mix of aircraft types and speeds, routes, wind conditions, departures, and destinations. These scenarios can be run repetitively to investigate the influence of new air traffic structures, operator support tools and operational procedures on the flow of air traffic, the resulting air transport capacity, and the workload of air traffic controllers.

Air traffic control simulation

The DLR Air Traffic Management and Operations Simulator (ATMOS) employs the airspace and air traffic data bases and the air traffic scenarios created by the air traffic generator to run the scenario and to feed the radar consoles of the air traffic controllers with realistically looking air traffic (fig. 1). ATMOS also accommodates new support tools for air traffic controllers to be investigated in a simulated operational scenario. A group of so-called pseudo-pilots (fig. 2) monitors the simulated aircraft, communicates with the air traffic controllers by voice or data link and implements advisories received from air traffic controllers by a modification of the state of aircraft under control. The air traffic controllers in turn monitor the aircraft reaction to a given advisory on their radar screens thereby closing the ATC control loop.

Simulation of the airport of Frankfurt/Main

A visual simulation of the airport of Frankfurt/Main provides views as seen from the working position of the tower controllers as well as from the working position of a pilot approaching at / departing from and taxiing on the airport of Frankfurt. The simulation includes the infrastructure of the airport (passenger buildings, hangars, navigation aids, runways, taxiways, etc.) as well as moving objects (approaching/ taxiing/departing aircraft, support vehicles). This photo-realistic representation of the airport is visualized by a 3-channel backprojection system. The three screens have a size of about 4 x 4 meters and provide a view of about 150 degrees horizontally by 40 degrees vertically.

The DLR test aircraft

The DLR operates the jet test aircraft ATTAS (Advanced Technologies Testing Aircraft System) with a rear experimental cockpit and a bi-directional air/ground data link. The test aircraft carries advanced avionic systems which co-operate with ATC in order to develop and negotiate an optimum space and time based flight path (4D trajectory) and to exchange situation information, sensor data, and planning information between the aircraft and the ground.

5. Application of DLR's ATC simulation suite

The views, concepts, and tools described in the previous chapters form the background of research at DLR in air traffic control with particular emphasis on the role and integration of the human operator in a future ATC system. A typical application is presented next.

First, a more general remark on ATC simulations in a European context: The simulation of a future European ATC system lives (and sometimes suffers) from the fact that a different education, training, and cultural background of air traffic controllers must be considered. Air traffic controller teams participating in ATC simulations are selected by their national authorities and are made available for a very limited period of time only at the place of the ATC simulation. No homogeneous nor representative group of test subjects can be expected. An attempt is made, therefore, to reduce differences within and between the groups of test subjects by intensive instruction, training, and demonstration of the new ATC scenarios and support tools to be investigated. This requires a substantial effort and consumes a major part of the time budget available for an experimental investigation.

5.1 An example: the PHARE demonstration PD/2

A successful application of an ATC simulation including human operators was run within the Programme for Harmonized Air Traffic Management Research in EUROCONTROL (PHARE). The objective of PHARE is to organize, co-ordinate and conduct studies and experiments aimed at providing and demonstrating the feasibility and merits of a future air-ground integrated air traffic management system in all phases of flight. The results of the program should help to refine the description of the future Air Traffic System concepts needed to satisfy demand and to provide information on the best transition from the current to a new system (EUROCONTROL, 1997). The program is currently planned to extend over a period from 1989 to 1998 with an overall cost of about 91 MECU. Participants are DERA and NATS in the UK, CENA and STNA in France, DFS and DLR in Germany, RLD/LVB and NLR in The Netherlands, and EUROCONTROL. DLR was in charge of the second PHARE Demonstration (PD/2) which focused on advanced tools for the management and control of arriving air traffic in the extended terminal area of an airport.

5.2 Experimental set-up of PD/2

The tools investigated in PD/2 were designed to transfer cognitive and planning functions of air traffic controllers to machines in an attempt to reduce the workload in a future air traffic scenario with much higher traffic volume than today (Schick and Tenoort, 1997). This approach to more efficient man/machine systems in ATC addresses the following general topics:

- time-based tactical and strategic control of air traffic in the extended terminal area of an airport,
- support of the human operator by „intelligent" machines in controlling arriving air traffic,
- delegation of tasks to machines by the human operator while maintaining ultimate responsibility.

An important assumption was that in the future more and more aircraft will be able to calculate and to implement space and time based flight trajectories onboard which fulfill the space and time constraints of a computer-based manager of arriving traffic on the ground. Future aircraft will be able to negotiate these trajectories with the arrival manager via an air/ground data link. Aircraft with this capability are called 4D-equipped aircraft. In PD/2 the ATTAS with its Experimental Flight Management System represented such a 4D-equipped aircraft.

The objectives of the experiment were:

- Determine the effect of various automated support tools on air traffic controller workload and arriving air traffic flow.
- Determine the effect of 4D-equipped aircraft on air traffic controller workload and arriving air traffic flow.
- Determine the degree of air traffic controller acceptance of new automated support tools.

Four test organizations were set-up as follows:

1. A reference operating mode representing current tools and procedures with spatial separation of arriving aircraft (Org0).
2. An advanced operating mode with automatic space and time (4D) based planning of aircraft trajectories, detection/resolution of planning conflicts on the ground, and a novel human/machine interface (Org1).
3. Same as Org1 but with 30% 4D-equipped aircraft of all arriving aircraft (Org2/30).

4. Same as Org2/30 but with 70% 4D-equipped aircraft of all arriving aircraft (Org2/70).

Each of the organizations was run with a medium and a high traffic load. The term „medium“ represented today's traffic demand while „high“ corresponded to about 33% more traffic demand than „medium“. Data was gathered at four different air traffic controller working positions (ACC tactical, Approach Pickup/Planner/Feeder).

Eight air traffic controller teams each consisting of 4 controllers from 7 European nations (France, Germany, Italy, The Netherlands, Romania, Sweden, United Kingdom) participated in the investigations.

Eight test runs per team - balanced by order - were recorded and analyzed. These included runs with medium and high traffic load for each of the four organizations Org0 to Org2/70. Quantitative statistical methods and non-parametric statistics based on matched pairs of observation were employed for data analysis.

5.3 Data acquisition in PD/2

Data was gathered in the following categories:

- System performance
  Number of landings, flight time, inbound delays, precision of delivery and flight accuracy, and aircraft separation.
- Air traffic controller workload
  Objective workload indicators included the number of ATC instructions issued, frequency of radio communications, and percentage of time spent for radio communication.
  The subjective workload estimates were obtained by the Subjective Workload Assessment Technique (SWAT) and by the NASA Task Load Index (TLX).
- Acceptance
  The air traffic controller acceptance of the simulation environment and training, human/machine interfaces, operational procedures, tools and functions was assessed by post-run debriefing interviews and questionnaires.

In addition all experimental runs were video-taped.

5.4 Representative results of PD/2

General findings

The results obtained showed that all teams were highly qualified and motivated, that they accepted their role in the experiment to test a simulated and not a pre-operational ATC system, and that they passed their training successfully and were able to participate in all phases of the experiment without problems. The teams rated the set-up of the experiment and the trials as being realistic and valid.

System performance

The results obtained showed that a medium traffic load could be handled almost equally well for all organizations Org0-Org2/70. Under high traffic load, however, it was immediately evident that Org0 reached its limits and that air traffic was handled much more smoothly with the more advanced organizations Org1-Org2. While in Org0 about 62 landings/hour were measured this value increased to about 64 landings/hour for Org1-Org2 for the same traffic demand (for comparison: landing one B747 aircraft more per hour (average) at Frankfurt/Main in reality could result in an annual profit of about 10 Mio. DM). Furthermore the variability of the number of landings per hour as well as of most other performance parameters like flight time, inbound delays, precision of delivery, and aircraft separation was considerably reduced for the more advanced organizations. This is because the advanced support tools provide a much improved predictability of the expected air traffic flow.

Air traffic controller workload

The objective workload indicators showed a high correlation with each other and a very uniform pattern of results. They indicated a workload reduction or no significant change of workload for the least advanced organization Org1 in comparison to the reference organization Org0 for the air traffic controller working position with the highest load (Pickup). However, for the more advanced organizations Org2/30 and Org2/70 a significant reduction of workload was measured for all air traffic controller working positions.

The subjective workload estimates collected by means of SWAT and TLX also correlated well with each other. The Pickup controllers rated their own workload considerably lower when they worked under Org1 in comparison to Org0. The Feeder controllers did not indicate any difference whereas the ACC West controllers experienced a bit more workload when changing from Org0 to Org1. However, the more advanced organizations Org2/30 and Org2/70 led to a reduction of perceived workload for all controller working positions.

The objective as well as the subjective measures of workload showed the same trend in workload reduction for the more advanced organizations together with some re-distribution of workload between the Approach and ACC working positions. But because of the low overall workload level of the ACC working position the slightly greater workload for Org1 and Org2 was considered to be within acceptable limits.

Acceptance

The human/machine interface characteristics (mouse as input device, availability of pop-up menus, display design such as color coding, display options like highlighting a selected trajectory) received a high degree of controller approval. Most operational aspects (support for safe traffic handling and „maintaining the picture", concept of handling 4D-equipped and non-equipped aircraft, partitioning of tasks between working positions) were also very well accepted.

From the results obtained by this experiment it was concluded that the concept of the more advanced organizations to control arriving traffic at an airport has proven its suitability. The concept has shown some potential to improve air traffic throughput and quality of service. Improvements can be achieved at acceptable levels of air traffic controller workload. Although the concept was approved by the participating air traffic controllers there is room for further improvements of the automated support tools.

6. *Further human/machine interface design experiences and observations*

The PHARE demonstration was only one of a number of experimental investigations in ATC at DLR with particular respect to the human operator. Further observations in similar experimental investigations showed that:

- Concerns were raised that better automation tools designed to enhance the performance of air traffic controllers may take away interesting tasks from the human operator he/she is able and willing to perform. The new tools may render certain jobs redundant.
- New monitoring tools provided information normally not available to the air traffic controller which was considered sensitive by the ATC authority. Selective access mechanisms had to be designed into the tools to control the availability of information to different parties.
- A new monitoring tool documented encounters of the legal operating limits too close sometimes when air traffic controllers tried their best to resolve a demanding situation. This type of documentation was not available in the past. Adverse effects on human operator motivation and performance were expected.
- When air traffic controllers were provided with the opportunity to select alternative colors/color schemes for a graphical user interface, only a small amount of experimentation with colors was observed. The air traffic controllers stayed with the color scheme offered by the design.
- In one case the color convergence and the focus of the monitors were not optimum. Therefore a light blue background of the screens was chosen to avoid too many different non-convergent colors and to achieve a certain level of apparent sharpness of the image. Knowing the background of this decision the air traffic controllers accepted the design very well.
- A color scheme for ATC consoles developed with great effort and care by one European nation and accepted by their national air traffic controllers did not find the same degree of acceptance by air traffic controllers of other European nations.

These and similar observations and experiences are going to be incorporated into human factors design guides for ATC systems. An example of such guide is the documentation „Human Factors in the Design and Evaluation of Air Traffic Control Systems“ by Cardosi and Murphy (1995).

7. *Conclusions*

Despite the progress of automation in air traffic management and control, the role of the human operator in arriving at safe, economic, and acceptable ATC systems of high performance gains increasing importance. This is accompanied by a growing demand of real-time ATC simulations to test and to demonstrate the benefits and acceptance of new automated support tools with particular respect to the role and the work of air traffic controllers before a final decision about their possible introduction into operational use is made. Experience has shown that human factors/engineering knowledge, an advanced automation strategy and a real-time ATC simulation in combination are a sound basis to serve the needs of research institutions, air services organizations and airports in the future development of air traffic control.

Figure 1: DLR Air Traffic Management and Operations Simulator (ATMOS).

Figure 2: ATMOS pseudo-pilot working positions.

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Horses for Courses - Simulation in Air Traffic Control

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Abstract

Simulation is the traditional method for the development of Air Traffic Control (ATC) systems. The Eurocontrol Experimental Centre houses an extremely flexible and advanced 'Real-Time' simulator, which is employed for the operational evaluation of developments in specific ATC systems, and for the development of generic future systems (ODID, PHARE etc.). Real-time simulations are expensive (about 100,000 ECU per hour), require skilled staff and participant controllers (up to 50 controllers and 20 staff) and take about a year to prepare. Faster and cheaper alternatives have therefore been developed. 'Fast-time' simulation uses a computer-based simulation, where the human controller is replaced by pre-defined algorithms and data values, and exists at various levels of detail (RAMS, EAM, SIMMOD). A single-person Real-Time simulator, (TRACON/Pro) with AI-based synthetic 'pilots' and speech generation and recognition is used for the evaluation of measuring tools. 'Rapid Prototyping' is used for the development and initial investigation of new displays. 'Part-task' simulations which investigate specific aspects of human performance are used to provide data on the speed and accuracy of human operators in ATC-related tasks. These data are used in Fast-Time simulation, and in operator-oriented simulations using generic and special-purpose Micro-SAINT models, to investigate generic changes to existing methods - use of computer-based inter-sector transfers, or multi-sector planning. Finally, small simplified models are developed on PC-compatibles to demonstrate more radical approaches to ATC. (DEMON and DEMFAST, for example, show the effects of a radical re-structuring of the ATC system using data-links, computer-based conflict monitoring and pre-evaluation of conflict resolution strategies).

Introduction

Eurocontrol is the European Organisation for the Security of Air Navigation. It is an international organisation established by treaty, to which 24 nations are currently signatories. The purpose of the organisation is to improve Air Traffic Control procedures throughout Europe.

The Eurocontrol Experimental Centre, at Bretigny-sur-Orge, near Paris, is concerned with the evaluation and development of ATC systems, and, to a lesser extent, with fundamental research into Air Traffic Control. Simulation has traditionally been, and remains, the major tool for these activities. The ways in which simulation is employed have diversified in recent years, so that the Centre now provides an instructive showcase for simulation methods for the investigation of complex multi-agent dynamic control systems.

"Horses for courses" is a traditional English proverb, meaning, literally, that you should choose a horse which suits the type of race you are riding in. In general, you should choose a tool that fits the task you are undertaking. In particular, in ATC research, you should choose the type of simulation method to suit the question you are asking.

Real-Time Simulation

The Eurocontrol Experimental Centre was originally devoted to, and literally built around, a Real-Time simulator. When this was originally built in 1967, it was the first digital Real-Time simulator in the world, based on a Telefunken TR4 digital computer. It was then, and probably remains, the only large simulator which is not tied to a particular real system. Each of the main components of the simulator: computer; piloting equipment; control room; video and recording systems has been replaced several times in the last thirty years, but, like Jack Hobbs's cricket bat, after three new handles and five new blades it is just as good as new. The current simulator is capable of running two large-scale simulations simultaneously. Simulated control rooms are constructed for each simulation, corresponding to the physical layout of the existing or proposed future system. Up to 40 control positions can be simulated simultaneously, representing up to a dozen sectors in one or more ATC centres. These control positions resemble the existing positions, providing similar functions to the controller. Strip bays and strip printers can be provided where needed, although Electronic Data Displays are increasingly used. Monochrome or colour-coded radar displays can be provided, using various sizes of display up to 20-inch (50 cm) square raster-scan displays showing 2,000 by 2000 pixel images in full colour. Additional 'feed' sectors are manned by EEC Controllers, who simulate the adjacent and underlying sectors. One or more 'pilot-operators' simulate the pilots of the aircraft in each sector. These pilot-operators, some of whom are qualified pilots in reality, translate the controller's orders into instructions to the computer, and speak the computer-generated messages (position reports, etc.) to the controllers. Several hundred aircraft may be simulated simultaneously. Simulated RTF and ground communications are provided and can be recorded. Where needed, data-links can be simulated. Elaborate video-recording equipment is available, and a special system, Ergo-ISA (Instantaneous Stress Analysis) (Hering and Coatleven, 1996) can be used to provide a virtually 'on-line' self-assessment of controller strain from each working position, displayed at the central simulation control position.

By any standards, this is a large system. The major costs lie, not in the hardware, but in the software of the system. Each Real-Time simulation consists of ten to forty exercises, each lasting one to two hours, spread over three to six weeks. For each simulation, route structures, sector layouts and traffic must be defined. Specific software functions must be programmed and communications and other links prepared and checked. (Our previous chief programmer, retiring after 25 years' experience, told me that he had never received a specification which did not have at least one major omission, sufficient to make the system inoperable.) The programming of a large, distributed, Real-Time simulation of this sort is very specialised skill, and is only slightly less complex than programming a real system. Even when the software is as close to complete as can be managed, the data representing the traffic must be prepared with extreme care, since controllers are very sensitive to abnormal traffic, such as heavy aircraft programmed to land on grass airfields. Apparently trivial inconsistencies can greatly affect the willingness of controllers to accept the realism of the simulation. About fifteen skilled staff are involved in the programming of current simulations and anticipating future requirements. A further ten are employed in collecting and preparing traffic data. (This is never entirely routine, even when a simulation is concerned with current and near-future traffic. When 'future systems' are being simulated, it is particularly difficult.) Each simulation is controlled by an experienced project leader, who is an experienced controller, with an assistant. Although the time-scale for a Real-Time simulation is about twelve to eighteen months, and we normally run about ten simulations a year, most project leaders are involved in several simulations at the same time,preparing one simulation, managing a second and reporting another. If we include the staff involved in procuring and maintaining equipment, in analysing the 50 megabytes of data from a routine simulation, producing training and briefing programs and documents and interim and final reports, finding accomodation for visiting controllers and for management visitors during the simulation, about a hundred staff are involved in the running of the Real-Time simulator.

A Real-Time simulator exercise is very expensive. If a technician fails to switch on the recording system for a ninety-minute exercise, it costs the equivalent of totally destroying the Centre's two best offical cars.

A Real-Time simulation is not undertaken lightly. The yearly programs are negotiated several years in advance. It takes about six to nine months to prepare a simulation, one or two months to run it and three or four to analyse it, although the major results are usually obvious during the running, and the customer often puts them into application without waiting for the formal report.

Real-time simulation is best used as a final verification of a well-researched system, or for revisions of the airspace of an existing system. It is, however, also used to investigate potential future systems.

Two major series of simulations have been carried out at EEC to investigate some significantly different systems. The first series of simulations (ODID - Operational Displays and Input Devices) took place in 1987 (ODID I, Prosser and David,1988a), 1988 (ODID II,Prosser and David,1988b), 1990-1991 (ODID III,Prosser et al 1991) and 1993 (ODID IV,Graham et al, 1991). These studied ways of presentation increasingly remote from the traditional. ODID IV, in fact, employed a widowing system using several innovative forms of display, and radar labels that could be expanded to provide full flight plans, and allowed the controller to record his instructions to the aircraft directly through the label. A great deal of attention was paid to the detailed ergonomic design of the display, which led to general recommendations (Jackson and Pichancourt, 1995), the use of colour being based, for example, on the recommendations of Reynolds and Metcalfe (1992).

The second set of simulations (PHARE - Program for Harmonised ATC Research in Europe) began with PD/1 (Autumn 1995), has now reached PD/2 (Autumn 1996), and will culminate in PD/3 (Spring 1998). These simulations involve radical innovations, such as the linking of Real-Time simulators in different member states, and data-link transmissions to real aircraft in flight. The financing, organisation and administration of such simulations involve tremendous efforts, and take a very long time.

From a research point-of-view, Real-Time simulation has other drawbacks. It is rarely possible to repeat an exercise, since the human variations introduced by the feed sector controllers and pilots introduce variations in the exact sequences of traffic, leading controllers to adopt different solutions to problems, so that the repeat exercise diverges from the original. Even where a close repetition is possible, the controller, being human, remembers his previous actions, particularly if he made mistakes, and does better the second time round. Comparisons between controllers are difficult, since each controller has a repertoire of preferred tactics, based on his working experience. Controllers tend to judge a system as a whole, so that a technically minor flaw may lead them to reject an otherwise promising system out of hand. On the other hand they often display a 'can-do' attitude, finding ways around flaws in official procedures, and sharing duties within a sector so that expected overloads do not happen. Admirable as this trait may be in real-life, it can totally distort a carefully planned simulation. Finally, however much effort is devoted to training, controllers continue learning throughout a simulation. (In real life, it takes a controller up to six months to 'learn' a new sector - in simulation he rarely occupies the same position for as much as a week). Properly balanced experimental designs are extremely hard to achieve.

Fast-Time Simulation

Historically, the first alternative to Real-Time simulation was Fast-Time simulation. This technique is purely computer-based, and uses essentially the same data generation and analysis procedures, but replaces the actual simulation by a computer-based simulation. While the software of the Real-Time simulator calculates and presents successive images with a fixed cycle time (usually 5 or ten seconds), a Fast-Time simulator maintains a store of future events, and carries then out in succession as fast as it can, advancing its 'internal clock' accordingly. If there is not much traffic, or if the level of detail required is low, this process may run much faster than Real-Time. On other occasions, 'Fast-Time' may run slower than 'Real-Time'. The original Eurocontrol Fast-Time model (EAM) has been through almost as many modifications and revisions as the Real-Time simulator, and its current avatar, called RAMS (Revised Arithmetic Simulator), is designed to share data generation and analysis software with the Real-Time system. Since human intervention is essentially eliminated, repeated runs of the same exercise should give identical results. Estimates of the probable workloads on controllers can be obtained, using a post-processor, which allocated pre-defined quantities of effort or working time for specific events. Fast-time simulation is inherently cheaper and more consistent than Real-Time simulation, but it lacks the error-detecting facility and self-awareness of Real-Time simulation. Where a controller in Real-Time simulation will stream aircraft so that potential conflicts do not happen, the Fast-time simulator will 'solve' individual conflicts as they occur, with no strategic insight.

Practically, Fast-Time simulations take nearly as long as Real-Time simulations, since the preparation and analysis phases are essentially similar. More exercises can be carried out, since a few hours, or days, of computer time are now cheap, and simple methods can be developed for modifying traffic samples to generate minor variation. Fast-Time simulation may be used by itself, or as a preliminary to a Real-Time simulation to weed out the more unpromising alternatives. (Vergne and Tewes,1996)

A Fast-Time simulation requires two or three months of preparation, about a month of running and about a month of analysis and reporting. About ten people are involved, mainly in data preparation, in liaison with the client and in analysis. Controllers are not required as such, although the team must contain, and is usually led by, staff with considerable control experience who can communicate effectively with the client.

SIMMOD

SIMMOD, developed by the US Federal Aviation Authority, is similar to the Eurocontrol Fast-Time simulator, except that it is more oriented towards airports and that it has some technical constraints on traffic behaviour. SIMMOD can be used to study the ground movement of aircraft, for which the EAM and RAMS are not suitable. It is not concerned with individual working positions, but with presenting a global appreciation of a set of alternative situations.

SIMMOD studies are mainly concerned with the physical movement of aircraft, and the alterations to be expected if procedures or facilities are changed. Watkins et al (1997) investigated the reduction of separation that could be applied if a moderate cross-wind was blowing wake vortices away from the runway, for example.

In general, SIMMOD studies take two or three months, and involve two or three staff.

TRACON

The TRACON/Pro simulator is a single-position autonomous Real-Time simulator. Initially designed as a training simulator in the USA, we use it as a test bed for measurement techniques for the main Real-Time simulator and for reality. It has some unusual features. Traffic can be generated relatively easily to produce representative samples, and can be made to behave in a more realistic manner than is usually the case in our main Real-Time simulator. Pilots can be 'programmed' to miss or misunderstand orders, and will refuse impossible or incorrect manoeuvres. Weather problems and communications failures can be simulated if desired. It can operate using voice recognition, provided the controller observes strict ICAO phraseology, and provided that he trains the system to recognise his voice. This task takes one to two hours, and leads to an average recognition rate of 94% allowing three repeats, in active control. The system generates a 'score' for each run, awarding points for correctly controlled aircraft, and deducting them for errors, and to a lesser extent for redundant orders. A first study (David and Pledger, 1995) showed that control using speech recognition was more efficient than control using keybord input of code instructions, possibly because the controller did not need to divert his attention from the screen whem using voice control. The same study showed that both the SWAT (Subjective Workload Assessment Technique) (Reid and Nygren 1988) and ISA (see above) produced a measurable decrease in control efficiency. We are currently using the TRACON/Pro system to evaluate some potential measures of 'strain', incuding the analysis of cortisol in saliva, and a test of the relative incidence of alpha-rhythm in the EEG with eyes open or shut. We intend to use it in future to evaluate other methods and to obtain base-line data on the time taken to perform common ATC operations.

TRACON/Pro comes as a unit, including compiled software. We are not, therefore, able to modify the human-computer interface in line with modern developments, but, as a basic test-bed it is sufficiently close to current practice as to be accepted by controllers

(A simple version of TRACON/Pro, lacking a separate screen for strips, strip printer and voice recognition facilities, is available as a computer game under the name TRACON II. We recommend this to students or experimenters needing a basic ATC simulation.)

A TRACON/Pro study takes about six weeks of planning, one to three days of controller participation for each controller, and a month of analysis.

Rapid Prototyping

Rapid Prototyping can in principle be used for the development and initial investigation of new and unorthodox ATC displays and methods (Broadbent 1993). Although some studies can be done on static images, it is generally necessary to provide dynamic images, which implies a background ATC model. Since communications are an integral part of ATC, it becomes necessary to provide some form of 'pilot-operator' and some form of 'feed controller'. Traffic must be more-or-less realistic, so that the rapid prototyping system becomes a miniature Real-Time simulator, with all the administrative and organisational problems that implies. For the moment, we are not pursuing this approach, although it may be necessary to meet some future problems.

GENERIC MicroSAINT Model

The 'GENERIC' model is a Fast-Time simulation model written in MicroSAINT, which is an event-based discrete-event simulation system. Micro-SAINT provides the underlying operating and analysis facilities and permits the user to define linked chains of events. GENERIC is essentially a mirror-image of RAMS and SIMMOD. Aircraft are defined only by their times of flight through successive sectors. Each sector is represented by a network which itself contains networks representing the activities of procedural and executive controllers. The tasks within the networks representing the individuals may require to joint activities of one or more individuals, and reqire times that may be fixed, normally or exponentially distributed. The probabilities that additional tasks will be required are defined by expressions reflecting the traffic density. Times before which tasks must be performed are carefully noted, and sequential dependencies observed. (For example, the executive controller cannot alter the flight path of an aircraft before the procedural controller has treated it.) The number of occasions where a task is not completed in time is recorded, as are the total occupation times for each controller.

We have used this model to investigate the probable workloads resulting from grouping several executive controllers under one procedural controller, and the effects of introducing a strategic 'super-planner' (David, 1997b)

Using this model requires a sound grasp of the principles of MicroSAINT, and close attention to the definitions of priority of tasks. It also requires reliable figures for the duration of standard ATC tasks. Subjective estimates, widely used for this purpose, have been shown to be unreliable, and the few available 'objective' measurements are, to put it mildly, obsolete (David 1972).

We hope to obtain more reliable figures by analysis of video and audio recordings of TRACON exercises, and to adapt the GENERIC model to a more modern version of MicroSAINT.

We will then use the model to complement Fast-time and other studies of aircraft movement to confirm that the corresponding workloads for controllers can be carried out in the available time, to make more detailed examinations of the consequences of assumptions about workload distributions, (For example, assuming that all activities take exactly the average time produces generally optimistic figures, while the times taken for most human ATC activities tend to be at least exponentially distributed) and to examine the consequences of changing operating methods. (For example, verbal coordination requires the simultaneous attention of both parties - computer-moderated coordination requires only sequential attention.)

Part-Task Simulations

Part-task simulations can be used to study specific aspects of ATC tasks, such as the choice of symbols for use in ATC labels (David and Thomas, 1996). Such studies must be taken with some reserve, since it is rarely clear how such items are used in practice, but they may be used to identify what subsequently appear to be obviously unsuitable choices. In the past, we have used standard IBM PCs with VGA colour screens as test-beds, writing the necessary display software in QuickBASIC, for speed and convenience. Part-task studies of this type should take from four to six weeks, and require the cooperation of controllers, or non-controllers for about one half day per individual. Since these part-tasks usually require basic perceptual abilities rather than integrated ATC skills, untrained volunteers can usually be substituted for controllers - always a scarce resource.

Demonstrators

Demonstrators are small, self-contained programs developed to demonstrate new concepts, or to afford practice in unfamiliar methods. They are usually written in relatively high-level languages and presented on PC compatibles. Training versions can be sent to participant controllers before they come to a simulation (as was done with ODID IV), or copies can be distributed to provide the opportunity for 'hands-on' experience with EEC Reports. For example, a 3.5 inch disk containing three demonstrators is distributed with EEC Report No. 307 (David, 1997a). These allow readers to compare models of the current system (DEMOLD), a radically revised system (DEMON) and a more tightly-coupled predictive system (DEMFAST).

More elaborate demonstrators are available at the Experimental Centre, for example, to demonstrate HIPS displays (Meckiff and Gibbs, 1994).

Demonstrators are usually constructed by one or two persons during a few weeks. They may be employed in formal experiments taking some months, but they are, more often, used to demonstrate features of planned or actual systems.

Conclusions

This brief outline shows the variety of simulation methods that are available at the Eurocontrol Experimental Centre. Some of these methods involve the active participation of skilled controllers (Real-Time simulation, TRACON/Pro), others are purely computer based (Fart-Time Simulation, SIMMOD, MicroSAINT), complemented by measirements of task times from isolated real activities (Part-Task simulation, Rapid Prototyping.) Each type of simulation is appropriate to particular problems, and it is only by an intelligent use of different methods that a fair approximation to reality can be achieved.

It should not be forgotten,however, that even the best simulation cannot guarantee that a system will pass the ultimate test, that of reality.

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(EEC Notes and Reports starred (*) below can be read at the Experimental Centre Website 'www.eurocontrol.fr'. Paper copies of all EEC publications are available on request to Mrs. J. Roelofsen, Eurocontrol Experimental Centre, BP 15 Bretigny-sur-Orge, 91222 CEDEX France - roe@eurocontrol.fr.)

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PC-based training for Air Traffic Controllers

A feasibility study

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Abstract

To meet the needs of growing air traffic, new air traffic control (ATC) systems are being constantly developed. Training air traffic controllers to operate these systems requires a lot of time, because the controllers must be familiarised with both new human-machine interfaces and modified operational procedures. For that reason, the National Aerospace Laboratory (NLR) of the Netherlands decided to conduct a study into the feasibility of computer based training (CBT) programs running on PCs as a means of familiarisation training for air traffic controllers. By presenting the familiarisation training prior to high fidelity, operational ATC training, it was expected that air traffic controllers would be better prepared for the latter and thus require less operational training time. During the study a PC-based tutorial, as well as a PC-based simulation training, were developed. As a basis of the training modules the Converging Runways Display Aid was chosen. After performing a training analysis and designing the structure and human-machine interface, both modules were implemented using Authorware. Subsequently, the training modules were evaluated by operational air traffic controllers. From the study it can be concluded that application of PC-based familiarisation training for air traffic controllers is feasible and that the PC is an appropriate platform for this kind of training.

Introduction

To meet the needs of ever-growing air traffic and to restrict the workload of the air traffic controller to acceptable levels, new air traffic control (ATC) systems are being constantly developed. Before these systems can be put into use, air traffic controllers must be trained to operate them. Such training usually comprises familiarising air traffic controllers with new human-machine interfaces, changed task-allocation between human and machine (as well as between controllers themselves), and modified working procedures. This results in unacceptably long training periods. In addition, ATC training programs often require high fidelity ATC simulation equipment, which is in general costly, scarce, and complex to organize.

Hence, NLR decided to conduct a study into the feasibility of a so-called computer based training (CBT) running on personal computers as a means of familiarisation training for air traffic controllers. This PC-based familiarisation training sought to introduce air traffic controllers to the new ATC system. By presenting the PC-based familiarisation training prior to the operational, high fidelity ATC simulator training, it was anticipated that air traffic controllers would be better prepared for the latter, thus reducing the time and costs associated with operational training.

During the feasibility study a PC-based familiarisation training was built and evaluated. This training consisted of two modules: a PC-based tutorial[1] and a PC-based simulation training[2]. As a basis of the familiarisation training an existing ATC system was chosen: the Converging Runways Display Aid which will be introduced at Amsterdam Airport.

The Converging Runways Display Aid

To increase the landing capacity of Amsterdam Airport during peak traffic hours, ATC switches from a single runway to a dual simultaneous runway configuration. Depending on the wind conditions (and thus landing directions) these two runways may converge. A disadvantage of the latter is that during poor visibility it can be dangerous to land aircraft on both runways simultaneously. Under such circumstances the controllers in the control tower cannot directly observe the in-trail separation between arriving aircraft. This in-trail separation is of vital importance, because in case two aircraft break off their landing one after the other and make a climb, the danger exists that they will collide at the intersection of both runways. To mitigate this danger, the Converging Runways Display Aid (CRDA) is used to set up a safety buffer between two aircraft. To do this, the concept of ghosting is used. *Ghosting* refers to replicating the on-screen image of an aircraft at a different spot on the same radar display. Such a copy of an aircraft is called "ghost" (see figure 1). The CRDA is the software tool that generates the ghosts and shows them on the radar display.

One of each pair of converging runways is designated the "Master Runway", whereas the other is designated the "Slave Runway". The Master Runway is the runway from which ghosts are copied. The Slave Runway is the runway to which ghosts are copied. Of every aircraft that approaches the Master Runway, a copy is shown on the (extended centre line of the) Slave Runway. This is done by drawing an imaginary circle centred on the runway intersection from the actual aircraft to the Slave Runway. At the intersection of the circle and the extended centre line the ghost is displayed. As the actual aircraft approaches the Master Runway, the ghost approaches the Slave Runway as well; that is, the ghost and its original behave identically.

Master Arrival and Slave Arrival controller

Both the Master and Slave Runway have their own air traffic controllers. The air traffic controller of the Slave Runway is called "Slave Arrival", whereas the air traffic controller of the Master Runway is called "Master Arrival". On the Master Arrival's radar display only real aircraft are displayed, whereas the radar display of the Slave Arrival also shows ghosts. The Master Arrival's task is to direct air traffic to the Master Runway in such a way that the separation between the aircraft remains constant. To prevent collisions at the runway intersection, the Slave Arrival has to direct his / her traffic at a specific minimal distance behind the ghosts. This minimal distance is the above-mentioned safety buffer. Since estimating the distance between aircraft on a radar display is perceptually difficult, it has been decided to put the ghosts at the minimal distance behind their initial positions. In this case the Slave Arrival only has to direct his traffic onto or immediately

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[1] PC-based tutorials present to be learned knowledge to the trainee, ask him questions about this knowledge, evaluate his answers, and present him feedback about the correctness of these answers.

[2] In a PC-based simulation training trainees acquire skills in solving problems and executing working procedures. This is done by simulating a part of the real world and letting the trainee interact with it. Each time the trainee interacts with the simulation, the latter responds by changing its state, so that the results of the trainee's actions are presented to him.

behind the ghosts to prevent collisions (see figure 2). The process of directing traffic onto or behind ghosts is called “tying”.

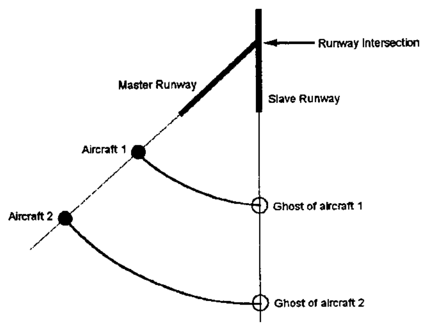

Figure 1: ghosting

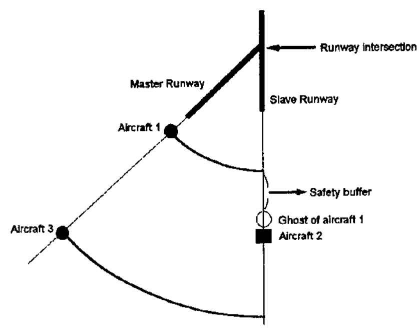

Figure 2: ghosting with safety buffer

Training analysis

To develop a PC-based familiarisation training based on the CRDA, a training analysis was performed first. The analysis phase of the CBT development consisted of four steps:

1. Select the *air traffic controller position* (Slave Arrival or Master Arrival) to be used as a basis for the training.
2. Perform a scenario based *task analysis* (i.e. determine which tasks the selected air traffic controller position performs in which operational scenarios).
3. Determine the *skills* that are related to these tasks (i.e. determine what actually has to be trained).
4. Formulate the *learning objectives* (i.e. describe what the trainee should have learned after the training).

This top-down approach ensured that no necessary skills were missed, and also facilitates consultations with the customer (ATC Amsterdam Airport), as it relates closely to their current training practices.

Selection of air traffic controller position

The very first step in the training analysis was selection of a CRDA air traffic controller position as a basis for the CBT. Because the project was intended as a feasibility study, it was decided to base the CBT on the air traffic controller position that would benefit the most from the training.

This resulted in the selection of the Slave Arrival controller position. There were three reasons for this decision:

1. The tasks of the Slave Arrival are mainly “new” tasks (i.e. tasks that are not part of the regular operations of the controller).
2. The correct functioning of the Slave Arrival is crucial for the success of the CRDA operation.
3. The Slave Arrival’s function requires the highest effort from the controller.

Task analysis

The next step in the training analysis was to determine the tasks performed by the Slave Arrival. According to the air traffic control of Amsterdam Airport, there are 4 operational scenarios related to the Slave Arrival's function, each of which have implications for PC-based training. These four scenarios are:

A. *Traffic does not cause any problems: normal flow of traffic.*

B. *Missed approach above 750 feet.*

A missed approach is a runway approach that is broken off. In this scenario, the aircraft performs the missed approach above an altitude of 750 feet.

C. *Worst-case situation with two missed approaches.*

A worst-case situation is a situation in which the minimal safety buffer would be jeopardized when two aircraft (one on the Master Runway, one on the Slave Runway) are at the runway intersection. If, during such a worst-case situation, both aircraft successively initiate a missed approach, unpredictable variations in aircraft behaviour could easily lead to a critical loss of separation.

D. *Excessive approach speed.*

If the approach speed of an aircraft is too high, the chance of a double missed approach (and hence the danger of a collision on the runway intersection) is no longer minimal.

For each of the operational scenarios, a task analysis was performed. The tasks the Slave Arrival performs in these scenarios can be summarised as follows:

- Monitoring whether an aircraft is under his / her control.
- Issuing speed, altitude and heading instructions to the aircraft in order to direct it to the correct position for tying.
- Monitoring whether the tie-process proceeds correctly.
- When an aircraft initiates a missed approach, executing one of a number of so-called "default solutions" to prevent a collision on the runway intersection. The default solution to be chosen depends on the runway combination used.
- Redirecting aircraft that had a missed approach back into the "main" stream of aircraft to approach the Slave Runway again.

Training skills

The third step in the analysis was to use the identified tasks to determine the skills to be trained. A training skill is defined as the product "task × task context × time pattern". The context of the tasks at Amsterdam Airport was defined by the runway combinations used (which depend on wind conditions), and the type of aircraft being involved in the CRDA operation. Because the number of aircraft per hour is roughly constant when CRDA is in operation (as the CRDA is only used during peak traffic hours), the time pattern (the time available for each task) is constant. Therefore, the skills are a result of the product "task × task context". For the four given scenarios, this resulted in 60 different training skills (15 tasks, 4 different task contexts).

Since the trainee population comprises skilled air traffic controllers, not all training skills identified need to be trained. Certain skills (e.g. ATC - aircraft communication, updating aircraft labels) would likely already have been mastered by the Slave Arrival.

To determine which of the training skills would be suitable for training with CBT, it was decided to add each of these to the CBT one by one, starting with the simplest scenario, scenario A.

Learning objectives

Finally, the last step in the training analysis, was to write learning objectives based on the training skills. The formulation of the learning objectives was based on recommendations by Hannafin and Peck (1988), which include the following:

- Each learning objective should contain the behaviour to be shown by the trainee.
- Each learning objective should contain the circumstances under which the behaviour should be shown.
- Each learning objective should contain the criteria the student behaviour should satisfy.

An example learning objective for scenario C is the following:

> *"The trainee is able, for runway combinations 06/01R and 27/19R and air traffic consisting of heavy, medium and light aircraft, to check using radar display and aircraft labels, whether the tie-process is proceeding correctly, and whether a worst-case situation is caused".*

However, it became clear that learning objectives like these are difficult to read, and not suitable for presentation to the trainees. Therefore, the objectives were reformulated. For the given example, this resulted in:

> *"The trainee is able, for runway combinations 06/01R and 27/19R, to check whether traffic is causing a worst-case scenario".*

Selecting the type of computer based training

The learning objectives could be classified into two categories: those related to the basic knowledge of CRDA, and those related to the procedures and tasks to be executed by the Slave Arrival during the identified scenarios.

For the learning objectives on CRDA knowledge, it was decided to develop a PC-based tutorial module. Historically, CRDA knowledge training has been offered classroom style (with paper and pencil). Therefore, the PC-based tutorial uses a sequence of screens with CRDA information (e.g. when is CRDA used, under which circumstances), interspersed with "yes/no"-type questions.

It has been known for well over ninety years that transfer of learned knowledge and skills from training to the real world is only achieved if the training situation and the real world contain identical elements (Thorndike & Woodworth, 1901). Therefore, to achieve a high positive transfer of the knowledge and skills acquired during the familiarisation training to the real world, it was decided to use simulation training to train the procedural learning objectives.

By means of a simulation training the radar display as used by the Slave Arrival could be imitated. In order not to have the simulation training result in a high fidelity simulator of the Amsterdam Airport ATC system, only the elements relevant to the CRDA procedures of the Slave Arrival were included in it. The input of the instructions to the aircraft would have to be as identical to the real world as possible, except for the radio telephony inputs. The PC-based simulation training was intended to be offered after completion of the PC-based tutorial.

The PC-based tutorial

For the tutorial, the CRDA-manual was chosen as a starting point. From this manual, the information that should be known to the Slave Arrival before he / she is able operate the CRDA was extracted. This information was organized in a number of topics, like "CRDA terms and definitions", and "Specific Schiphol Airport CRDA procedures".

The information on each of these topics was organized in a number of screens containing information. Where appropriate simple, non-interactive animations were added to explain some terms. For example, the difference between ghosting with and without safety buffer was demonstrated using two animations. In these animations, all unnecessary details were left out, so that the trainee could concentrate on the example given.

The topics were interspersed with questions in which the trainee had to indicate whether the statement made in the question was correct ("yes/no" questions). A trainee could only proceed to the next topic if all questions in a block were answered. For each question that was answered incorrectly, the trainee was presented feedback indicating why the answer was incorrect. For some questions, there was additional clarifying feedback after correct answers as well.

Additional requirements to the simulation training

Following the decision to develop a PC-based tutorial, as well as a PC-based simulation training, additional requirements on the simulation training were defined. These were of the following categories:

- *Requirements with respect to the structure of the simulation training.* It was decided that the simulation training should consist of a familiarisation lesson in which the trainee can become familiar with the radar maps of both CRDA runway combinations and with the procedures for issuing aircraft instructions. Further, a lesson was required in which trainees could practise tying air traffic on both runway combinations in each of the operational scenarios.
- *Requirements with respect to information shown to the trainee.* For instance, update rate of aircraft positions, shape of aircraft position symbols, content of aircraft labels (altitude, speed, etc.), layout of radar maps, colours.
- *Requirements with respect to interactions between trainee and training.* For example, how to select an aircraft in order to issue instructions to it, how to input aircraft instructions, how to update aircraft label data.
- *Requirements with respect to the behaviour of simulated aircraft.* Such as rate of turn, rate of climb, rate of descent, runway approach routes, initial aircraft separation.

Design of the simulation training

Based on the learning objectives and additional requirements, a design of the simulation training was made. Figure 3 shows the design of the structure of the simulation training.

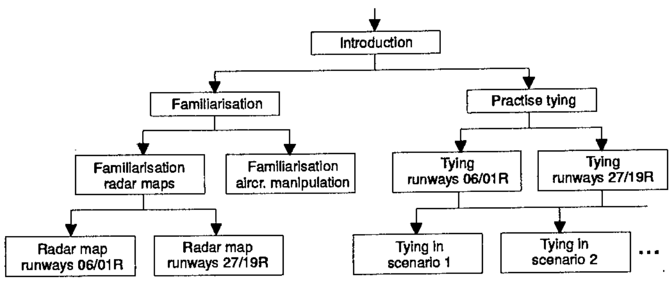

Figure 3: design of the structure of the simulation training

The simulation training took off with an introduction that briefly described the content of the training. After the introduction the trainee could follow the familiarisation or the tying lesson. On request of the trainee the familiarisation lesson presented explanations about elements of either of the radar maps. In this lesson the trainee could also practise issuing instructions to aircraft. In the tying lesson the trainee could practise tying aircraft on both CRDA runway combinations (06/01R and 27/19R) and in each of the four scenarios.

In addition to the structure of the simulation training, a design of the interface between trainee and training was made. This interface design was based on the DenK architecture (Ahn et al., 1994). In accordance with the DenK architecture the interface between trainee and training can be illustrated as shown in figure 4.

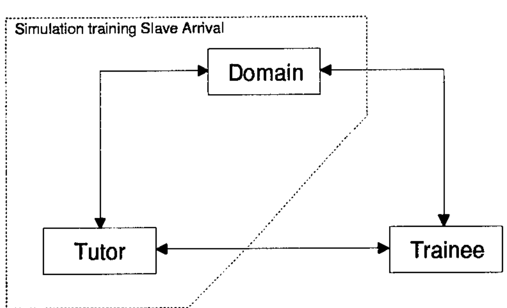

Figure 4: interface between trainee and simulation training

The simulation training embodied two elements: a domain and a tutor. The purpose of the domain was to simulate the real world in which the Slave Arrival performs his / her tasks. Depending on the training's state, the domain could be of different types. For instance, if the simulation training was in the state *Radar map 06/01R* (see figure 3), then the domain contained a picture of the radar map, as shown on the Slave Arrival's radar display during CRDA operations for runway combination 06/01R. When the training was in the state *Familiarisation aircraft manipulation* the domain held the aforementioned radar map, as well as simulated air traffic and an input field to issue aircraft instructions. The domain interacted with the tutor by for example supplying it with trainee performance data. The trainee interacted with the domain by requesting explanations about radar map elements and by issuing instructions in order to change aircraft behaviour.

On the trainee's request the tutor showed help-info and interacted with the domain to start and end lessons and domain types. Also, the tutor read in and verified aircraft instructions issued by the trainee. Based on performance data received from the domain the tutor also presented the trainee feedback about the correctness of his / her behaviour. Cohen (1985) and Sales (1988) say that such feedback is both motivating and informative. This means that the feedback attempts to alter the trainee's behaviour by rewarding correct behaviour by praising him / her and by discouraging incorrect behaviour by telling him / her about mistakes and their consequences. It also means that the discouraging feedback offers the trainee information about where the mistakes were made and how they can be corrected. Furthermore, the training presented feedback about the degree to which the trainee was reaching the learning objectives. The training showed for instance the number of correctly tied aircraft and the utilised landing capacity. According to Latham and Locke (1979) this feedback type improves the trainee's commitment to the learning objectives.

Another educational concept that has been included in the PC-based simulation training is the concept of overtraining. *Overtraining* means presenting trainees additional learning opportunities after they have reached the learning objectives. When applied, overtraining improves the retention of acquired knowledge and skills (see Schendel & Hagman, 1982). The concept of overtraining was included in the simulation training by restarting the tying lesson whenever the trainee succeeded for the first time in tying all aircraft offered to him / her during the lesson.

Implementation of the CBT

For the implementation of the CBT modules, Authorware Professional was used. For the tutorial, no major problems were met. Nevertheless, for the simulation training it became clear that a real-time interactive simulation required a number of adjustments to be made, especially in order to keep the simulation running during trainee interactions. Further, it proved impossible to make a scaleable simulator; that is, a simulator in which the number of Master and Slave aircraft can be changed easily. For training purposes though, there would be a fixed maximum number of aircraft on the radar display at a given time, so this problem was more or less circumvented.

Figure 5 shows a sample screen image containing the main radar screen of the simulation training.

Evaluation of the PC-based tutorial and PC-based simulation training

After they had been implemented, the PC-based tutorial and PC-based simulation training were evaluated by air traffic controllers from Amsterdam Airport. These controllers were asked to attend the tutorial and simulation training and to offer feedback on each of them. After correction of all shortcomings that were found in the modules, a questionnaire was developed in which controllers were requested to rate the tutorial and simulation training on a number of topics, including aircraft behaviour, feedback, and help-information. The intention was to deploy both modules during the official CRDA training of the Dutch air traffic control services and to hand out the questionnaire among the trainees attending the latter. However, due to circumstances beyond the control of NLR, dates have not yet been finalised for this empirical evaluation.

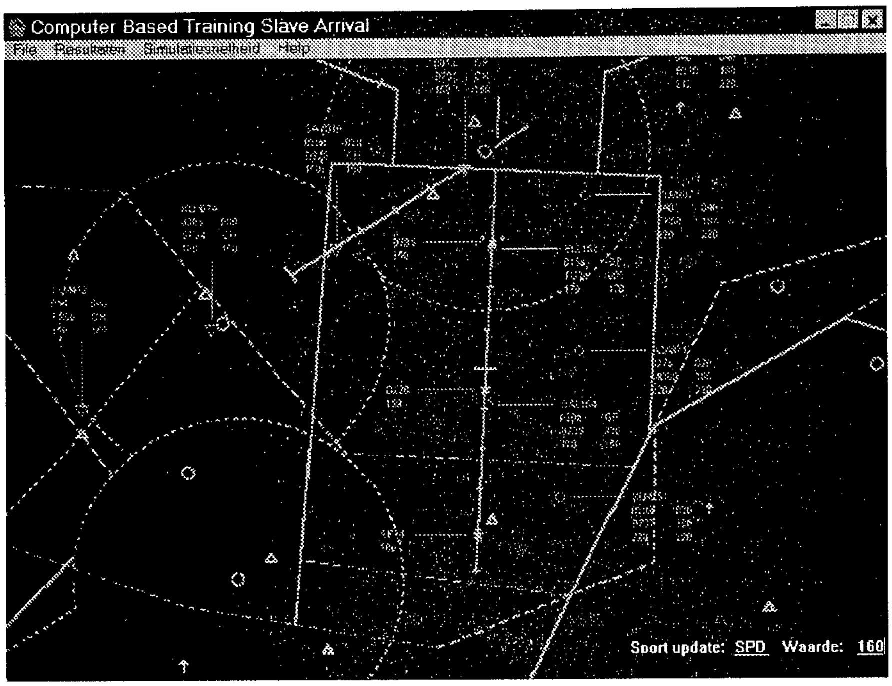

Figure 5: sample screen image from the simulation training

Conclusions

Even though the PC-based training modules have not been empirically evaluated yet, the software developed so far, and the remarks from Amsterdam Airport air traffic controllers indicate that the application of PC-based training for familiarisation training of air traffic controllers is feasible, and that the PC is an appropriate platform for this type of training.

During the study it was experienced too that a formal approach to training analysis assists in determining the skills and learning objectives to be satisfied with the training, as well as supports consultations between developer and customer.

Furthermore, the feasibility study revealed that application of Authorware Professional to develop real-time simulations is not optimal. Instead, it might be better to create external simulation modules, which could be integrated into the Authorware training-software.

Acknowledgement
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Deep Design - Beyond the Interface

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Abstract

Many large-scale dynamic control systems are moving from traditional equipment-determined control systems to computer-mediated wholly or semi-automated systems. There has been a tendency for computer-based systems to mimic traditional displays. This approach fails to make use of the enhanced information-handling capacity of the computer, and often produces displays that are in practice inferior to those they replace - occasionally with tragic results.

A better approach is to begin with an qualitative functional analysis of the control task, with as little reference to the existing system as possible, then to consider the component tasks, selecting those for which the operators are best suited to compose an interesting but not overloading workload, and delegating the remaining tasks to the computer-based system. Where the workload varies with time, particularly if the variation is unpredictable or uncontrollable, it may be necessary to provide 'fall-back' automation, which will maintain safety without regard to efficiency.

Only after the operators' overall tasks have been defined should consideration be given to what and how to display information to the operators, and to the communication links to be used. In many instances graphical images will be preferable to tabular and symbolic to numeric forms. Displays need not be confined to current data - historical trends and projections of future situations can be displayed. The latter can be particularly valuable if linked with projected sequences of control actions, to verify their effectiveness before applying them. Where control is largely 'by exception' displays must be designed to enable the operator to obtain the necessary information for effective control in adequate time. Training may include drills for the allocation of tasks between operators, as with CRM (Cockpit Resource Management) in civil aviation.

Introduction

Dynamic control systems control processes that are operating in 'real-time'. The events or processes controlled are happening now, and usually continuously. Examples are chemical plants, assembly plants, automated factories, water and sewage distribution systems, electricity generating plants (nuclear, coal, hydroelectric or others), electricity distribution systems, road, rail and air traffic control systems, ambulance services, and even military command systems.

These systems usually have control rooms, where operators , usually in teams, receive information, (as verbal messages, by radio, telephone or data-link, TV images, readings on dials or chart-recorders, warning lights, gauges, or simply by looking out of the window) form a picture of the activity (which may be literally a picture, some form of semi-mechanical analog display, a computer record, or other display), decide on the necessary control actions required, and communicate these to the components of the system, by whatever means available (Button pushing, verbal messages, maneuvering controls etc.). Finally,(and often forgotten), they must check that their intended actions have actually happened, and that they have had the desired effect.

Many of these systems are made up of more or less autonomous units. The degree of centralization or delegation of authority is usually the result of historical or technical accident rather than design. Although the general problems are similar, accidents of technical development have led to different styles of display in different fields of development. Ergonomists have spent much time and effort in the design of 'knobs and dials'. The studies by Fitts and Jones(1961) are classic examples.

There is, however, a contemporary trend that must inevitably affect the design of control rooms. More and more of these systems are computer-based. Rather than displaying raw radar data, the signals from several radars are smoothed and combined, weighted according to the reliability of the individual radar and used to construct a digital track for an aircraft, which is then displayed on a computer VDU. (My life's experience is in Air Traffic Control, so I shall draw examples mainly from that field, but the message I wish to send applies to all the fields I have mentioned, and to many others. Hansen (1995) provides a similar example for a coal-fired power station.) The circular display with rotating sweep so familiar from films is now unnecessary, and a standard CRT can be used. Ironically, some effort has made to produce a synthetic digital representation of the trail of decaying 'blips' behind the aircraft.

The Horseless Carriage Method

This is an example of the 'horseless carriage' effect. In order to ease perceptual problems in the transition from traditional electromechanical to digital systems, it is tempting to reproduce the traditional image on the CRT screen. This may have disastrous consequences. The image available on a flat CRT screen may be far less salient than that provided by a bank of electromechanical dials, so that minor but critical differences can be overlooked. A more subtle problem occurs in Air Traffic Control, where the traditional planner is provided with a strip, in a strip-holder, for each aircraft. He moves these strips around, marks the surface of the strip, moves it in its holder to signal to his partner, and finally discards it and rearranges his board after the aircraft has left his area of responsibility. Electronic strips lack these facilities, and, in some systems, may even remove themselves automatically when the aircraft leaves, so that when the controller next looks at his strip bay the aircraft are not where he left them. This is, to put it mildly, intolerable to a busy controller.

Examples abound of similar short-sighted adaptations of pre-computer displays. They have some superficial attractions. They do not, in principle, require significant input from the users, and they are usually sufficiently close to the previous system that no training or transition period is apparently necessary. Often neither of these is true, but, by the time this becomes apparent, the system is in place.

Beyond the Interface

I propose a different approach to the development of these systems. None of the individual elements of this approach is unprecedented, and most of what I am saying can be derived from various studies, ranging from neurophysiology to anthropology to systems analysis, carried out in the last twenty-five to thirty years.

Task Definition

The starting point of interface design should be a careful, in-depth study of what are the real purposes of the control system being investigated. Most organizations have a standard definition, which will be produced in answer to the initial question. In Air Traffic Control, this is usually 'The Safe, Orderly and Economic control of Air Traffic", for example. If, however, you analyze the components of this statement, you find that the first is a constraint, the second is practical requirement of pre-computerized systems arising from the limits of human memory and information processing capacity, and the third is often a hope rather than a true goal. Although it is always possible to argue over abstract definitions, ATC's purpose can be defined as to allow air traffic to fly from origin to destination as quickly and/or cheaply as the individual flights require, with the minimum disturbance necessary to maintain safety.

Task Analysis

The second stage of the process is to analyze the 'real' task. This may well not be closely related to the formal task as traditionally defined. It is particularly important to distinguish between a task 'analysis' and a task 'description'. The construction of a task description involves observation of the existing system, often in extraordinary detail (Phillips et al, 1984), has the unfortunate consequence of producing a mental 'set' in favor of the existing method of control. For simplicity and convenience, I shall take as example 'en-route' ATC, which concerns aircraft in the major part of their flight, after they have left the region around their airport of origin, and before they arrive at their destination. The TMAs (Terminal Maneuvering Areas) around airports or groups of airports have their own problems, which will not be discussed here.

A modern Upper Airspace Control centre, such as Maastricht UAC, where Eurocontrol controls the upper airspace of several busy states, and part of another, is organized into sectors, each defined by a geographical area and upper and lower flight levels. Within the sectors, routes are defined by sequences of beacons. Ground-air communication is by voice links. The data for each flight, stating its intentions, is abstracted from standard flight plans and combined with information from a network of radars to provide current aircraft positions. Although Flight Process Strips are still generated, in some sectors controllers prefer to refer to electronic data displays. Usually sectors are manned by two controllers. The Planning Controller (PC) examines the future traffic, and plans how it can be organized to minimize the disturbance to the aircraft while maintaining safe separations and satisfying entry and exit conditions. The Executive Controller (EC), referring mainly to the radar picture, makes short-term decisions, and communicates with the aircraft in the sector. Controllers communicate with aircraft by Radio-telephony (RTF), with adjacent sectors and centers by telephone or by computer-based digital messages, and with each other by voice, supplemented by gestures and computer or strip notations. In all modern ATC systems, the controllers are obliged to update the computer system when they take action, and in most modern aircraft, the pilots insert the changes in their flight path into their Flight Management System (FMS).

Figure 1 (based on Dee 1996) sketches the tasks currently carried out by en-route Air Traffic Controllers.

1) 'learn' sectors
2) manipulate and mark strips
3) plan future streams of aircraft entering their sectors.
4) check that they will not conflict with each other within the sector,
5) determine how to resolve conflicts
6) match radar images to strips
7) acknowledge aircraft coming on to the frequency when they enter,
8) intervene to resolve conflicts
9) coordinate their actions with the next sector
10) monitor aircraft behavior for deviations from track
11) hand aircraft over to the next sector
12) attempt to comply with any special requests, (for example for direct routings or changed routings).
13) handle unexpected emergencies.

Figure 1 - Task List

We do not have enough space and time to carry out a systematic analysis of these tasks (See David 1997), although it should be noted that the first mentioned task - 'learning sectors' is particularly interesting from an ergonomic point of view,. It takes a fully-trained controller about six months to 'learn' a sector. Too little attention has been paid to this process, which is generally one of apprenticeship. The controller accompanies an experienced controller on the sector, apparently absorbing a vast quantity of information about the sector, the usual traffic and its peculiarities, so that this information is in his permanent memory for recall. The necessity for this feat of memorization is a criticism of the current systems of training and information presentation. This information is a considerable burden to the controller, fading rapidly after a few days' interruption of the task. Many 'coping strategies' are required to maintain it, even with the present level of traffic. (Stein and Bailey, 1994)

Many of the tasks listed here are essentially routine, linked to the traditional methods of communication by RTF, occupying a considerable proportion of the controllers' time. Others reflect the need to match the strip or tabular data on which planning is based, and the decisions arrived at during planning, to the image of the current situation presented by the Electronic Data Display (EDD) on which the annotated radar data is displayed. This operation is inherently wasteful, since the computer has already done it. Some modern stripless systems (Graham et al, 1994), eliminate this part of the workload by displaying the 'strip' data as part of an aircraft label. This approach has other drawbacks - it covers the screen with tabular data, or requires separate windows to be opened for each aircraft.

Communication

The communication of information by RTF is inherently error-prone, and the attempt to achieve mechanical levels of reliability by drilling human operators is futile and inhumane. Cushing (1994) draws on reports of the (US) National Traffic Safety Board, and the Aviation Safety Reporting System, to show that this form of communication is no longer viable. He sketches a potential 'data-link' alternative.

Human Tasks

To summarize an extensive argument, the tasks particularly suited to, and enjoyed by human operators are conflict resolution (but NOT conflict detection), dealing with special requests from aircraft, and rectifying errors identified by computer monitoring of traffic, such as may arise from incorrectly set Flight Management Systems. Controllers are also good at imposing a strategic direction on the system, by developing and applying conventions to reduce workload and increase overall efficency.

The human-computer interface should therefore be designed to facilitate these tasks, rendering the data necessary for these tasks easily accessible, while not prohibiting the controller from looking further into the data when opportunity offers.

As Woods (1995) remarks, the now traditional windowing structure is not well adapted for dynamic control, since it requires the user to search out the correct window to find the data or formulate the instruction required. It is far better, if at all possible, to show all necessary information on one screen. This may at first seem a difficult task, but it is not impossible, if the nature of the data and the way they are used are taken into account.

The data

For design purposes, we can simplify the actual ATC situation by considering the trajectory of each aircraft as a series of linked straight-line segments. Each begins with a position in space, expressed as X, Y and H coordinates, and a (constant) rate of change of each of these. The position is true at a time T and the segment continues until one or more of the rates of change alters after an interval dT. Segments before the current time are fixed, and of no immediate interest for control purposes. Future segments describe the planned future path of the aircraft. These can be compared with the future segments of other aircraft to identify losses of separation at future times. The use of straight-line segments permits a fairly simple algorithm to be employed. Changes in future flight path can be specified simply, and converted into an alternative sequence of segments, which can be tested to identify new or remaining conflicts.

Traditional displays

There are two traditional means of displaying this data. The radar image displays the current X and Y dimensions as positions on the display surface, dX and dY by a 'speed vector' and codes height (H) as a three-digit numbers displayed close to the aircraft marker, in a 'label' containing the call-sign, and more or less other data expressed as letters and digits. The strip display (usually) reduces the X and Y dimensions to a series of named points (usually beacons where routes intersect) for which estimated times (T) and heights (H) are specified as numeric values. The strips themselves may be arranged in various ways, for example, under a label for the next beacon, arranged by height or estimated time, where the labels are arranged in a roughly geographical layout. It is very difficult to cope with aircraft which do not follow predefined routes using a strip-like display.

Apart from the position and speed vector, virtually all the data are presented in letters and digits. To complicate matters further, beacons are usually shown by abbreviations, if they are labeled at all, and spoken as their full names. Commercial flight call-signs contain a company identifier such as PA for the (defunct) Pan-American Airways, which was spoken as 'Clipper'.

From the cognitive point of view, this is a mess. If the theories of cerebral asymmetry of cognitive function (Springer and Deutsch, 1993) have any validity, it would be hard to design a worse display system. Graphical and textual indicators are scrambled together unsystematically. In some systems, rates of climb, known to the computer system to a high degree of accuracy, are deducible only by watching the rate at which the last digit, representing hundreds of feet, changes. If, as is usually the case, the display is updated only at five or ten seconds intervals, it may take up to half a minute to obtain even an approximate idea of the climb rate. Controllers adapt to this by learning the trajectories to be expected of common types of aircraft in the hands of particular company pilots, and by allowing enormous safety margins (Lafon-Millet 1978).

Conflicts, the main justification for en-route air traffic control are usually not shown to the controller. (Some systems have last-moment short-term conflict alerts, but many of these rely only on radar data, so that they cannot cope with aircraft which have been instructed to cease climbing below the level of the opposing traffic, for example, and generate many false alarms.) In the ODID (Prosser et Al ,1991, Graham et al 1995) research simulations, a Conflict Risk Display was provided which consisted of : -

- A rectangular display showing time-to-go as the horizontal and minimum separation as the vertical axis. Numbered points identified unsolved conflicts. A line represented the duration of separation loss.

- A table showing the call-signs of the pairs of aircraft involved in each conflict.

To resolve a conflict, the controller made a mental note of the number, referred to the table, made a mental note of the two call-signs, then searched the radar display to find the two aircraft involved. He then estimated their relative speeds, noted their heights, checked or recalled their future trajectories, estimated their relative positions at the time of conflict. (It is often easier to solve a conflict by maneuvering the second aircraft to pass the crossing point.) Experienced controllers would scan the table of call-signs to see if one aircraft was involved in several conflicts, and search for a maneuver which would solve them all. This display was greatly liked by controllers. It may be that this was because it was usually blank, assuring them that that they had not missed a conflict in their normal scanning of the display, a constant fear of all controllers.

Revised display

We will assume that we use a map-like display as our primary display, showing aircraft at positions by symbols. Figure 2 shows a representative contemporary and a revised aircraft symbol.

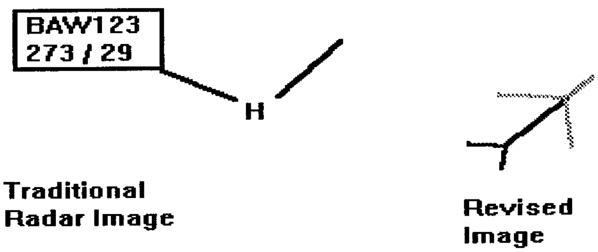

Figure 2 - Aircraft image

Figure 3 lists the aspects displayed, with brief notes justifying the choices of display method.

ASPECT	Traditional		Revised	
Identity	Call-sign		Not used	select by mouse
Position	X,Y position	of symbol	X,Y Position	of wing/body cross
Heading	Speed Vector		direction of ion	body
Size	Code	H=Heavy	Size of symbol	
Speed	Vector length		Wing sweep	
Height	3-digit code		Colour	
Attitude	symbol	+ final level	Colour combination	

Figure 3 - Coding

Height is indicated by colour coding. Eastbound cruising levels are shades of yellow, westbound are shades of blue. Aircraft in level flight are normally at a fixed level, and are coloured accordingly. Aircraft climbing or descending have the front end in the level they are approaching, and their rear in that they are leaving. The speed indication is highly approximate, but is rarely significant (see below).

Figure 4 shows a representative screen, as displayed on a rather primitive VGA display. There are 40 aircraft in random flight on this display. Seventeen of these aircraft are involved in ten potential future conflicts.

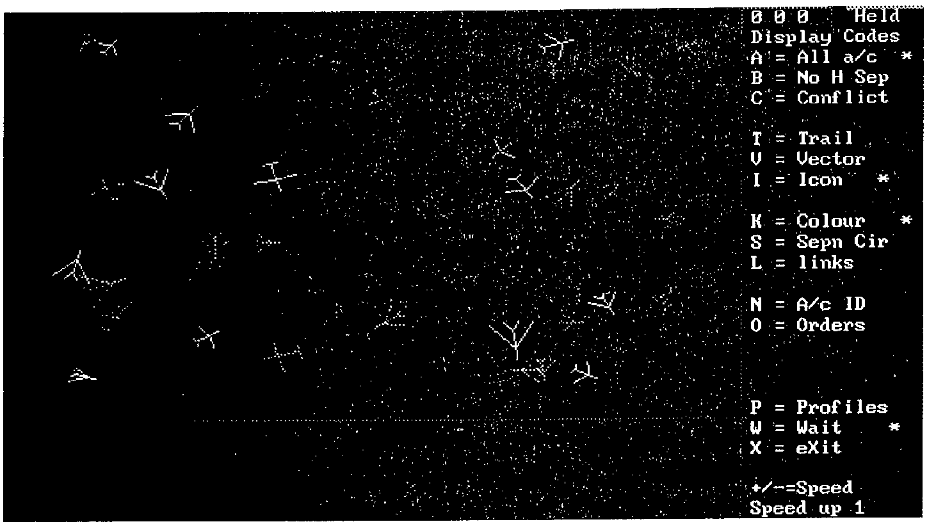

Figure 4 - Revised Display

Figure 5 shows the potential conflicts present in this image. Conflicts are displayed by linking the aircraft involved. This leads the eye to the aircraft most involved in conflicts. Lines linking conflicts are made more salient as the time to go before loss of separation becomes shorter. Figure 5 also shows a logical extension of the simplification process, where aircraft that are not involved in conflicts are not shown to the controller. Many, possibly most aircraft would pass through the airspace without contacting the controller at all.

(The reader is invited to try to identify the aircraft and their conflicts before looking at Figure 5.)

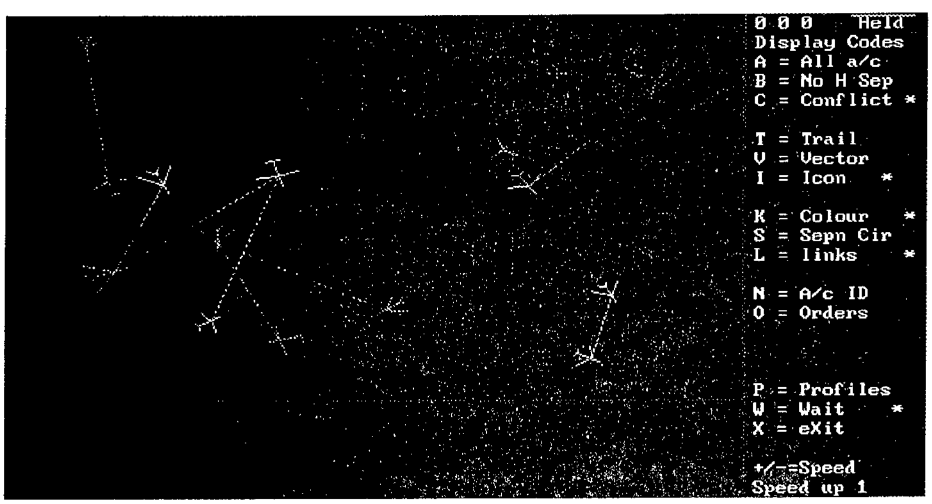

Figure 5 - Potential Conflicts

To resolve conflicts, instructions must be given to one or more aircraft. At present, these are given by the Executive Controller, by RTF. The EC, operating in the present, gives instructions to be executed directly by the pilot. He must monitor the pilot's reply, to be sure that his order has been correctly received. He must check a minute or so later that the aircraft is actually doing what he asked. He must note, or remember, when he has altered the direction of an aircraft, in order to return it to track or height later. He must estimate a sufficient diversion from track to respect the required separation. For safety's sake, he overestimates. Where the separation minimum is five miles, he usually adds "two more for the wife and kids".

Conflicts are often detected by the Procedural controller, when comparing strips. He may annotate a strip to tell the EC to move the aircraft to a higher or lower level before a certain beacon. Since he cannot be certain exactly when the EC will make the move, both levels may be blocked for a considerable time.

Our proposed display (Figure 5) allows the controller to choose which aircraft he will maneuver, but the system can be set up to choose the next aircraft to treat according to pre-defined criteria. In the currently available version, the pair of aircraft which will first lose separation is selected, then, within that pair:

- The aircraft involved in most conflicts
- The aircraft that not at the level it should leave at
- The aircraft that has furthest to go before leaving - because this is easiest to return to track after a maneuver.

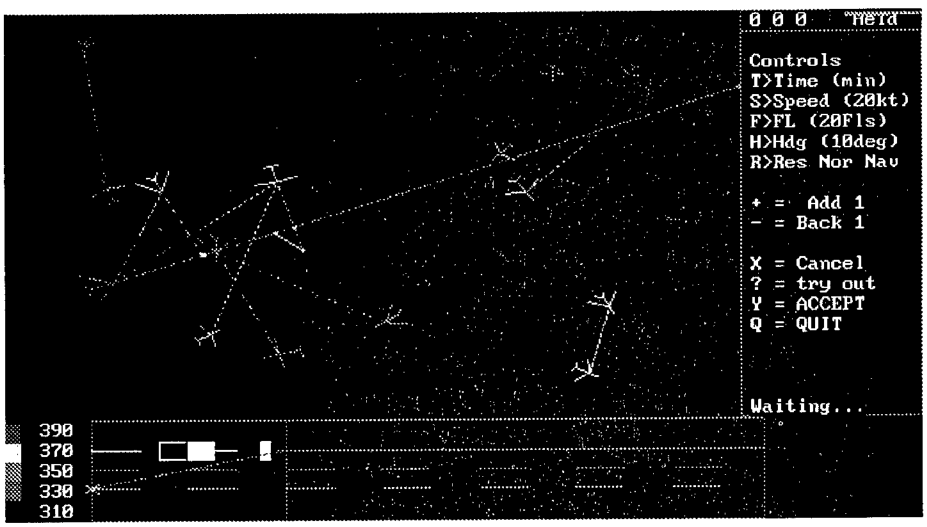

Figure 6 - Aircraft Trajectory

Having selected an aircraft, the system shows its future trajectory superimposed on the display, with the trajectories of conflicting aircraft, and their relative positions at closest approach. An auxiliary display shows the flight profile of the aircraft, with a horizontal scale representing distance to the same scale as the EDD, and a vertical scale showing the height (flight levels) available. Solid blocks represent aircraft which will be in conflict, and hollow blocks represent aircraft which pass over or under the flight, and therefore would be in conflict if the flight level is changed. (Figure 6)

The controller can construct an order to solve the problems of this aircraft. (In the demonstration version DEMFAST, available with David (1997), keystrokes are used, because the software available does not support a mouse, although a mouse would be preferable.) As the order is constructed, the trajectory is revised, so that the consequences of each maneuver can be seen. The controller can instruct the aircraft to return to track after the problems have been solved. Once an acceptable order has been developed, the controller accepts it, and the system transmits it by data-link to the FMS of the aircraft, adding the call-sign. The message would be spoken to the controller and to the pilot and co-pilot of the aircraft addressed (and of any other aircraft in the vicinity) by voice synthesizers in the language of their choice, eliminating the classic Zagreb problem (Weston and Hurst, 1982). The controller can now turn his attention to the next problem without needing to verify the correct reception of the order, or to remember to return the aircraft to track later.

After a little practice, this system is considerably faster than spoken control. A non-controller can handle the demonstrator's limit of 40 aircraft simultaneously, where each aircraft remains in the airspace for 12 minutes, corresponding to an entry rate of 200 aircraft per hour, at twice real-time rate.

In a real system, this demonstrator would be expanded to include methods of monitoring deviations from track, or learning more about the aircraft. Controllers would learn to recognize particular 'hot-spots' in the traffic, and anticipate problems, as they do in the existing system. Additional displays might be designed to help the controllers cope with 'foreseeable emergencies', such as emergency decompression or engine failure, where one controller would take charge of the aircraft in difficulties, while his partner would supervise the re-routing of other aircraft.

Back-up

Although controllers enjoy, and are good at, solving conflicts, there may be occasions where a temporary overload means they cannot solve all the problems in time. There should be a process triggered by the equivalent of a 'short-term conflict alert' to ensure safety if potential conflicts are not solved within a safety limit. The ACAS (Airborne Conflict Avoidance System) is in fact, such a system. The fall-back system should be essentially safe, while not as efficient as the human controller. Given the nature of human beings, the temptation to rely on the back-up system should not be offered.

Organizational Repercussions

The alternative display system designed here is not simply a cosmetic re-design of the existing system. It produces a considerable increase in capacity, reducing the number of sectors, which itself reduces the amount of coordination involved. It reduces the mental workload of the controller at the cost of his ability to maintain a continuous 'picture' of the present and future traffic. It can be argued, although it would be hard to prove, that he could not maintain a picture of this amount of traffic in direct flight in any case. The traditional distinction between the Planning and the Executive controller disappears. (In real life ATC practice, the 'official' distinction between these two tasks is already considerably blurred.) The 'style' of control changes from a continuous 'hands-on' style to a 'control by exception', where the controller must react to the (future) problems detected by the system, and the immediate problems presented by emergencies. This would have considerable implications for initial and continued training. There are very good reasons not to reduce the control team to one man, as there are not to reduce aircrew. (Yerkes Law - "One chimpanzee is not a chimpanzee at all" (Yerkes 1945) also applies to controllers) As for aircraft, the trend will be to a pair of controllers, each capable of all the control tasks. Training may include drills for the allocation of tasks between operators (and the system), as with CRM (Cockpit Resource Management) in civil aviation.

Concurrence

Finally, it is an illusion, induced by the linear nature of written communication, to see these stages as separate steps in a process. In reality, each step will interact with every other. To attempt to develop a complete system by following each step rigidly is rather like trying to tell a car driver how to drive from one place to another by providing a detailed, carefully timed set of instructions how to move the steering wheel, the clutch and the accelerator for an hour or so. The processes of task design and interface specification are inherently interdependent. Practically this means that crude models rapidly available are more valuable than elegant models that take six months to modify. It implies that the number of people involved in the design and development phase should be as small as possible. (Ideally, one.) This type of development requires the attitudes and commitment described in "*Skunk Works*" (Rich and Janos, 1994), although the physical resources need be no greater than a standard PC with a good display screen.

Conclusions

Most large-scale real-time control systems have evolved, rather than been designed.

The advent of fast, cheap and reliable computer-based information transfer and analysis systems presents an unprecedented opportunity to re-design such systems to provide a major improvement in the quality, reliability and efficiency of the system.

It is not sufficient to imitate the existing display system on a CRT screen. The actual control task should be re-analyzed, and the human operator provided with a satisfying task appropriate to his natural abilities. Tasks the human fails to do should be taken over by the system, although it is important that the system should be safe, rather than as efficient as the human operator.

These changes imply shifts in the location of information storage, in the means of transmission, and in the manner in which operators work.

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Advanced Manoeuvre Flight Training on PC's and Transfer to the Real Aircraft

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Abstract

Through ongoing progress in computer hardware, numerous improvements became possible in flight simulation. In general, low-cost desktop simulators now provide possibilities that in the past could only be achieved on expensive and complex systems. In addition to a quality improvement in low-cost desktop simulation, there is also a quantitative advantage. A wide range of complex tasks can nowadays be trained on relatively simple and inexpensive equipment. In fact, a number of tasks can already be trained with 'State of the Art PC's, providing the opportunity to procure a larger number of this type of simulator.

This paper examines whether PC-based equipment can be used to support training of perceptual-motor skills, or more specific manual flying skills, i.e. skills that to date supposedly can only be acquired in more expensive simulators or the real aircraft.

The motivation for the research described in this paper is lead by the basic question: what task-critical features are needed in simulation to achieve positive transfer to manual flying skills in real flight?

To examine this question, a training experiment has been conducted. The objective of this experiment was to test the training-effectiveness of PC-based simulations used in advanced manoeuvre flight training. The experiment was set up such that transfer-of-training from two PC-based training devices- a standard (Commercial Off- The-Shelf, COTS) and a customized PC-based configuration – to the real aircraft could be examined.

Three groups of trainee-pilots participated in the experiment. Each group went through identical in-flight training to learn to fly a complex sequence of aerobatics manoeuvres on a single-engine propeller aerobatics aircraft. The second and third group, though, received extra training: each in-flight lesson was preceded by a simulation session using the respective PC-based configurations.

It was found that the group trained with customized PC-based simulation showed a clear advantage over the two other groups, trained with respectively standard PC-based simulation and no simulation. The use of customized PC-based simulation leads to a higher rate of learning in the aircraft. Most remarkable improvement of in-flight performance of the group trained with customized PC-based simulation takes place in the first lessons, giving them a headstart, causing an improvement that is existent throughout the remainder of the training. It is discussed that this higher rate of learning observed by trainees using customized simulation can be accounted for by the following abilities learnt in the simulation that transfer to real flight: (1) the improved ability to extract visual cues from

the outside world that are needed to perform the time-critical elements of aerobatics (2) speeded up learning of procedural elements of aerobatics in an earlier stage of training (3) an improved basis for in-flight development of "seat-of-the-pants skills".

Introduction

This research applies in the first place to the training of perceptual-motor skills, more specific advanced manual flying skills for military operations. Military operations with jets and helicopters continuously depend on perceptual motor-skills. A real-life military scenario is likely to be a continuous sequence of very complex manoeuvres. Additional tasks, most often with cognitive and procedural aspects, must be performed in parallel with manoeuvering. Therefore, a high degree of skill automatization is desirable for succesful completion of such a scenario. Such a high degree of automatization of perceptual-motor skills can only be obtained through extensive training. Unfortunately, shrinking military budgets and increasing public environmental awareness restrict the number of hours that military pilots can spend training advanced manoeuvres on real aircraft.

PC-based systems have already proved useful in training of aircraft system knowledge, flight management system programming, radio-telephony phraseology, navigation, and many more areas. Thus far, such systems have not been used for teaching manual flying skills. These skills were usually taught on real aircraft or on training devices for which the design was most often guided by the desire for high engineering fidelity under the assumption that the more a training device is like the real aircraft, the better will be the training.

Above restricting circumstances and advances in PC-based software and technology provide a reason for the aviation community to investigate cost-effective use of advanced PC's in part-task trainers for manual flying skills. Not with the intention to replace the real aircraft training or the full flight simulator but with the intention to support the training program, thus to use the real aircraft and the full flight simulator more effectively and more selectively.

In our view, for a part of flight training, the term low-fidelity does not necessarily imply a sub-optimal training environment when compared to the real aircraft. A first condition for an effective low-fidelity device is the presence of identical elements that are critical to required task-performance, allowing the trainee pilot to develop the proper response strategy. This characteristic of the training device to allow the development of a proper response is more important than having an exact replica of the cues involved (the stimulus).

Secondly, the low-fidelity training device may provide some instructional strategies superior to those attainable in the real aircraft. Examples of such instructional strategies are part-task and adaptive training, extensive feedback, for example through Knowledge of Results (KR) followed by an explanation and demonstration of the correct response, provision of replay possibilities and *cue augmentation,* that is the use of cues that are not present or have insufficient cueing effect in real flight, but may have a positive effect when they are introduced or amplified in the training environment. Lintern (1996) provides an overview of transfer-theories and existing research on flight simulation fidelity research to date.

The current research is distinguishable from earlier research in the field of training effectiveness of low-cost/low-fidelity simulation because of its focus on the acquisition of perceptual motor skills (aerobatics skills), in-flight measurement of both learning curves and final performance, the optimal configuration for PC-based simulation and the use of augmented cues, and implications for selection of pilots.

Method

Experimental set-up and hypotheses

The experiment entails a comparison between three groups of subjects during 10 flying lessons; the first 8 flying lessons were considered as training and the last 2 flying lessons considered as the transfer demonstration phase. The experimental set-up involving those three groups is depicted in table 1. Choices concerning duration and number of lessons were based on experience and common sense.

	Control Group (C)	**Exp. Group 1 (X1)**	**Exp. Group 2 (X2)**
In-flight training	10 lessons of 30 mins. each.	id. to C-group.	id. to C-group.
Simulation training	no simulation sessions	10 simulation sessions of 50 mins. each.	10 simulation sessions of 50 mins. each.
Simulation configuration	n/a	PC-based standard equipment.	PC-based customized equipment + augmented cues.

Table 1: Experimental training set-up

From table 1 it can inferred that the experimental manipulations were:

- the use of PC-based standard equipment in simulation sessions for group X1,
- the use of PC-based customized equipment and augmented cues in simulation sessions for group X2.

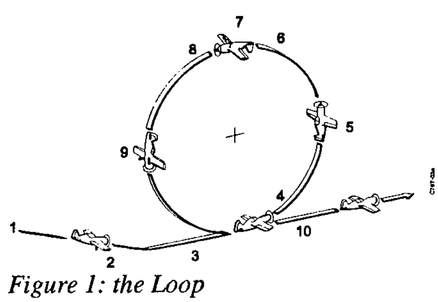

Figure 1: the Loop

The average score (see following section on performance measurement and scoring) of each group in the transfer-demonstration phase will be mutually compared under the hypotheses that the average score of the X1-group is higher than that of the C-group and that the average score of the X2-group is higher than both those of X1- and C-group.

The same hypotheses will be tested[1] with respect to the average progress per lesson (learning speed) during the training phase. Further, the magnitude of the effects (if any) resulting from the experimental manipulations wil be investigated and those effects will be related to the shape of the learning curves for the three groups.

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[1] The Statistica software package (StatSoft, 1994) will be used for statistical analysis. Significant results will have a p-level smaller than 0.05.

Task

The goal of the aerobatics training was to fly five aerobatics manoeuvres in a fixed order continuous sequence on an aircraft (see section 'aircraft'). Those five aerobatics manoeuvres are the Loop, Slow Roll, Inverted Flight, Immelmann and Split-S. Each of those manoeuvres takes a skilled pilot approximately 20 seconds to complete.

The order *Loop-Slow-roll-Inverted-flight-Immelmann-Split-S* was a logical choice: The loop and the slow-roll form the basis for both the Immelmann (which is a half-loop-half-roll) and the Split-S (which is a half-roll-half-loop). The Slow-roll is the basis for inverted flight (which is a half-roll, level inverted for 15 seconds, and again a half roll). Moreover the Split-S was the last manoeuvre in the sequence since it is physically the most demanding, mainly caused by the transition from negative to positive g-force, and also the most critical manoeuvre with respect to loss of altitude.

Performance measurement and scoring

The manoeuvres were judged by the aerobatics instructors (instructor ratings) on a restricted number of criteria. The criteria were chosen and prioritized in agreement with the instructors on the basis of importance of a particular criterion for the manoeuvre and the ability to observe whether a criterion is fulfilled. For example, a g-force of 3.5 to 4 g, pulled at loop-entry, is very important for succesful completion of the loop and can be observed by both instructor and trainee and is therefore a suitable criterion. On the other hand, during a slow-roll manoeuvre it is very hard for the instructor to observe and judge the roll-rate in an absolute sense, although it is an important criterion. Therefore a roll rate of say, 20 degrees per second, is not a suitable criterion as a basis for instructor rating. In this case a relative criterion (e.g. roll-in-rate equals roll-out-rate) is more suitable.

A sufficient small number of criteria were chosen, such that the instructor, seated behind the subject on the back seat of the airplane, was able to fill out the pre-printed score-forms. Scoring was based on criteria of equal importance, that is all criteria had an identical weight factor. All manoeuvres were considered as being of equal importance, that is were scored on an equal number of criteria. During the in-flight lessons, the trainee gained a point for each criterion that was fullfilled, that is when the associated parameter value fell within the acceptable range (see table 2 for an example).

Parameter	***Phase in manoeuvre***	***Ideal value***	***"acceptable" range***
Roll angle	pull-up (phase 4)	0 deg. Constant	-5 tot +5 deg.
Max g	pull-up (phase 4)	4g at entry speed of 145 mph	3.5 to 4g
Roll angle	top (phase 7)	0 deg. Constant	-10 to +10 deg.
Heading	top (phase 7)	Constant	-5 to +5 deg.
Altitude	exit loop (phase 10)	equals altitude at loop entry	- 100 to +100 feet

Table 2: Example: criteria for scoring the quality of the loop

Selection of subjects for the experiment

In order to compose three groups of 8 subjects, 24 subjects were needed for the experiment. These were selected in three selection-rounds.

In co-operation with a school for commercial pilots, approximately 60 trainee pilots attended a briefing and completed registration forms. The first selection-round took place on the basis of body weight (max. 80 kg, because of the restriction in take-off weight of the airplane), age (max. 27 yrs), fixed-wing flying experience (max. 250 hrs), previous aerobatics experience (no previous aerobatics experience allowed).

With a remaining number of 31 trainee pilots, in a second selection round, the Aiming Screening Task (AST) was used to collect data on individual ability. The AST was developed for the Learning Strategies Program (Donchin et al, 1989). This eye-hand coordination task was used since it is a well know selection task for research into perceptual-motor skills. The objective of the AST is to destroy as many targets on a computer-screen as possible within a session of 2 minutes, using a joystick. The task consists of three sessions of which the highest score (number of targets destroyed) was taken as the selection measure.

In the current research the AST was not used to remove potential subjects from the actual experiment but merely for balancing purposes between the three groups (conditions). On the basis of AST score, 4 ability-levels were distinguished: Low (L), Low-Medium (LM), High-Medium (HM) and High (H), corresponding with respective quartiles of the distribution depicted in figure 2. After assignment of subjects to groups, each group of 8 subjects contained 2 L, 2 LM, 2 HM and 2 H subjects. The remaining subjects were assigned to a spare group. The third selection round consisted of a 20 minutes test-flight on a single-engine propeller aircraft of make Fuji, a side-by-side seater with aerobatics capabilities. Deliberately, this aircraft was of a different type than was used for the actual experimental training to avoid confusion between the pre-training and training-phase. The subject had to perform a number of basic flight manoeuvres and a number of aerobatics manoeuvres, the latter deliberately being different than those included in the actual experimental training. The test-flight had two objectives: firstly to collect data on the basic and advanced flying abilities of the subject and secondly to test and possibly remove subjects that had insufficient physical resistence against air sickness to complete the aerobatics training. A pre-printed score-form was used by the instructor. On the basis of test-flight results three subjects were removed from the experiment and replaced by subjects from the spare group. To avoid a potential bias in the behaviour of subjects, due to knowledge of the objectives of the experiment, the experimenters presented the project as a study of in-flight instructional strategies rather than a study into PC-based training. The three groups were trained separately.

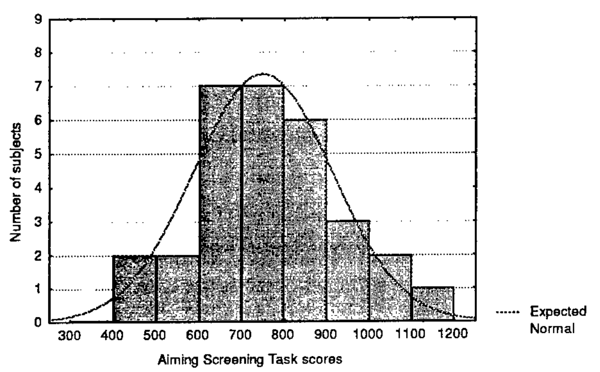


Figure 2: Distribution of Aiming Screening Task Scores

Training procedure

Table 3 represents the total training structure for the different groups. The contents of the lessons in each phase will be briefly described, starting with the training elements that all groups had in common.

In the *pre-training phase*, all subjects received the training manual. The theory in the manual had to be mastered before the start of the training. Before entering the flight training, the subjects had to go through a theoretical test on the contents of the manual.

C	Theory and test		Flight lesson 1		Flight lesson 2		Flight lesson 3-8		Flight lesson 9		Flight lesson 10
X1 X2	Theory and test	Sim. Session 1		Sim. Session 2		Sim. Session 3-8		Sim. Session 9		Sim. Session 10	
	Pre-training	Fam. Phase		Training phase				Transfer-demonstration phase			

Table 3: Organization of training sessions for C group and X1/X2 groups

Before and after each *flight lesson* the trainee received a briefing by the instructor. The first flight lesson (*Familiarization phase*, see table 3) was used to familiarize with the aircraft. Furthermore, the instructor demonstrated the complete sequence of five manoeuvres after which the trainee could try the sequence him/her self in a talk-through manner.

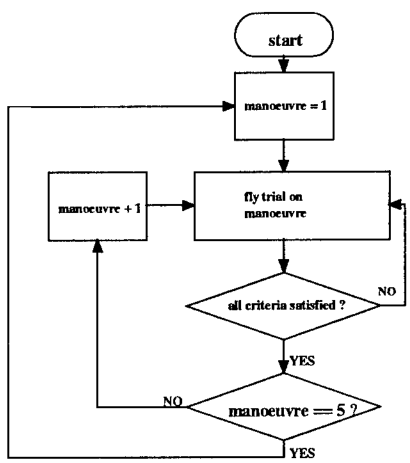


Figure 3: Organization of a flight lesson in the training phase

In the *training phase* (flight lesson 2-8) a part-task instruction strategy (see Wightman and Lintern, 1985) was employed. The basic organization of each in-flight lesson is depicted in the flowchart of figure 3. A logical choice was to segment the whole task (flying the sequence) into its component manoeuvres 1-5 (loop =1, slow-roll = 2, etc.) and train those as part-tasks. Thus, the second in-flight lesson started with trials on the least complicated manoeuvre (the loop). If this manoeuvre could be flown according to the criteria, trials on the next manoeuvre (the slow-roll) were undertaken and so on[2]. Once all separate manoeuvres were mastered, the same order of manoeuvres was repeated (outer loop of figure 3).

In the *transfer demonstration phase* (lesson 9-10, see table 3), the trainee had to demonstrate the whole sequence of five manoeuvres in a continuous and errorless fashion. Emphasis was on accuracy: "try to fly the sequence as accurate as possible".

Both X1 and X2 group subjects received 50 minutes *simulation sessions* preceding each in-flight lesson. Simulation sessions for both groups were identically organized.

The first simulation session (in the *familiarization phase*, see table 3) consisted of familiarization with the simulation, a trial on each manoeuvre and a trial on the complete sequence.

Simulation sessions 2-10 consisted of (1) structured repetition of problematic manoeuvres as indicated by the flight instructor during the previous in-flight lesson and (2) preparation of new manoeuvres. No mediation by instructors was needed.

Aircraft

The aerobatics aircraft used for the training is of type Bellanca Super Decathlon depicted in Figure 4. This single-engine propellor aircraft is thrusted by a four cylinder 180 HP Lycoming piston engine. The aircraft can take g-loads in the range -5 to 6 G. Equipment on-board of the aircraft was used for recording 12 relevant flight parameters during the training. The recorded data is not yet taken into account in this article.

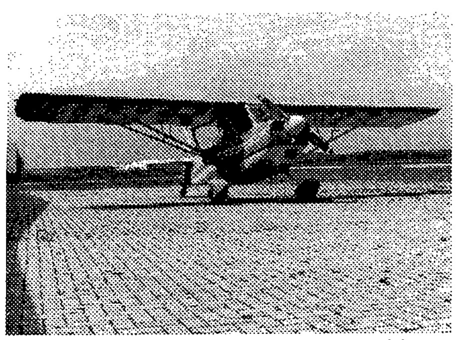


Figure 4: The Bellanca Super Decathlon

[2] For didactical reasons, the instructor had the possibility to start with a next manoeuvre even though not all criteria were fulfilled. The rate with which trials were repeated was left to the decision of the instructor and his opinion on the skill-level and prospects of the trainee.

PC-based training equipment and software

Both groups used the aerobatics training software package "Flight Unlimited" from Looking Glass Technologies (MS-DOS version, Looking Glass Technologies, 1995). Flight Unlimited is a PC flight simulation with relatively accurate aircraft flight models (including that of the aircraft used in the experiment) and 3D photo-realistic landscapes. A view was selected in which on the lower half of the screen the instruments were depicted, while the upper half of the screen was used for out-of-the-window view. Furthermore the "renderer" was set up such that terrain was in lowest detail, haze was on highest level, clouds were turned off, blending set on lowest level, g-effects were on and wind strength was set to a maximum.

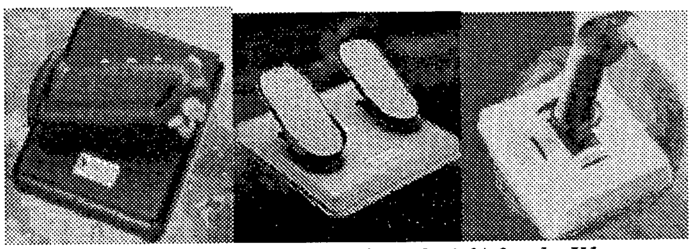


Figure 5: Controls (throttle, pedals and stick) for the X1-group

X1- and X2-groups used the same simulation software and the same PC (Pentium 166 equipped with a sound card and speakers and a CD-ROM player). The differences in equipment are listed in table 4.

	X1-group	***X2-group***
PC-monitor	17" colour monitor, used in VGA-mode (640x480 pixels)	21", further identical to X1
Throttle	Pro Throttle by CH-products (see figure 5)	Throttle, rudder pedals and stick were customized and mounted on a base such that their shape, position and displacement resembled those in the aircraft (see figure 6)
Pedals	Pro Pedals by CH-products (see figure 5)	
Stick	Flightstick Pro by CH-products (see figure 5)	
Seating	Standard bureau chair	Mounted on base and resembled the chair in the aircraft such that trainees were able to occupy the same bodily posture as in the aircraft (see figure 6)

Table 4: differences in equipment configurations between X1- and X2-groups

Furthermore, subjects of the X2-group were presented with the following augmented cues during their simulation sessions:

- guidance by a digitized instructor voice (feature of the Flight Unlimited software) during their simulation sessions (subjects were "talked through" the manoeuvre);
- lesson arrows (feature of the Flight Unlimited software), those are indications for suggested stick and pedal movements were presented in real-time on the screen

Results

Invalid data and outliers

For methodological reasons, data from three subjects had to be removed from the experiment. From the C-group, data from one subject was removed from the analysis since incorrect information had been received from the flying school. On the basis of new information, it was decided that this subject could not be considered as representative for the trainee pilot population under study. From the X1-group, data from one subject was removed since this subject had a physical problem that hindered the subject to look sidewards under the high g-forces that occurred in most manoeuvres, and could therefore not complete the aerobatics training. From the X2-group, data from one subject had to be removed since this subject turned out to have significantly more fixed wing experience than initially reported. Furthermore, one outlier (unusual low-score score of a C-group subject) was removed on the basis of the 3s-criterion used in residual analysis.

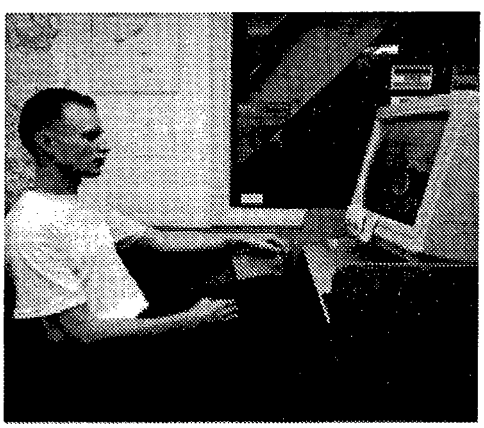


Figure 6: Customized PC-based trainer for the X2-group

Instructor ratings

It must be noted that the results currently presented in this article are based on instructor ratings. [3] The three instructors were randomly assigned over a total of 240 flight-lessons and were instructed to score using pre-printed score forms with performance criteria in terms of objective and observable flight parameters (see example in table 2). To examine inter-rater reliability, stepwise regression analysis was conducted, in which the variables representing the instructors (3 levels/instructors coded in two dummy variables) were two of several independent variables (simulation-configuration, ability-scores measured in the pre-training phase, etc.) and in which the score during the transfer-demonstration phase was the dependent variable. The dummy variables representing the instructors did not significantly contribute to the model for regression, nor did those variables account for a substantial percentage of the variance in scores. It is realised that these results do not formally prove interrater reliability. In view of time constraints and the availability of objective measurements more formal tests have been abandoned for this article.

[3] At the time of preparing this article the analysis of the recordings with the airborne measurement equipment is still ongoing and will be reported in the course of 1997.

Representation of in-flight scores

The instructional strategy employed in the training-phase was directed on learning-by-doing and thereby flying as many manoeuvres as possible. A different approach was taken in the transfer-demonstration phase where emphasis was put on demonstrating a restricted number of sequences with the highest possible accuracy. For the training phase, we therefore calculated the in-flight score per lesson by summing the total number of points gained in that lesson, thus representing both speed (number of trials per lesson) and accuracy of the manoeuvres. For the transfer-demonstration phase however, we will calculate the in flight score by dividing the points gained in flying the sequence by the number of sequences flown in that phase, thus merely representing the accuracy of the sequence. For interpretation and comparison purposes, all scores will be scaled to 100%, through division by maximum attainable accuracy score and maximum number of manoeuvres per lesson observed.

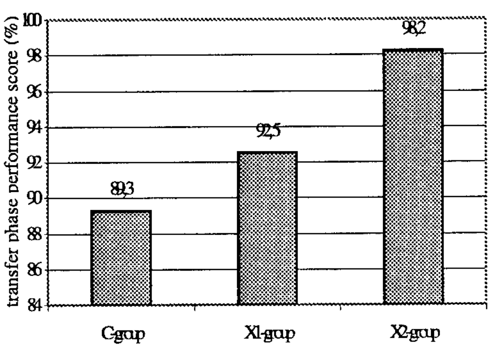


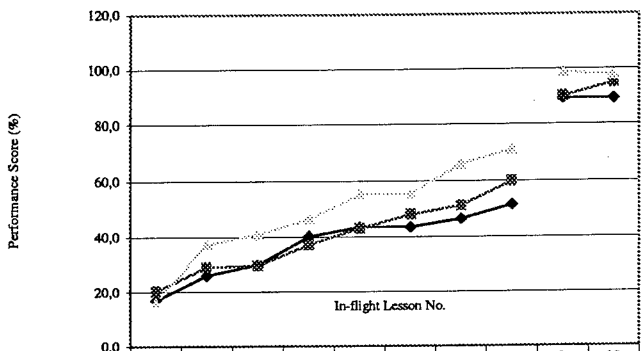
Figure 7: Mean scores in transfer demo phase

Transfer-demonstration

The objective of the transfer-demonstration phase was to fly continuous sequences with maximum possible accuracy. Mean scores for the three groups are depicted in figure 7. The C-group scored 89.3% (M=89.3, s=13.6), the X1-group scored 92.5% (M=92.5, s=5.5) and the X2-group scored 98.2% (M=98.2 s=2.91). Wilcoxon matched pairs test was used to compare means. The difference in mean score between C and X1 group is not significant, the difference between C and X2 group is significant (p=0.017), the difference between X1 and X2 group is significant (p=0.015).

Thus, while the X1-group, that is the group using the standard simulation equipment, failed to show significant transfer, the X2-group proved to have a significant advantage from using the customized configuration. The differences in performance score in the transfer demonstration phase are relatively small (The X2-group scored only approx. 9% better that the C-group). However, it must be noted, that scores had a tendency towards 100% in the transfer-demonstration phase. Since scores were based on a restricted number of relatively simple criteria, near-maximum accuracy could relatively easy be achieved. This ceiling-effect in performance score (based on accuracy) is thought to mask the real difference in skill level in the transfer demonstration phase. Further analysis of in-flight data on the basis of a larger number of more sophisticated scoring criteria would reveal whether this assumption is true.

Learning speed



	1	2	3	4	5	6	7	8	9	10
C-group	16,8	26,0	29,8	40,1	43,4	43,4	46,3	51,4	89,4	89,1
X1-group	20,4	28,9	29,6	37,1	43,0	48,0	51,2	59,7	90,1	94,9
X2-group	16,2	37,3	40,8	46,5	55,0	55,2	66,1	71,1	98,7	97,7

Figure 8: Learning curves

The in-flight learning curves for the three groups are depicted in figure 8. Learning speed is evaluated in terms of average score-improvement per lesson. It can be seen from figure 8 that initial levels of performance (lesson 1) are approximately equal. Looking at the training phase as a whole, the C-group had an average improvement of 4.6% per lesson, the X1-group had an average improvement of 5.3% per lesson and the X2-group had an average improvement of 6.9% per lesson. The differences in improvement per lesson between C- and X2-group and X1- and X2-group are significant (p resp. 0.00045 and 0.0025), while the difference between C – and X1-group is not significant (p=0.14). From figure 9 it can be seen that the most remarkable improvement of the X2-group (approx. 20%) is booked early in the training phase and is existent throughout the remainder of the training.

Linear approximation of learning curves

In order to assess aerobatics skill-level during the training phase of the three groups in terms of speed and accuracy under the assumption that performance will eventually level-off at an asymptotic level the scores per lesson were approximated by linear curves, using the same data as in figure 8 (see figure 9). Results of the analysis, using least square approximation are included in table 5.

Model: Score = A * lesson no. + B					
Group	***Intercept B (begin level)***	***Slope A (learning speed)***	***R^2 (coefficient of determination)***	***F-value (overall model utility)***	***p-level***
C	16.4 %	4.6 % per lesson	93%	76	<0.01
X1	15.7 %	5.3 % per lesson	99%	418	<0.01
X2	17.5 %	6.9 % per lesson	94%	88	<0.01

Table 5: results of linear approximation of the learning curves

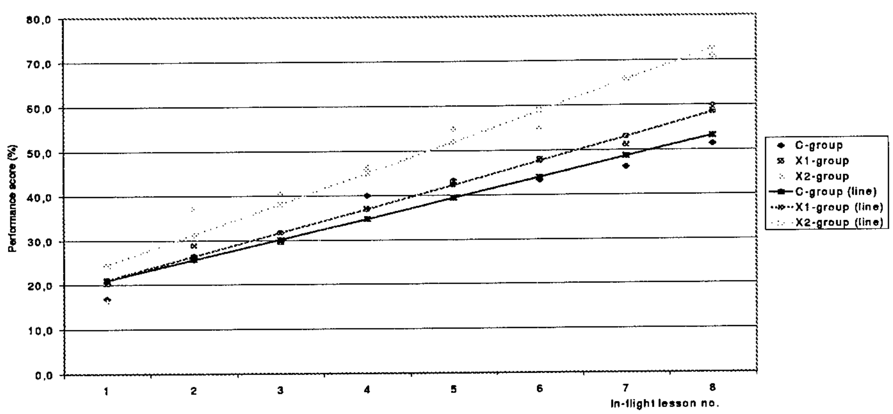


Figure 9: Linear approximation of learning curves

These results show that all learning curves are approximately linear and do not curve towards an asymptote, indicating that skill level could be further improved and the training phase was too short to approach the maximum attainable skill level with the task given.

Ability data and relation with aerobatics performance

It was hypothesized that ability data collected in the pre-training phase (AST-scores, standard flying skills scores and advanced flying skill scores) are good predictors for aerobatics performance. To evaluate their relative predictive value ability scores were included as variables in a standard multiple regression analysis together with the independent variable of the experiment. For this purpose, the experimental manipulation of the experiment at three levels (no simulation, standard simulation, customized simulation) is coded with two qualititive dummy variables X1 and X2. The dependent variable is the performance score (accuracy) obtained during the transfer demonstration phase. The results are summarized in table 6 (significant results are underlined).

Model: Score (transfer demonstration phase) = $B_o+B_1*AST+B_2*STD+B_3*ADV+B_4*X1+B_5*X2$ R = 0.64, R^2=41%, F(5,35)=4.77, p<0.002			
Variable	**Magnitude B_n of the effect scaled to a range [-1,1]**	**t(35)**	**p-level**
Aiming Screening Task (AST)	0.28	2.1	0.042
Standard flying task (STD)	-0.16	-0.95	0.347
Advanced flying task (ADV)	0.485	2.94	0.005
Use of COTS simulation (X1)	0.078	0.51	0.611
Use of customized simulation (X2)	0.49	3.17	0.003

Table 6: Multiple regression analysis results, relating several variables to aerobatics performance in the transfer demonstration phase.

The results from the analysis show that advanced flying ability (ADV, measured on three advanced manoeuvres: wing over, barrel roll and spiral dive), use of customized PC simulation (X2) and AST-score yield significantly to the prediction of aerobatics performance in the transfer demonstration phase, of which the latter one is of less importance, in terms of the magnitude of the effect. The use of standard PC-simulation does not contribute significantly to the model, as could be expected from our earlier analysis. Standard flying ability, as measured during 9 standard manoeuvres, does not seem to bear a correlation with aerobatics performance.

Conclusions and discussion

Research has been carried out to evaluate transfer-of- training of perceptual motor skills (aerobatics skills) to the real aircraft from three different types of ground-training. It was found that the group that was trained with customized PC-based simulation (X2) showed a clear advantage over the two other groups, trained with respectively standard PC-based simulation (X1) and no simulation (C).

The learning curves of the three groups show that those results apply to the initial skill acquisition phase, where the learning curve is approximately linear and skill-levels are one relatively low level of automaticity. In this phase, the use of customized PC-based simulation leads to a higher rate of learning. During the training phase, the group with no-simulation (C) was able to improve their performance by approx. 37%, the group with standard simulation (X1) by approx. 42% and the group with customized simulation (X2) by approx. 55%. Most remarkable improvement in score of the X2-group takes place in the first lessons, giving them a headstart, causing an improvement that is existent throughout the remainder of the training.

Concerning the validity of these conclusions, the question may be raised whether the flight performance differences between the X2- and respectively the X1- and C-group can be accounted for by other factors than the imposed experimental manipulations. A possibility that could give the X2-group an advantage over the X1- and C-group and not stemming from the customized simulation itself is biased treatment by the flight instructors, since it was practically impossible the keep the flight-instructors unaware of the ground-training that each group received. To minimize the likelyhood of this possibility, scoring criteria and scoring standards were used that left the least room for free interpretation and subjective judgement. Further validation of the results with the performance data logged with the airborne equipment and during simulation is needed to fully exclude this possibility and to gain more insight in the reliability of instructor ratings.

Viewing the conclusions of this research, the key question is raised: Why does the X2 group show significant positive transfer, where the X1 group does not? What makes the difference in training effectiveness of perceptual motor skills when using customized PC-based simulation?

A prominent and valued improvement (by expert aerobatics pilots) of the customized simulation over the COTS simulation was the realistic position and displacement of stick, rudder-pedals and thottle relative to the body of the pilot. Our interpretation of the results is that by providing a realistic design of the workspace in simulation, perceptual-motor strategies transfer better to real flight, thus decreasing the need for paying (visual) attention to the different configuration of stick, rudder-pedals and throttle during real flight. The observation that subjects in the X1-group noticeably payed visual attention to stick-handling during simulation-sessions further supports this view. Also, we hypothesize on the basis of the results that realistic design of the simulation workspace, such that the trainee occupies a postural position that is identical to that in normal (straight and level) flight, serves a baseline cueing requirement for further development (in-flight) of seat-of-the-pants skills, i.e. skills that relate to the perception and processing of vestibular, tactile and kinaesthetic cues. We further hypothesize on the basis of the results that the use of augmented cues, i.e. a digitized instructor voice during the simulation lessons and the use of the lesson arrows (visual indication of the direction in which to move the rudder pedals and stick) made learning of the procedural components of the manoeuvres easier, thereby decreasing the cognitive load, such that during simulation more attention could be paid to the visual components of the manoeuvres. The in-flight observation by instructors that X2-subjects had a better out-of-the-window visual orientation, while X1-subjects seemed to concentrate more on the cockpit instruments, supports this view. It is thought that the use of a larger monitor (21" rather than 17") in the customized simulation has further contributed to positive transfer. The partial contributions of those customizations could not be established experimentally and is worthwile focussing upon in further research.

The higher rate of learning observed during the in-flight lessons with the group that used customized simulation can thus be explained by (1) their improved ability to extract visual cues from the outside world that are needed to perform the time-critical elements of aerobatics (2) speeded up learning of procedural elements of aerobatics in earlier stage in training (3) an improved basis for in-flight development of seat-of-the-pants skills.

An additional factor that is hard to catch in figures or concrete observations, but may well be overlooked, is a possible higher level of motivation by the X2-group, i.e. to train with the customized configuration was notably more fun than to train with the standard configuration. Although all participating subjects were highly motivated, differential extrinsic motivation caused by the differences in ground training may have added to incremental transfer of the X2-group.

This research has contributed to the fidelity database for flight simulation by focussing on some low-cost, state-of-the-art, multi-media solutions. Configurations such as those experimentally evaluated can be applied to several settings: (1) Customized PC-based simulations can be used to support the first stage of in-flight training and training on high-fidelity moving base simulators. (2) It was observed in the current training program that trainees in the X1- and X2-groups needed very little pre-flight briefing. Briefing times went down from approx. 15 minutes for the C-group subjects to approx. 5 minutes for the X1-group subjects to almost zero for the X2-group subjects. Thus, both simulation configurations could be applied as automatic briefing tools, therewith saving flight-instructor time. (3) It is a well-known fact from learning psychology that lower-ability subjects benefit more from advanced instructional strategies than higher-ability subjects. Although not yet apparent from the current results, it is not unthinkable to employ customized PC-based simulation as a remedial instruction tool throughout initial training, therewith lowering wash-out rates in this stage of training. (4) The data in this experiment reveals that performance on standard flying tasks is by no means a good predictor for aerobatics performance, probably since aerobatics tasks appeal more to seat-of-the-pants flying. Further research could therefore be directed to the utility of customized PC-based simulations for the selection of military pilots.

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A Systematic Approach For Applying Multimedia Techniques To Aviation

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Abstract

For its central theme this paper will address some of the problems which arise because the human is often considered as the weakest link in the aviation system. By striving for a systematic integrated approach of the technical and human considerations the authors suggest that all the players in the aviation system can make a contribution to improving aviation safety. The paper addresses a number of human factors aspects need to be addressed in detail if they are to act as effective drivers in the efforts to improve aviation safety.

The advent of modern multimedia techniques suggests that a paradigm shift in capabilities has now occurred. This allows us to realistically model complex large-scale systems whilst also allowing individuals to specifically address their particular area at whatever level of complexity is appropriate to them. The paper will look at how multimedia techniques are particularly applicable to some of the aviation issues addressed earlier in the paper. This theme will be central to establishing the benefits which multimedia techniques can bring to the aviation system in order to create an effective and systematic integrated approach to the human performance interactions in the cockpit and air traffic control.

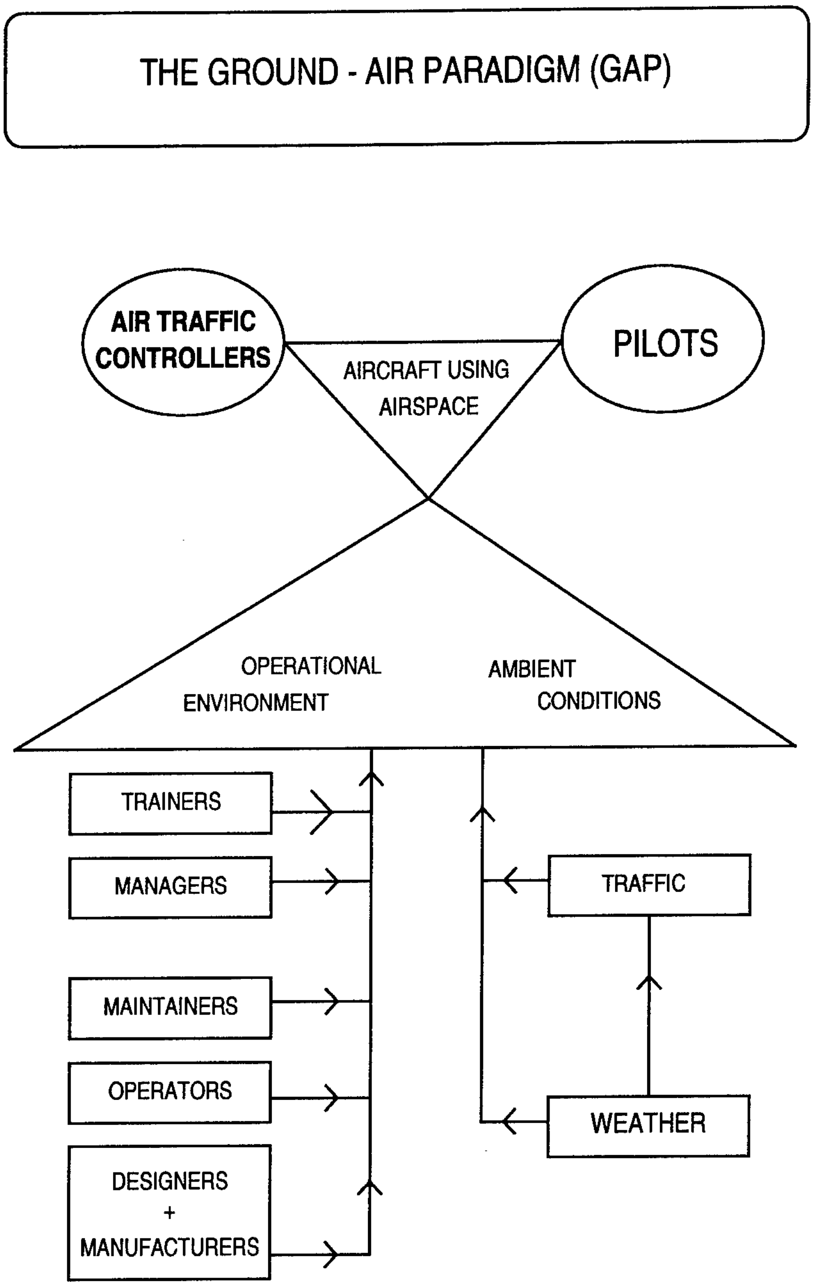
Introduction

Human-system interactions have recently been the focus of extensive study and discussion. A central point of this effort has been the recognition that the human is often the weakest link in the system framework. This is particularly true within the aviation community. Human error is the most cited single cause of aviation accidents. This is not surprising when one considers the myriad of aspects and stages of the aviation system development and implementation where the human is a major component: design and manufacture, operators, maintainers, managers and trainers.

Human Factors in aviation

The connections among some of the various aviation activities can be illustrated by the diagram shown in fig.1.

FIG 1.



As the model illustrates, the human is central to all aspects except the ambient weather conditions. The challenge is to address and optimize the interactions among all of these humans so that the system functions as effectively and efficiently as possible. Multimedia is often touted as the newest and most effective solution to all of the problems that plague the aviation human interactions. However, multimedia presentation of information both in the cockpit and on the ground has been in use for decades.

First consider the cockpit. Flight information is displayed on color LCD primary and secondary displays in many modern aircraft. The identification of some controls is presented as labels and in some cases, the controls are identifiable by shape. Digital ATIS messages are present in many cockpits. Voice communications are prevalent both between the air and ground, and in military environments, between aircraft. Checklists use printed media. Communication between the cockpit and the flight attendants is by telephone on most commercial airlines. Clearly, the modern commercial and military aircraft utilize multimedia to present and exchange information .

The situation in Air Traffic Control is similar. Information on the location and identification of aircraft in the airspace is shown on a radar screen. Flight strips which contain information about aircraft are still present in printed format. Instructions to aircraft and interactions with aircraft are imparted verbally. Interaction with a computer terminal is also involved. Again, multimedia are involved.

Despite the fact that the use of multimedia is prevalent, it is not with out problems. Central to this problem is the fact that the end users of cockpits -- the pilots, and the end users of ATC systems -- the controllers, must interact. However, the systems which they are using have often been designed in isolation. That is, designers of ATC equipment and designers of cockpits are most often two independent entities. To further exacerbate the situation, even within the cockpit and within ATC systems design, the development and testing of the components of the systems have often been independent. The use of "off-the-shelf" components is hailed by many to be a great time and money saving endeavor. However, each of the components, operating alone, may function quite adequately, incorporating it into a system configuration without utilising proper integration studies could prove disastrous.

A number of human factors aspects need to be addressed in detail if they are to act as effective drivers in the efforts to improve aviation safety. In addition these drivers should be used in a proactive, rather than reactive way and the multimedia tools used to support the actions must be appropriately chosen for the particular activity.

The first problem which arises is how to categorise the Human Factors actions as the air and ground aspects are often addressed in different ways. One of the earliest was the definition given by the military's MANPRINT (MANpower and PeRsonnel INTegration) programme This essentially takes into consideration all system aspects which are concerned with Manpower, Personnel, Training, Human factors engineering, System safety, Health hazard assessment.

Organisational and management aspects can be added as many aviation organisations have traditional mechanistic structures which need to be modernised, in order to meet modern task requirements and more effectively use the skills and expertise of the personnel.

However, more appropriate recent conceptual models have been put forward in order to help classification of work. The one put forward by ICAO (Human Factors Digest No.1) is called the SHELL model from the terms Software, Hardware, Environment and Liveware. This notation is particularly useful in identifying the usefulness to aviation of HF studies as HF is essentially concerned with solving practical problems. Thus for Flight Operations the specific applications are categorised as but not limited to:

reduction of human error
training
evaluation
human factors
motivation
flight documentation
flight deck design
cabin design
visual performance
collision avoidance.

Eurocontrol (1996) have built on the SHELL concept to specifically address ATC matters and consequently categorise specific applications as:

Communication
teamwork
customer focus
rostering and working practices
human factors techniques
career and personnel development.

Although further types could be developed it is important at this stage, to concentrate on the essential HF disciplines which impact on aviation safety. Thus the ICAO and Eurocontrol categories can be combined as follows:

HF Category	Meets ICAO characteristics	Meets Eurocontrol characteristics
Physical requirements	Physical size and shape Physical needs	
Working practices	Output characteristics	Rostering and working practices
Information processing	Input characteristics Information processing	Communication/Teamwork/Customer focus
Organisational, regulation, management and training aspects	Environmental tolerances.	Human factors techniques (management) Career and personnel development

Working practices

Despite the fact that multimedia have been extensively involved both in cockpits and ATC, the problem of integration of all the information and required functions is pervasive. Even within a single display the problem of integrating all of the information and presentation issues can be problematic. To illustrate the problem, in a recent study by Shaffer and Mills (1993) to develop guidelines for a display avionics management unit for a military cargo aircraft, it was found that there had been no non-proprietary studies that addressed the interactions of menu development with its presentation, including font size, contrast, lighting, location and display density. There were numerous studies which addressed each of these elements in isolation, but none that addressed the issues as they interact. The require font size is dependent upon the location (in this case in the cockpit) which determines the lighting and contrast requirements. These also limit the amount of information that can be portrayed on the display given the display density guidelines. When one tries to make trade-offs, it is difficult, if not impossible to consider all of the interacting factors based upon today's published literature.

Subsequent to this effort, Toms, et al (1995) performed studies at Wright Laboratories in Ohio using simulated flat panel displays incorporating the best "guestimate" of combinations of display characteristics. The question being asked was "is the performance with the new display as good or better than performance with the existing display?" Since existing displays were being utilised by crews in the cockpit, this was considered to "validate" their usability. However, nothing could be said about optimising performance, or whether performance might have been even better using a slightly different configuration. While its scope was limited to the study of only one new configuration, the study was important as it is one of the few recent studies of display integration that is finding its way into the published literature.

Most studies that address displays as an integrated part of a total system, if they exist at all, are considered to be the exclusive property of the researching company. As a result, each researcher must "reinvent the wheel," and the body of literature addressing integration studies remains woefully small. Furthermore, the conduct of parametric studies of the myriad of display and system characteristics which interact to create the end product is, at best, an Herculean task. This task probably is too large, and cannot be entirely accomplished. Nevertheless, the industry and the traveling public would be better served if there were greater sharing of information among the researchers, particularly where integrated systems are being evaluated. Or perhaps a centre for technology exchange should be instituted.

New solutions for existing and new problems

Models and case studies have always suffered from looking backward and thus solving yesterday's problems. The advent of modern multimedia techniques suggests that a paradigm shift in capabilities has now occurred. This allows us to realistically model complex làrge scale system whilst allowing individuals to specifically to address their particular area at whatever level of complexity is appropriate to them.

Obtaining relevant data

Utilising models of complex systems to address complex issues depend upon accurate, relevant, and sufficient data. These data should be derived from an operational context for them to be maximally useful. Fortunately, the miniaturization of video cameras offers a unique opportunity to obtain such data. Empirical tools, using video offer more reliable and valid data since they do not rely upon self-report by operators on what they do and how they do it. Sometimes such self-report reflects what people think they do, or what they think they are supposed to do, not what they actually do. Models using such data, are therefore of limited utility.

Subjective assessments translate into the "eye of the beholder",. and there are times when such a view is not complete. A case in point is revealed in a study on the stressful conditions affecting pilots during aircraft carrier landings (Miller et. al,, 1970). The study found a three times higher level of serum cortisol levels (indicating stress) even among experienced pilots. This occurred despite pilots rating themselves, subjectively as being calm. Ergo, subjective analysis has its limits.

An Empirical Methodology

Video using Empirically Validated Task Analysis (EVTA) offers some realistic answers to this dilemma. It allows a presence in environments where observation has been impossible; it allows one to replay the segments to determine what is "really going on"; and it allows one to verify the tasks performed, to see how problems are faced and how they are successfully and sometimes unsuccessfully solved. Because the camera is unobtrusive (some cameras are smaller than a man's thumb), the operators quickly forget that they are being taped. This means that they are more likely to behave as they normally would, not as they think they should.

The camera captures images and conversation on videotape that may be viewed repeatedly and concurrently with the time consumed. Provide this information to a team of qualified observers who record tasks and time through consensus, and there is a considerable improvement in the quality of empirical data derived.

To assist in the analysis process, Paradigm developed the proprietary EVTA software program. The EVTA process generates a task-descriptive data base from a detailed analysis of operator's observable activities and audible communications. In some environments, it is possible to also record the information that is presented on a computer screen, so it is possible to determine the information that is present to which the operator is responding. The essential features of the EVTA process are the use of video/audio equipment to gather permanent records of operator functions from operational environments, and the generation of an empirical record of function times through a software package which builds, manages and analyses the resulting data base. The output from the EVTA software is intended to provide the data required by and compatible with simulation environments such as Micro SAINT (Anon., 1987, SWAS (Holley and Parkes, 1987,) and HOS (Lane et al, 1981). More recent models may also use such data.

The focus of EVTA is on observable behaviours such as hand movements, body movements, internal and external communications and visible information presented on CRTs, LCDs or other idsplays. Cognitive activity is caputred only when communications between operators or an overt activity indicate that it has occurred, it is not inferred.

Enhancements to the process

One of the difficulties with using data obtained video analysis, rests with the analysis process itself: it is time consuming; tedious, and both boring and demanding. To address some of these problems, (primarily with the input process), a new system was designed by Monterey Technologies Inc. for the U.S. Navy: the Video Information Extraction Work Station (VIEWS). This system digitizes the audio/video tape which allows for random access anywhere on the audio/video stream without the time consuming, inaccuracies of rewinding of tapes. Start and stop times can be entered with a single keystroke, eliminating the necessity for entering the individual numbers in the time hack thereby reducing errors. Multiple sources of data can be entered. Digital information such as eye movments can be integrated with information from the audio/video stream on the same timeline It is possible to zoom into a portion of a video frame for closer examination. The audio/video stream can be viewed on a frame by frame basis, if very precise time information is required. One of the most useful features is the loop capability, which allows the analyst to identify the start and stop of an event and to replay the loop repeatedly until all of the information about the event is recorded. This is particularly useful in deciphering garbled communications which frequently occur in operational environments particularly in aircraft. Finally, future versions of the VIEWS system will include the ability to enhance images and audio quality.

The only study performed to date using data obtained from VIEWS is a study for a major telecommunications firm which addressed a detailed job analysis of customer service representatives. That study used a prototype version of VIEWS and despite its pre-production bugs, it offered some assistance in translating multi-media source information into useable data. As the technology matures, these types of data can be useful in modeling complex systems that are becoming commonplace.

Information processing

In many cases it is not possible to engage in in-depth studies such as those involving EVTA and VIEWS and data must be provided in the most effective manner that expert opinion feels is appropriate. One such area is information processing. This is, of course a major activity at present, due to the immense amount of information which is available and relevant to every job. As a safety critical activity, the aviation field has always been in need of current information to allow for timely processing, as so many aspects of the flight environment change rapidly, and flying is a notoriously unforgiving environment for errors. Fortunately, multimedia techniques now give us an opportunity to provide instant communications of whatever information is available and appropriate to the situation. Because of advanced technology, it is possible to present information in a hierarchical fashion: the most important information provided first and foremost. This information can be presented in a myriad of ways. The most appropriate media can be selected for the particular application, with the ultimate goal of reducing errors.

Application to training

Applications to information processing are well understood in the operational context, however, the real challenge is to transfer the capability into the off-line activities such as training, where traditionally the demands have often not been so stringent. There are several aspects of these off-line activities that deserve special attention: ensuring up-to-date information in the airspace environment and maintanence of up-to-date instructors., training time, and controller education for new technologies.

1. Recieving appropriate information on characteristics of new aircraft entering an airspace.

Keeping up-to-date on all of the relevant information about new aircraft is traditionally a problem in developing countries, and can, because of volume, become a burden even to large counries. The ISO 9000 series stresses that as a part of the quality management process, it is critical that relevant information must be provided to the actual user and not left in the manager's office.

With current multimedia techniques this information can be placed directly with the actual user by using CD-ROM or via the Internet thus providing on the job training. Adding to this, the realistic use of video, there can be a reinforced connection between the type of aircraft and its performance. This can be provided at the level of detail required by the specific user.

2. Maintaining up-to-date instructors.

When the instructional staff must be removed from their operational capacities, it is is difficult, particularly over time, for them to maintain their currencies. Special skills can be lost, and up-to-date examples can be sacrificed. This problem applies particularly to controllers but also to airline pilots. While simulations are useful in providing hands-on experience particularly with pilot training, the importance of having instructors with up-to-date, current , and extensive expertise is invaluable. With the availability of Web sites on the Internet, such information can be documented and available to trainees from diverse geographic localities.

3. Training time

Training time, particularly for controllers has always been considered a lengthy process, and many countries are making great efforts to reduce the time. New techniques include the use of PCs to match training presentation to individual student learning styles. Simulator exercises tailored both to the geographic area (with its accompanying level of complexity) and to the student learning styles provide a cost effective and timely training philosophy.

4. Contoller education for new technologies

With the introduction of the Advance Automation Techniques (AAT) into ATC there are questions regarding the extent to which the present generation of controllers are adequately educated to understand the understanding principals of the new technology and the implications of its practical implementation. Both CD-ROM and the Internet offer appropriate and cost-effective training in these new techniques. Self-learning can be a powerful tool for providing currencies, however it should be noted, that, given a variety of learning styles and management incentives, not all of the current controllers will respond appropriately to such techniques. A vehicle to identify those controllers who might "fall between the cracks" and not respond appropriately should be developed. For those controllers, more conventional techniques of classroom training may be necessary.

Other applications

There are many other applications which are reciving attention and the present situation will make for an excellent discussion. Among some of the topics must be mentioned:

1. The ability to strengthen the data, information and knowledge links between regulatory authorities, licencing authorities and operational organisations (eg. for monitoring, control and recording of results).
2. The ability to link simulators to CBT and thus improve trainnig programmes for standard training or for re-validating licenses).
3. The ability to link flying simulators and ATC simulators and thus practice realistic cockpit skills. Pilots, ATC skills and to produce CRM scenarios.

Management and future challenges.

Management must always be concerned with the competency and currency of its staff. Given the competitive marketplace present in the aviation community, this presents constant challenges. Adequate and appropriate communications are essential for all. Simulations (using PCs and more sophisticated computers), CD ROM, the Internet, Computer Based Training (CBT) all offer appropriate technological solutions to modern aviation problems.

However, the challenge is for the multimedia models to stay current with the real systems and the real problems and thus to be continuously looking forward. This is the challenge for management. This then is central to establishing and ensuring the benefits which multimedia techniques can bring to the aviation system in order to create an effective and systematic integrated approach to the human performance interactions in the cockpit and air traffic control. This is a holistic approach that affords the opportunity for everyone to stay abreast of the latest technology.

This is both the opportunity and the challenge for integrating technology and multimedia.

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Controller Work Position for future automatic dependent surveillance

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Introduction

The plannings of the ICAO (International Civil Aviation Organsiation) concerning the global implementation of future communication, navigation and surveillance, and air traffic management require worldwide operational satellite based systems (Global Navigation Satellite Systems, GNSS) [ICAO, 1988]. By the use of satellites for navigation and data communication purposes it will be possible to create surveillance (Automatic Dependent Surveillance, ADS) for air traffic control (ATC) independent of ground derived radar equipments. Based on a two-way air-ground data transmission a variety of onboard generated data, e.g. 4D data of flight profile or current weather data can be included in the planning and supervision process of air traffic control refering to its optimization. The improvement of quantity and quality of data however requires a redesign of the previous human-machine system ´controller work position´ (CWP) and a modification of the ATC procedures [ICAO 1995, EUROCONTROL 1991 und 1994].

In the context of a project promoted by Deutsche Forschungsgemeinschaft research was carried out to this at the Institute of Aeronautics and Astronautics at the Berlin University of Technology. The examinations reflect to operative and cognitive aspects of the air traffic controller´s work using the application of ADS. The aim was to get a user oriented design of the human machine system, and thus to specify necessary modifications of modes of operation used at present by air traffic control.

In a first approach the preliminary examinations were concentrated on the analysis of present air traffic control systems as well as on the task analysis of the controller´s work. A complex task scheme of the radar controller, the coordinator and their team work was developed based on the Goals Operator's Methods Selection Rules - model [Card et.al., 1983] declared itself through software ergonomy. Furthermore a knowledge acquisition was carried out for the conflict management process to get information about the subjective theories of the controllers regarding their main task of conflict detectionand solution as well as their mental processing. The knowledge about cognitive processes of the controllers completed the results of the task analysis. The knowledge acquisition proved as meaningful and necessary with regard to the implementation of numerous new information particularly into the ADS CWP. This scheme (task analysis and knowledge acquisition) formed a basis for the design of the future ADS CWP. It was valid to answer the question how the technically possible availability of new data has been brought into harmony to the required data for previous work tasks as well as the construction of subjective theorics of the controllers.

The development of requirements for the specification of the human-machine interface of the CWP then was carried out in a second approach as well as the development of the graphical dialog interfaces and the implementation in a simulation environment. At least the complex human-machine interface of the ADS CWP was evaluted heuristically by experts of interface design and air traffic controllers. So, an evaluated ADS CWP for further experimental, comparative examinations of possible ADS modes of operation exists.

Preliminary Examination

The analysis of the present situation covered documents such as ODID IV (Operator Display and Input Development) [EUROCONTROL, 1994] and the design guidelines for controller work position appropriate to COPS (Common Operational Performance Specification) [EUROCONTROL, 1991]. Observations and interviews of controllers at the ACC Tempelhof of the Deutsche Flugsicherung GmbH (DFS) were also carried out. The aim has been the analysis of different design concepts as well as the inquiry of the current state of development of air traffic controller work positions like DERD-XL (representation of extracted radar data/extended version). Potential design lacks and advantages of present air traffic control systems should be recognized.

20 experienced radar controllers (EC) and coordinators (CC) took part in the interview. They could refer to an average professional experience of nine years and had admittances for at least two and maximum twelve air traffic control sectors. Ratings and open questions formed the main emphasis of the questionare. These were useful to judge the design of the single control units and informational displays as well as the expected benefit of possible innovations.

The controllers named a variety of CWP shortages and estimated the general use of data link for the air-ground communication as very desirable. An expansion of the present information according to the aircrafts to be supervised seemed to be considered very positive. An absolutely required attention of design principles became in connection with this emphasis, too. Almost all of the controllers reported that they did not have sufficent support for the conflict detection and solution process by the present operational system. Need for action would particularly exists in the prediction of potential conflicts between aircrafts. One solution to a variety of the problems will be possible by the use of data as specified by ADS. By the use of data link safety in air transportation will increase by a more precise identification of flight targets, one improved supervision of airplanes in areas with no or less enlarged radar equipment as well as one enlarged quantity of information. A better usage of airspace capacity will be possible by reducing the separation standards. In addition, the correlation of the scheduled flight data with onboard generated position and flight intention data will be a relief for the execution of planning and coordination tasks.

Further examination was carried out for completion of the analysis of present operative air traffic control systems regarding the current and future state of development to functionality and operability of ADS in air traffic control. This served to the inquiry of perhaps available specifications for the ADS functionality respectively its application into future air traffic control system. No standardization for ADS was carried out by the ICAO [ICAO, 1995] until today. The exchange of ADS data between air traffic control and aircrafts will be initiated by any of them. This can be carried out periodically or on request. This so called ADS report can contain up to eight blocks of data of various information. The composition varies in dependence of the avionic standard, the volume of air traffic and operational aspects. The transferred data refer e.g to the position of the aircraft (basic block), the current speed and heading (ground/air vector), the 4D-profile calculated by a flight management system (projected profiles) or actual flight weather data (met info).

A detailed task analysis of controller´s work in the context of the first work package became necessary because it was not available at the beginning of the project. However, the description of possible modifications of future ATC procedures given by the introduction of ADS and the redesign of an ADS CWP required some task analysis (Hollnagel, 1990).

For this reason a document analysis has been conducted based on the BAFVK (operational procedures for air traffic service) and the EUROCONTROL Task Book AF51 (EUROCONTROL, 1995) as well as further observations and interviews with selected ATC experts at the ACC Tempelhof of the Deutsche Flugsicherung GmbH. The result was a clear structure of tasks to the present work of radar controllers and coordinators in connection with the used DERD-XL work station. To be able to better describe the distribution of tasks in the human-machine system, a customization of the determined tasks to the sooner mechanistic GOMS model, known from the software development discipline, was carried out on a functional level.

As a matter of priority observable shares to the very complex task of air traffic controller´s supervision were made visible with the task analysis already mentioned. It was valid to got a picture of this work as complete as possible including also the rules to the practice of the determined tasks being based and therefore subjective theories of the controllers. In an extensive, methodically complex examination with 20 subjects (controllers of ACC Tempelhof) the main task of the controllers, the conflict management, was analyzed. The methods used were an especially designed questionare, the method of network development and the method of constructive interaction.

The subjects spread out as follows on the single methods:

controller /method	network		questionare		constructive interaction	
	network new info	network known info	questionare detection	questionare resolution	type of conflict 1-4	type of conflict 5-9
EC	7	10	5	6	5	5
CC	10	8	5	6	5	5

Table 2.1: Distribution of subjects

The questionare used in the test consisted of so-called open questions and of ratings with main emphases concerning the demographic data, the conflict detection, and resolution.

Using the method of network development the test participants had the task to group a set of data cards containing information will need at present and future for the practice of their job as air traffic controller. In a first step they had to sort all cards so that all information which has a similar importance for the conflict detection process were summarized in a group. Then they should try to structure these cards in a network, which represents individual mental information structure of their personal conflict detection process.

Due to the number of subjects in comparison with the examined parameters (number of information to sort) an exclusively qualitative analysis of the obtained data in accordance with the network development seemed to be efficient [Lüer, 1987]. A quantitative comparison did not seem meaningful here. Observations during the execution of the method showed that controllers had some difficulties to structure the information units of such a highly automated task like conflict detection. The controllers consequently emphasized the missing general validity of their networks. This was caused by the variety of conditions and situation variables having an effect on the process of conflict detection which were not checked explicitly. Nevertheless relatively similar results were produced within the respective random sample and the low number of subjects. This points out that there are generally pure coherences within the conflict detection process.

Controllers were confronted with the method of constructive interaction (Nielsen, 1993) in the context of the examinations at the ACC Tempelhof. The potential conflict scenarios consisted of static variants designed as abstract radar pictures and control stripes. The conflict detectionand resolution was carried out during the series of experiments in a team of radar controllers and coordinators according to the organization in ATC. The task of the controller was to detect and solute potential conflict situations based on the information sources already mentioned (radar picture and control stripes). For the series of tests nine defined conflict types have been taken into account according to EUROCONTROL Task Book (EUROCONTROL, 1995). The conflict scenarios were formed on the radar sector UR 2 in the upper airspace of the UIR Berlin and checked in cooperation with active controllers with regard to its ecological validity. It had to be stated, that coordinators and radar controllers primary used flight level changes independently of the conflict type and secondarily measures affected the lateral profile like ´parallell offset´ and ´directs´. The decision about the application of one of the actions mentioned was dependent on the flight performance, particularly the speed of the aircrafts concerned, and the accordance of the partial routings of the conflict partners concerned.

By using an extensive catalog of methods a complex picture of the mental processes of conflict detection and resolution as well as a variety of specific controller´s knowledge had been determined. Because of the varying efficiency of the employed methods the single results were summarized with the intention to get extensive knowledge of information contents and their structuring at the human-machine interfaces of the CWP.

The resulting specification of requirements (see chapter 3.1) became the guideline for the further development of the human-machine interfaces of the ADS CWP. Main emphases were made concerning the primary tasks of controllers e.g. conflict detection and resolution and the design of tools for controller assistance.

Design of the HMI of a controller working position with ADS-functionality
Specification of the HMI

Resulting from the status analysis and the pre-studies, a catalog of requirements for designing the HMI of the ADS CWP was defined. The catalog is influenced by the guidelines of ICAO (1995), international guides for display design especially the ISO 9241 part 10 and part 12, the DIN 66234, part 8, the results of the ODID-Group and COPS-Specification from 1991, and topical research results of design of GUIs like the study of Charwat (1996).

Besides this analysis of documents, the results of described status analysis and the pre-study already mentioned (task analysis and knowledge acquisition) were used to develop the catalog. The results of knowledge acquisition and especially the conflict management in a team of controllers had have a great influence on the design process. Due to the collected results it was possible to fix a lot of important information have to be shown on the ADS CWP. Furthermore a number of conflict resolutions prefered by controllers could be recorded.

The requirement catalogue defines following rules of designing the ADS CWP:

1. **Realization of technical requirements of air traffic control (ATC):**
   - Real-displaying of airspace (map data, airspace structure),
   - Real flightplan data of aircrafts with standard avionik and ADS specific avionics (plan data and/or radar data are at controllers disposal) oriented by the ICAO standard of transmission rates of ADS reports in high density areas (1995),
   - Exact conflict detections,
   - ADS specific service functions e.g. displaying of planned flight profile, ADS events, and meteorological data,
   - Calculation and development of complete conflict resolutions which are possible by automated techniques and be prefered by controllers.
2. **Support of typical job tasks of air traffic controllers as well as their ATC functions defined by COPS**

   2.1.General requirements
   - Unique display for radar controllers and coordinators.
   - Possibility to adjust the interface to personal preferences.
   - Adjustments have to be saved by the system under a special personal code.
   - Possibility to execute all typically defined job tasks.

The ADS CWP has to hold the following information and functionalities (part 2.2. - 2.6.) to the controllers disposal in view of the functions of controllers defined by COPS.

2.2. Planning functions
- Presentation of the complete flight information by electronical stripes (sorted by time and deleted automatically; the stripes have to show at least the following informations: AC code, AC type, sector entry point, entry time, and entry level, sector exit point, exit level, and exit time as well as the planned flight profile with at most five waypoints inside of the bordering sector. Graphical flight path elements (lateral and vertical) should be shown on the central radar screen, likewise outside the controlled sector.).
- Facility of a simulation of flight path changes with a following-up check for conflict freedom.
- A long term conflict alert with an exact visualization of conflict partners and reasons.

- Holding possible conflict resolutions to controllers disposal, and displaying them in an understandable way.

2.3. Surveillance functions

- Presentation of the traffic situation of the controlled sector as well as the adjacent sectors (with a target symbol and the accompanying label, and at least the following informations: call sign, topical flight level, figure of merit, AC type, AC category).
- Conflict warning with a preview of more than two minutes (containing the reason of conflict and the conflict partners).
- Presentation of the following planned flight profile in a schedule and by means of graphical elements with the following information: sector exit point, exit time, and exit level).
- Supporting the orientation of controllers in the airspace by a flexible measurement vector and an understandable presentation of the vertical profile.

2.4. Monitoring and control functions

- A workload display.
- Status display of the particular modules e.g. conflict control.
- Implementation of a zoom function and the possibility to adjust the picture.

2.5. Coordination within the controlled sector, within the ACC, and between other ACCs (*was not the topic of the project at present.*).

2.6. Air-ground Communication (*was not the topic of the project at present.*).

2.7. With the help of ADS CWP the controllers should be able to detect and process the following conflict scenarios:

- high conflict potential caused by the structure of sector,
- potential conflicts resulting from aircraft movements,
- conflicts caused by weather conditions,
- emergencies.

2.8. Observance of general software-ergonomic and cognitive-ergonomic principles

2.9. System architecture

- The simulation should have been implemented in a UNIX environment.
- It should be designed according to the client server model to bear sufficient flexibility.
- The simulation should have a minimum of dead times.
- The controllers should be able to control a lot of traffic (approximately 60 AC´s per hour) with ADS CWP.
- Operations using a mouse as input device.
- Little keyboard usage (e.g. for input of controller codes).

Implementation into a simulation environment

The software part of the ADS CWP discussed here is a development from an experimental ATC simulation produced by the DFG project "Fluglotsenarbeitsplätze" (AZ.: Fr375/45-1). It is implemented on Unix workstations using the client server model and X-Windows. The server simulates the radar turn, keeps all flight plans, flight profiles, ADS data, and controls inter process communication.

The following figure 3.1 shows the communication scheme for the ADS CWP and other clients:

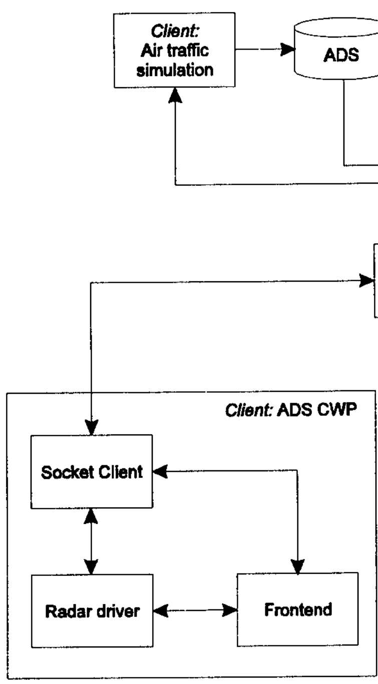

Figure 3.1: Communication scheme for ADS CWP

contains: ADS: ADS database, FPL: flight plan database, METEC: conflict detection, COREC: conflict solution

To improve performance, the CWP client was divided into three subprocesses, separating the communication with the server from its radar driver (calculation of aircraft positions and zoom functions) and frontend (visualization of air traffic situation display and user interaction).
Besides, in the ADS CWP, all mouse clicks can be recorded using log file protocols. This registration method allows immediate reproducability of all actions performed by the subjects, and thus makes it possible to conduct exact fault analysis, define reaction times, and to reconstruct all activity sequences. Log file protocolling is a substantial addition to interviews and video recordings as frequently used evaluation methods.

Development of the Graphical User Interface
At the beginning of this project there was no suitable ADS CWP prototype for simulation purposes. So the development of a new controller work position became a main part. This CWP then could be used as a test bed for the evaluation of the Computer Human

Interface (CHI).

The following figure depicts the structure of the CHI and its essential features. The frontend was built following the rapid prototyping paradigm with Tcl/Tk. This interpreter language comes with a lot of widgets which are good suited for developing Graphical User Interfaces under the X windows system.

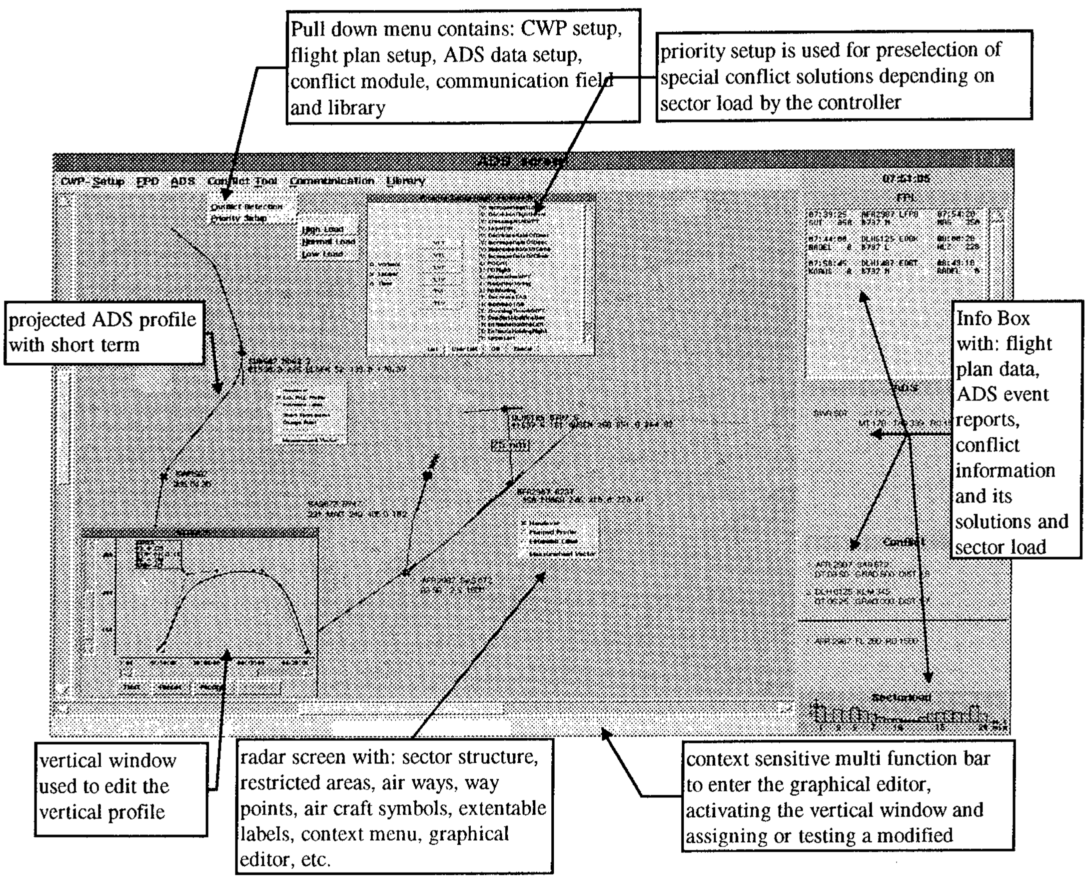

Figure 3.2: Frontend of the ADS CWP

The frontend is sub-structured in five main blocks: radar screen, pull down menu, context sensitive bar, info Box, and work load display. The radar screen with all its relevant information especially for short term management is placed in the center of the user interface. All additional information for instance flight plans or early detected conflicts will be accumulated in the Info Box. The work load widget displays the expected work load within next twenty minutes which is calculated by considering the given flight plans of the scenario.

Setup functionality is provided by the pulldown menu. The status bar is placed at the bottom of the screen. It permanently shows a scale of 15 NM based on the actual zoom factor. Additionally it contains the buttons of the graphical editor during edit mode. This editor allows editing of 4D flight profiles.

The CWP should be usable for aircrafts supporting different avionic standards. This is why context menus and labels of aircrafts contain different information. The following table summarizes this special information for the labels of ADS compatible and standard air crafts.

AC type	*aircraft label*	*Explanation of Abbreviations*	
Standard	ID, AC Type,	ID	AC code
	↑↓, Fl act, Fl koor, NexWP, Fl NexWP, Δt, TAS;	AC Type	AC type identifier
		↑↓	climb/descent indicator
		Fl act	actual height
		Fl coor	coordinated height
		NexWP	next (planned) way point
ADS	ID, AC Type, FOM;	Fl NexWP	height at next way point
	↑↓, Rates, Fl act, Fl coor, NexWP, Fl NexWP, Δt, TAS;	Δt	time to next way point
	wind direction, wind speed, turbulence, OAT	TAS	True Air Speed
		FOM	data quality of ADS avionic
		Rates	rate of climb/descent
		OAT	Outer Air Temperature

3rd line is activable exclusivly for ADS aircrafts.

Table 3.1: Information of aircraft labels

The ADS CWP frontend was extended by a graphical editor which was created in this project. It is partially integrated in the radar screen (lateral profile). The part of editing vertical profiles is implemented in a separate window which is activated on demand by the controller.

The editor allows modification of profiles without intervention of keyboard inputs. The modified and acknowledged profiles will be passed to the air traffic simulation and to the conflict detection module. This higher dynamic behaviour of the system allows a real time management near to reality.

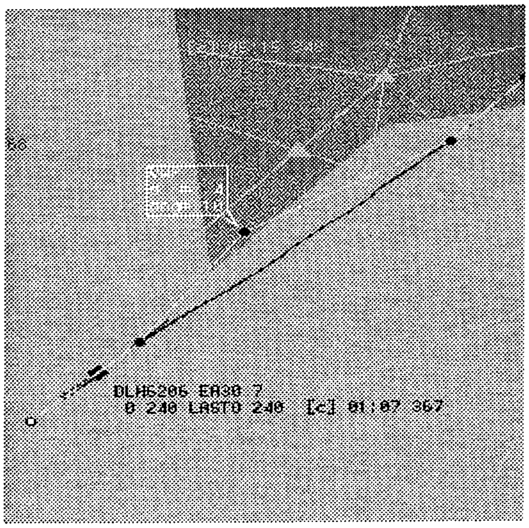

Figure 3.3: Graphical editor for modification of lateral profiles

The conflict management system is an additional client which is communicating with the ADS CWP. It consists of a conflict detection module (METEC), a conflict solution module (COREC) and a priority controller which is used for a user defined preselection of possible solutions. The detection module is configured by the pulldown menu (left part of following figure 3.4). The visualization of conflict regions and additional information are on the radar screen too (right part). The module for conflict solution is triggered automatically for the earliest conflict or manually for a specified one.

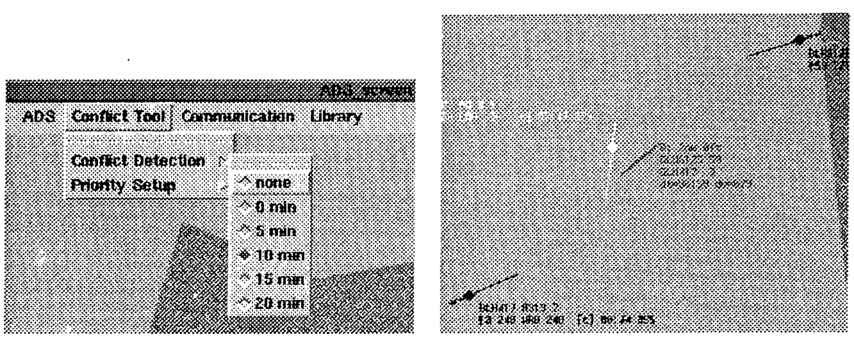

Figure 3.4: Configuring the conflict detection (left) and visualization (right) of a conflict situation

Heuristic Analysis of the ADS CWP Prototype

Description of the used method

After last system tests, a heuristic analysis of the interface of ADS CWP was conducted in May 1997. The subjects were experts of air traffic control as well as experts for interface design. The task was to judge the whole functionality of the working position, the monitoring of information, and the ability to manipulate buttons and other input devices. The qualitative evaluation was oriented by heuristics which are well known in literature (compare with Nielsen and Molich, 1990). So it was interesting to analyse the dialog, the reduction of memory strain, and possible faults of graphical presentation like wrong font size, errors in layout or trouble with controling the interface.

Before the test begun, the subjects had the possibility to learn about the interface and its functions and could „play" with it. Therefore a specific task-oriented handbook was developed in the project.

The aim of the heuristic analysis was the detection and exact description of all existing errors of interface design and the interaction of all components of the ADS CWP.

The results of the heuristic analysis of the ADS CWP show a lot of interesting faults of design, which can help redesigning the interface more user friendly. They do not call the ADS CWP into question but they are quite good suggestions.

Presentation of selected results

The subjects could work very quickly with the ADS CWP in an correct manner. They did not take long to learn the system operations. This observation points to a compatible, consistent, and clear design of the ADS CWP interface. Although, a further experimental study to check the possibility of working on job-tasks in a justifiable time and with less mistakes, has to be conducted.

The working on particular tasks was personally good valued by the subjects. The errors of design for instance overlapping of menus, to small types, and missed flexibility in colour design limit the fulfilling of tasks.

Quite interesting in the results was the different judgement of working with the ADS CWP by both subject groups. For example, the tasks „Detection of potential conflicts" and „Resolution of potential conflicts" were judged easier to solve by the experts of air traffic control. The experts of interface design had have a lot of problems. The following figure (Fig. 2.17, Page 13) will show these results more clearly.

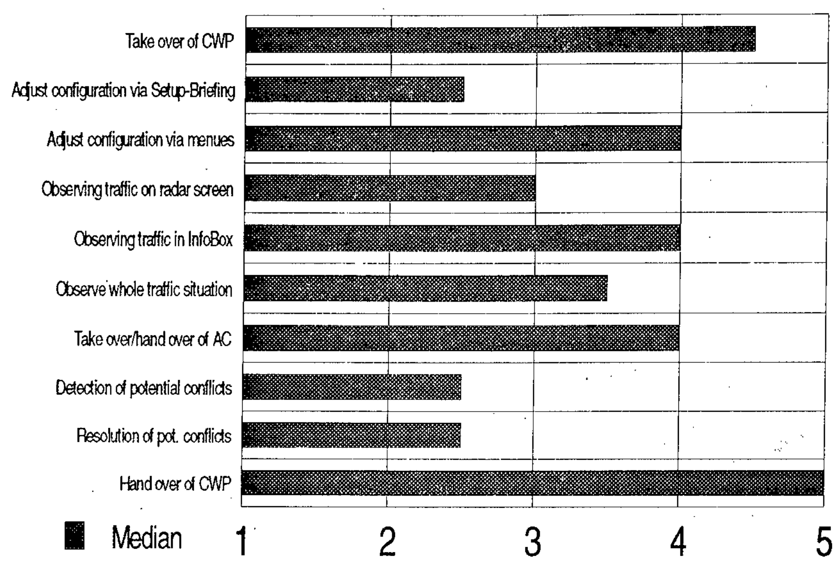

Figure 0-1: Evaluation of the quality of working with ADS CWP (experts of interface design); Evaluation standard: „The task is possible to execute in a good manner with the functionality of ADS CWP."; 1=is absolutely incorrect, to, 5=is absolutely correct.

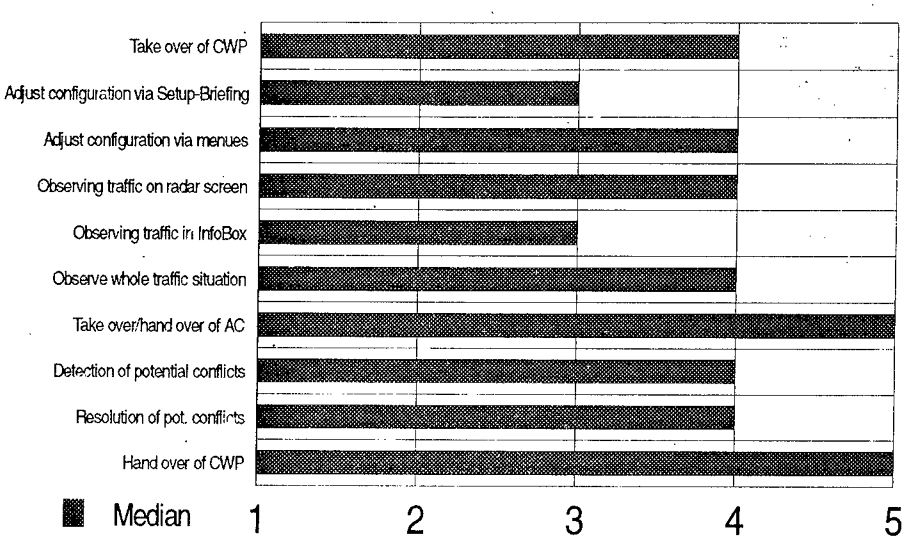

Figure 0-2: Evaluation of the quality of working with ADS CWP (experts of air traffic control); Evaluation standard: „The task is possible to execute in a good manner with the functionality of ADS CWP."; 1=is absolutely incorrect, to, 5=is absolutely correct.

A possible reason for the differences in evaluation is the amount of experience with the research topic, the air traffic control. To execute the given tasks it is necessary to use a clear interface, but also to have knowledge about the priorities of information and their meanings for instance in the solving process of conflicts. Which traffic constellation or information of the flight plans are indicators of potential conflicts? The controllers could use the showed information on screen in a good manner. Experts of interface design had much more problems with very complex scenarios compared with controllers. They could not control the whole traffic situation and could not distinguish between topical important information.

The obtained results confirm the splitting of subjects and show the importance of evaluation of such a complex interface by experts of interface design and users in future.

Conclusion

In the context of further research the ADS CWP will be completed by additional ADS events e.g. ´flight plan conformance monitoring´, and ´clearance validation´ as well as the revision of design lacks.

The modified ADS CWP will be the experimental system of further examinations of ATC operations using ADS. Therefore, a future structure of ATC sectors based on PHARE (Program for Harmonization of ATM Research in EUROCONTROL) has to be implemented. Furthermore, the definition of special ADS trails will permit an efficient exploitation of the airspace. Main emphases will be the examination of transition scenarios between ADS trails and standard routes as well as the impact on operational procedures. Changes possible in controller team work between CC and EC and their specific tasks require also additional research. Increasing quality of data given by ADS will propably enable an optimization of long term planning functions for CC. Furthermore, the impact of automated assistance e.g. for conflict management has to be analysed.

A further simulation phase will be the base for the experimental, comparative analysis of modifications mentioned above. The close co-operation with active controllers of the ACC Berlin will guarantee the user oriented approach. Finally, after the evaluation of the modified ADS CWP a styleguide has to be developed for controller work position using ADS.

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The DIADEM Software Development Methodology extended to Multimedia Interfaces

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Abstract

DIADEM, created by THOMSON-CSF, is a methodology for specifying and developing user interfaces. It improves productivity of the interface development process as well as quality of the interface. The method provides support to user interface development in three aspects. (1) **DIADEM** defines roles of people involved and their tasks and organises the sequence of activities. (2) It provides graphical formalisms supporting information exchange between people. (3) It offers a basic set of rules for optimum human-machine interfaces. The use of **DIADEM** in three areas (process control, sales support, and multimedia presentation) was observed and evaluated by our laboratory in the European project DIAMANTA (ESPRIT P20507). The method provides an open procedure that leaves room for adaptation to a specific application and environment. This paper gives an overview of **DIADEM** and shows how to extend formalisms for developing multimedia interfaces.

Introduction

From November 1995 to December 1996, the *Systems Engineering and Human-Machine Systems Laboratory* at the University of Kassel participated in the project DIAMANTA, supported by the European Union as project 20507 in the ESPRIT programme. Goal of this project was to confirm the suitability of the software development methodology **DIADEM** (Dialogue Architecture and Design Method) as a means of developing graphical user interfaces that inherently satisfy user needs. Our group had a two-fold role. First, we provided one of the three teams that experimentally applied **DIADEM** to a software development problem. Second and independently from the first, we designed and applied a formal method to observe the three teams, to determine their progress and experiences and, thus, to assess the benefits of using **DIADEM** itself. We write this paper from the views of the *manager* (a **DIADEM** *role* described later) of the development team as well as from the view of the main responsible person for the evaluation.

The other partners in DIAMANTA were *THOMSON-CSF* (France), *Sistemas y Tratamiento de Informacion S. A.* (STI, Spain), and *Informationssysteme für computer-integrierte Automatisierung GmbH* (ISA, Germany). THOMSON-CSF provided knowledge about **DIADEM** and supervised its application.

We will briefly outline the methodology itself and report our experiences gained during application of the methodology to the development of a process control interface. We will show how to extend **DIADEM** to different and new applications and figure out how these adaptations may look like for multimedia applications in process control.

The DIADEM Methodology

The process of user interface development becomes more and more an important economic factor for software development companies. Experience shows that the user interface software requires about 20% to 50% of the total software development costs. On the other hand, a well-designed user interface improves the usability of the product and, by this, the efficiency of its use and its acceptance by the users.

Against this background, the **DIADEM** methodology aims at giving software developers support for their development activities. Based on a dialogue model and an ergonomic approach to user interface design, THOMSON-CSF COMMUNICATIONS created **DIADEM** in 1992 in conformation to the THOMSON-CSF software reference system. From the beginning, the method featured an adaptable multi-modal dialogue based on ergonomic principles. Use in over 30 projects in the THOMSON group provided feedback for a new version, until from the end of 1995 the project DIAMANTA evaluated **DIADEM**.

The objectives of **DIADEM** are to enhance the efficiency in developing human-machine interfaces and to ensure the quality of the user interfaces to be developed. These objectives shall be achieved by providing a guide to structure, organise, and supervise all activities of the software development team. For the activities, **DIADEM** defines *development phases*, for the team members, **DIADEM** defines *roles*. We will describe both in the following sections along with our experience made during the DIAMANTA project.

DIADEM Roles

DIADEM suggests distinguishing the role of a *manager*, a *specifier*, a *human factors specialist*, a *programmer*, and a *user*. It was a large industrial company that developed **DIADEM**, and, therefore, the original users of the method were large teams. All teams in our project were smaller. The practical evaluation of **DIADEM** in our group as well as in the other development teams showed that it is difficult to have exactly these persons or group of persons covering these professions constantly available in a development team. Thus, it is better to speak of *roles covered* by different people in the development team while one person may cover different roles as well as one role may keep several persons busy.

By giving roles, **DIADEM** describes the responsibilities and activities of the people involved in the software development. The manager is responsible for the overall organisation and supervision of the development process. The specifier interacts closely with the end user during task analyses and develops comprehensive specifications for the user interfaces. These specifications formally describe the interaction of the user with the interface and build the basis for the software coding activities of the programmer. It appeared, that the original role of the human factors specialist should better be distributed to two roles: The *cognitive ergonomist* and the *practical ergonomist*. The cognitive ergonomist supports the specifier during the tasks analyses and ensures an appropriate breakdown of the user activities. The practical ergonomist generates the Man-Machine Interface (MMI) Handbook. This is an application-specific set of rules ensuring consistency and usability of the interface, based on a general set of ergonomic rules and guidelines. In addition to the task analyses at the beginning of the development, the ergonomists involve end users throughout the whole development process in usability tests.

The development team at the University of Kassel involved five persons on the development side and two end users. One student acted as specifier while writing his diploma thesis on task breakdown and operation strategies in the application. Two students worked as practical ergonomists, writing homework (Studienarbeit) on human factors guidelines in the application-specific MMI Handbook. The programmer was a mechanical engineer who just finished his degree. An engineer and a senior operator from a chemical plant supported the development team as end users of the system to be developed. Finally, one of the authors covered the roles of manager, human factors specialist, and partly of the programmer, and he also assisted the specifier. This last combination of roles in one person contradicts some of the basic ideas of **DIADEM**, in which the human factors specialist should defend the user's needs against the manager. However, the two practical ergonomists counterbalanced this inadequacy during enthusiastic debates.

DIADEM Formalisms

In the whole, **DIADEM** focuses on having a common basis for communication within the development team, and on being able to supervise and trace the development process. More than that, the comprehensive formal descriptions of the user interface make maintenance and further development of the software product easier. To co-ordinate the work within the development team, **DIADEM** provides several formal specifications. A *task graph* represents a first formal description of the users' task derived from a task analysis.

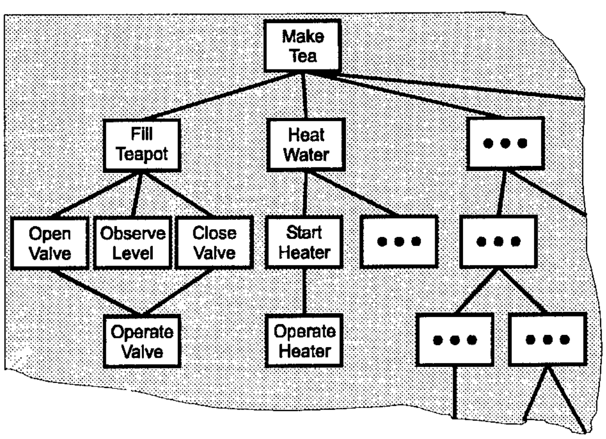

Figure 1 Sample Task Graph

The task graph shows a breakdown of the user's goals in a hierarchical structure. So-called *use relations* connect the levels of the hierarchy. To achieve the specific goal, the user *uses* the tasks on the lower level. The task graph in our application showed the overall goal "produce product" and lower-level goals like "start the system" and "correct error". Figure 1 shows a more everyday example.

The task graph enforces re-use of software components: On the lower levels, a small number of generic tasks were used to reach several goals on a higher level. In the process control application, the two tasks "change a pump status" and "set a valve position" alone could form the lowest level. For the implementation, this means only two software modules, one to control a pump and another for operating a valve.

Further formalisms provided by **DIADEM** are *technical sheets*, one for each task in the task graph. The technical sheet comprises a *strategy graph*, giving an abstract description of the interaction between user and dialogue system. The strategy graphs formed the main source of information for the programmer. Using a window-based system, the programmer created one dialogue window for each task. The strategy defined the logic of interactions in this window. It is important to note that the strategies only define the logic of interactions. They do not define the mechanism and media to be used. To keep use of mechanism and media consistent throughout the development, they are defined in the application's *MMI Handbook.*

This MMI Handbook is another formalism provided by **DIADEM**. With the specifications recorded here the programmer can turn the strategies into algorithms driving the interface in a correct, economical sound and consistent way. Rules defining how to implement an interaction in a specific application enforce consistency. This starts with common presentation choices like colours of window border, window background, character fonts used, and it continues with window organisation and failure handling. The MMI Handbook must cover the whole range of decisions to take when implementing the strategies. If not – it needs to be extended with the necessary additional decisions. Figure 2 shows rules from the handbook written for our application.

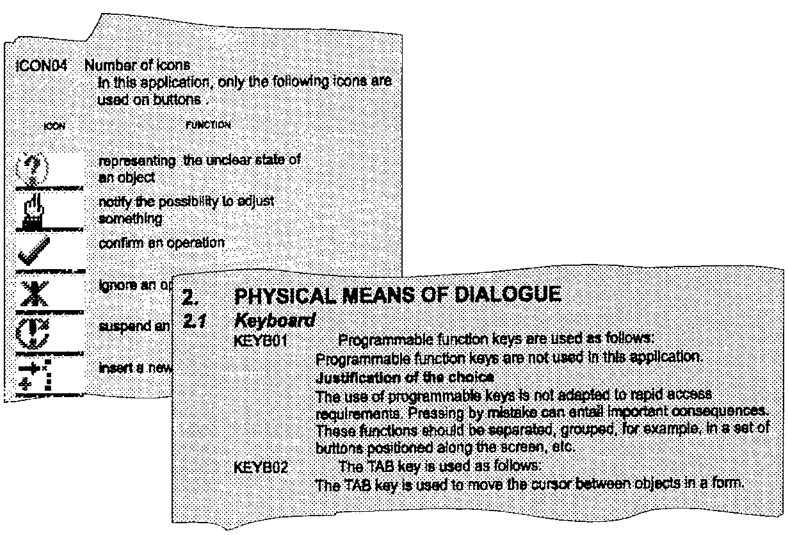

Figure 2 Definitions in the MMI Handbook (from Engel and, Quittkat, 1996)

The **DIADEM** handbook "Guidelines for Authors" (THOMSON 1995, 4) provides a table of topics to be treated in the MMI Handbook. A set of general rules is contained in a generic MMI Handbook (THOMSON, 1995, 5) that can be extended and adapted to any kind of application to ensure the consistency of the user interface and the adherence to ergonomics rules.

DIADEM Activities

Besides proposing a certain staff composition for the development team and providing formalisms to specify the user interface, **DIADEM** also suggests how to organise the development process. In the ideal case, this process should follow the downward part of the V-model, covering system specification, software specification, preliminary design, detailed design, iterative modification, and finishing phase. Nevertheless, even if the development process will not follow the V-model, this will not affect the possibility to make use of the concepts and formalisms provided by the method. **DIADEM** defines activities grouped in four development phases, called *System Requirements*, *Software Requirements*, *Preliminary Design*, and *Detailed Design*.

The System Requirements phase starts with a task analysis and defines requirements and capabilities of the user interface based on user goals and means necessary to achieve these goals. The Software Requirements phase defines descriptions of the user's tasks and user objects. The MMI Handbook is written during this phase, defining the future appearance of the interface or, at least, of the first prototype. **DIADEM** enforces the early generation and evaluation of prototypes involving end users, leading to modifications of the definitions in several cycles. The graphical formalisms described above ease user comments to software designers. The software architecture is designed during the Preliminary Design phase while in the Detailed Design phase presentation and dialogue descriptions are completed.

Our project covered a development process up to the preliminary design phase involving four prototypes of growing complexity and functionality. As with the roles, here again the problem of a small group compared to a large software development company shows up. It was not possible to follow strictly the sequence of development phases, as all the people in the development team must be kept continuously busy in the assigned roles throughout the project. Thus, phases were overlapping and not consecutive and activities were scheduled more regarding the availability of people than depending on the completeness of required inputs. For example, MMI prototyping started when the programmer was available and the first user task descriptions existed; it did not wait for a complete task analysis and a satisfactory MMI requirements definition. However, going through four prototyping cycles in four months step-wise compensated the early deficiencies.

Evaluation of DIADEM

The **DIADEM** methodology for user interface development has been designed to be applicable to any kind of software application. The Trial Application Project DIAMANTA was initiated to show that this goal could be achieved. Therefore, **DIADEM** was used to develop three very different kinds of software applications. These three applications were a tourism information system, developed by STI; a sales support system for used cars, developed by ISA; and an interface to chemical process control, developed by our group.

By applying **DIADEM** to develop the applications, its overall suitability was evaluated and the specific costs and benefits of using **DIADEM** were pointed out. This was done by means of an evaluation procedure especially designed for the DIAMANTA project.

The primary focus of the DIAMANTA evaluation activities was on the efficiency of the software development processes. However, the quality and usability of the user interfaces to be developed were a second important aspect. Therefore, we designed an evaluation and measurement procedure to cover these two criteria. This procedure, as shown in

Figure 3, is based on three parts: *Continual Evaluations*, *Periodical Evaluations*, and *Final Evaluations*.

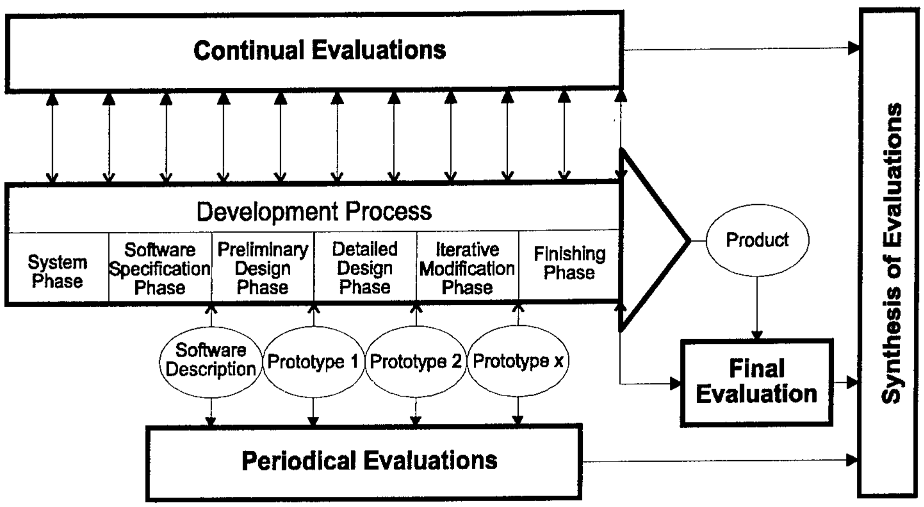

Figure 3: The DIAMANTA evaluation procedure

Weekly Continual Evaluations accompanied the development processes. They recorded the effort for development activities and subjective assessments by the developers in regular intervals. Periodical Evaluations followed each development phase completed. These aimed at recording the current state of the development process as well as the assessments by the developers referring to the respective development phase. Furthermore, we demanded to perform evaluations of the specifications and the interface prototypes in co-operation with real end users after finishing a development phase. The evaluation process ended with a Final Evaluation. It consisted of two parts: concluding assessments of the developers referring to the whole development process and a usability test of the developed interface by the end user.

All data recorded along the DIAMANTA trial application developments were processed, analysed and interpreted. Finally, the following conclusions were drawn:

0 **DIADEM** is sufficiently generic and flexible to use it in a large range of applications and organisations.
1 The adaptation of **DIADEM** to the specific projects would have been much easier with the *Customisation Guide* now available.
2 The generic MMI Handbook provided by **DIADEM** is a valuable basis to develop a consistent interface.
3 The formalisms provided by **DIADEM** turned out to be a good basis for communication within the development team. They represent unambiguous specifications for the user interface, improve the efficiency of the development

process, and make later modifications or extensions easier.

4 The dialogue specifications are to a high degree independent from the kind of interface, thus, it will be possible to re-use existing specifications as the basis for development of future interfaces, including interfaces which use emerging interaction technologies.

As pointed out above, the evaluation of the **DIADEM** methodology within the DIAMANTA project led to very satisfactory results. **DIADEM** increased the efficiency of all three application developments, and the user interfaces developed were of a good quality and usability by the end users of the respective systems.

The good overall result is based on a comprehensive definition of user requirements at the very beginning of the development activities and on a constant involvement of end users in the development process. This leads to a reduced effort for expensive changes at a later stage.

Furthermore, all requirements identified and all specifications become described in a formal way. This improves tracing the development process and communication between the people involved. Even validating the software developed is simplified by the formal descriptions. Finally, these specifications are invaluable means for developing future versions of the software.

One significant result of the evaluations performed in the framework of the DIAMANTA project is that the evaluations of the three very different applications led to the same conclusions. Additionally, evaluation results of the development processes correspond with the results of a heuristic evaluation of **DIADEM** from a theoretical point of view. This suggests that the conclusions drawn are valid even for a broad field of applications.

Customising DIADEM to Multimedia Interfaces

The common benefits of using **DIADEM**, as pointed out in the DIAMANTA project, are a result of the generic concept of the **DIADEM** methodology. However, this generality also induces the need to customise the method to a specific application.

Multimedia applications are a new field, providing features that are quite different from those of conventional software. Therefore, developing multimedia interfaces puts new requirements on the specification work. To meet these new requirements, the formalisms provided by **DIADEM** must be extended in an appropriate way. The significance of multimedia extensions to process control interfaces is already stressed in another contribution from our group in this conference (Borys and Johannsen, 1997). Backed by our good experience during the trial application of **DIADEM,** we now consider continuing the use of the skill gained in future software development projects.

The main anchor point we see for extending **DIADEM** to multimedia applications is the MMI Handbook. Task analyses deliver task graphs and strategy drawings describing dynamics of interactions necessary to operate an application. They leave completely open by what means or media this interaction would take place. The MMI Handbook is based on the "General Rules and Guidelines" (THOMSON 1995, 5). First, this handbook needs extensions to cover the decision "what medium to use for what type of interaction". A beginning is already made in Chapter 5 *Dialogue: Common Choices* with rule DIAM01:

"*The dialogue modes must be chosen taking into account the characteristics of the users and the task requirements: For example ... use frequency, ... time con-*

straints..." (THOMSON 1995, 5, pg. 59).

Some new basic rules should cover ergonomics of additional media: Size of video presentation, level of acoustical output, speed of synthesised speech. An interesting research topic would relate to spatial sound sources, corresponding to **DIADEM** rules in Section 4.6 of the handbook covering arrangement of elements on the screen. Rule SPGR03 defines the greatest distance for grouped objects, SPGR04 the minimum distance for separated objects, both in visual angel. Besides the angle, a rule for sound presentation must take care of differences in frequency, perceived distance, and loudness.

Some amount of new rules will certainly extend Chapter 4 ("Presentation: Common Choices") and Chapter 9 ("Interaction Tools"). Especially the latter, which currently only mentions cursor and mouse, will undergo some extensions. It must cover additional input media like voice or the famous (but expensive) cyber glove, but it also must regard additional more-dimensional mouse operations like pointing in space and rotations. Rules could be

> "when dialogue mode is question/answer and presentation mode is speech and answer is short, input medium should be voice"

or

> "when object moves, video bandwidth must permit a frame rate of...".

Finally, our aim is always to involve the user in the development. Thus, a basic guideline would be

> "when the user wants to hear it, provide sound, when the operator is used to feel it, provide vibrations".

This will bring back the operator from the distant control room to the plant again, as it is also required in our other contribution to this conference.

Conclusions

DIADEM, a methodology for development of user interfaces, leads developers through the developing process. One of the last steps is turning strategies, derived from task analyses, into program code. When extending **DIADEM** to multimedia interfaces, this last step needs to take into account the capabilities of new media available. Additional research, extending the rule set provided by **DIADEM**, will provide a useful basis to develop multimedia interfaces.

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What is Multimedia?

Proposal of a Taxonomy for Human-Machine Communication

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Abstract

That there is no accurate or standard definition of multimedia is a frequent statement in publications on this subject. After a survey on the resulting increasing variety of definitions, the existing terminology is characterised by discrepancy, inconsistency, incompleteness, and lack of task orientation. A proposal of a taxonomy for multimedia is developed with three categories: medium, representation and modality, which are part of a three-level concept being applicable to the input, and the output side of the human user as well. Thus, a clear separation of technical devices, modes of information representation, and of human sensory and effector channels is achieved. The importance of a task-related design of multimedia is finally shown by means of two examples which illustrate the relationship of the taxonomy to multimedia design tasks.

Structure and Development of Human-Computer Interaction

Before analysing multimedia human-computer interaction, the essential input and output channels of human information processing are briefly described. Figure 1 shows examples of the multimodality of human information input and output, i. e. there are multiple modalities for receiving and sending information. Sensory modalities on the input side are the classical five senses, however, actually only the eye, the ear, and the tactile sense are suitable for human-machine communication. For the output effector modalities such as mimic, voice, and gesture are used.

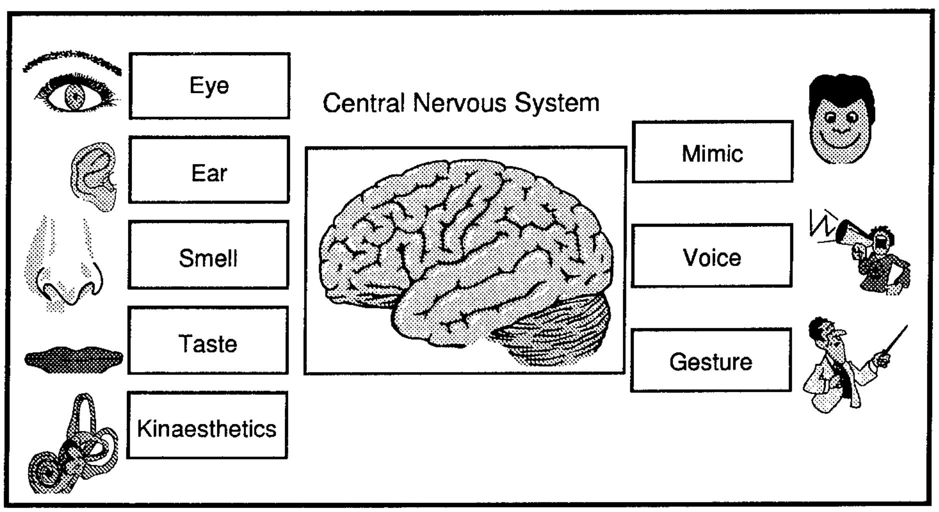

Figure 1. Human information input and output channels.

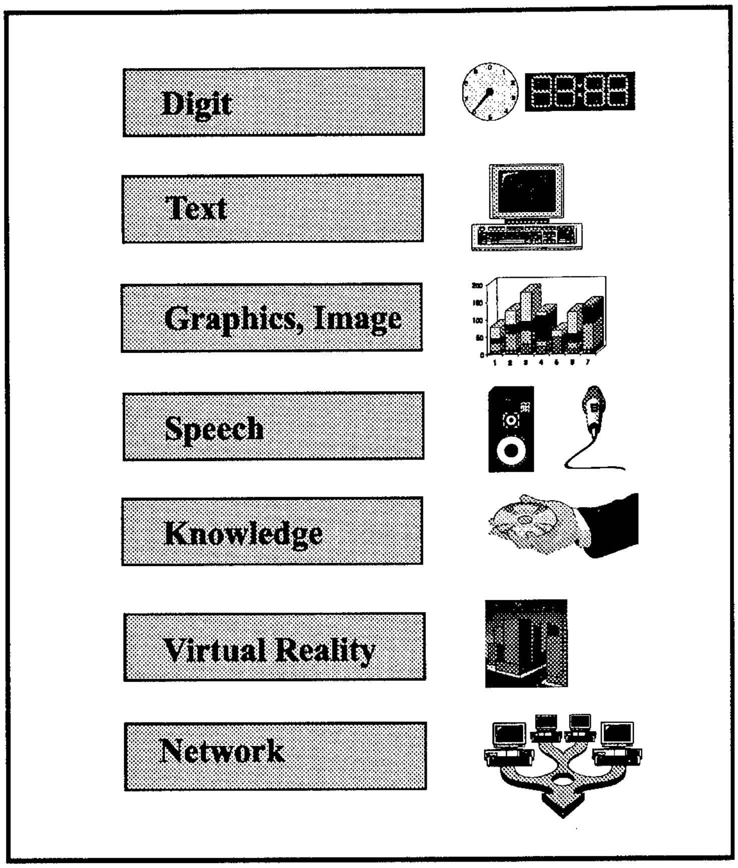

Figure 2. Development of human-machine communication.

These means given by human nature have to be seen in relation to the technologies for presentation, processing, and input of information. It is interesting to look at the history of the corresponding technical devices. In Figure 2, important steps of the evolution of human-machine communication are presented. First, digits were the coding form for information to be exchanged between human and machine, which were represented by means of dials, digital displays, and rotary knobs. Then screen and keyboard allowed to include text. Recently, speech and image are additional coding forms for input and output. And actually expert systems are including knowledge representation. Furthermore, virtual reality allows the simulation of working and learning environments which, up to now, were not available in reality due to cost reasons or dangers. Today computer networks offer increasing communication services for numerous professional and private applications.

This development results in multimedia technology allowing increased adaptation of machines to the properties of human information processing and even expanding human capabilities. A multimedia computer is supposed to process not only columns of numbers and sequences of letters as in the beginning of computer era but also to handle sound, speech, graphics, and image sequences as input and output material or as transmitted network information.

Various Definitions of Medium and Multimedia

In various application areas multimedia moved into the focus of interest, e. g. in marketing, telecommunication, and computer-based learning. Though used as a buzzword or collective noun, there are numerous efforts to find a taxonomy for this new technical area. In the following different definitions are compared by deliberately concentrating on the area of human-machine communication. Interpersonal communication as the other field of interest represented by publicity, television or arts is not considered here.

Even for the term "medium" many definitions can be found, few of them are listed in Table 1 in order to show the range of variance. In some references the definition of medium is omitted (e. g. Interactive Multimedia Association (IMA) 1996) or only an implicit definition is given by simply listing types of media (e. g. Heller, Martin 1995). Burger 1993 assigns medium to a transmission means in the sense of physics, e. g. air, water. ISO draft standard ISO/IEC CD 13522-1, 1993 (MHEG 1993) defines medium in a very comprehensive way as human and technical means for perception, representation, storage, transmission, and exchange of information.

Weidenmann 1994 points out that definitions of medium are often vague and therefore he specifies: A medium is a technical means for presentation or storage of information for the human user. Blattner and Glinert 1996 agree with him roughly when they designate media as information carriers. In their media taxonomy, Heller and Martin 1995 define text, graphics, sound and motion as four types of media and additionally they assign three categories of expression to each medium. Klimsa 1995 uses a similar classification of media types. Additionally he distinguishes between time independent (text, graphics) and time dependent (video, audio, animation) media.

Author(s)	**Definition of „Medium"**
Burger 1993	Means for transmission for stimuli: air, water etc.
MHEG 1993	Means for perception, representation, presentation, storage, transmission and exchange of information
Weidenmann 1994	Means for presentation and storage of information (paper, screen etc.)
Blattner, Glinert 1996	Information carrier (paper, paint, video, CD-ROM, screen etc.)
Heller, Martin 1995	Types of media: text, graphics, sound, motion
Klimsa 1995	Time independent (text, graphics) and time dependent media (video, audio, animation)

Table 1. Various definitions of "medium" by different authors.

As there is no agreement on the term medium, the definitions of "multimedia" inevitably must show at least a comparable variety. A first example is given by Steinmetz 1993: A multimedia system is characterised by computer-controlled, integrated generation, manipulation, presentation, storage, and communication of independent information elements being coded at least with one continuous (time dependent) and one discrete (time independent) medium. Whereas Koegel Buford 1994 calls the simultaneous use of different media (voice, video, text, animation etc.) multimedia.

Weidenmann 1994 criticises available definitions as confounding the categories technical devices, presentation modes, and sensory channels. He uses three terms for multimedia information presentation: medium, coding, and modality. In addition to his already mentioned definition of medium, he declares coding as symbol systems for presentation of information. Following established definitions he assigns modality to human sensory channels. Blattner and Glinert 1996 end up with similar terms, however they leave an ambiguity of modality by allowing the two meanings sensory channel and interaction style.

In his definition of multimedia, Klimsa 1995 claims the use and integration of several media, reference to the application and multimodality as essential aspects. Multimodality is understood as parallel processing and simultaneous presentation of several media and interactivity. Hofstetter 1995 points out four essential components: computer-based information processing, links that connect the information, navigation tools, and ways for user-specific interaction. He states: „Multimedia is the use of a computer to present and combine text, graphics, audio, and video with links that let the user navigate, interact, create, and communicate.“

The Interactive Multimedia Association (IMA) 1996 defines multimedia: „Delivery of information, usually via a personal computer, that combines different content formats (text, graphics, audio, still images, animation, motion video, etc.) and/or storage media (magnetic disk, optical disc, video/audio tape, RAM).“

These and other definitions of multimedia are characterised by one or several of the following deficiencies:

- *Discrepancy*: There are considerable differences between most terminologies.
- *Inconsistency*: Within some definitions terms are confounded, e. g. partially the definition of a single term relates to technical means and partially to presentation forms and sensory modalities. Furthermore, well established terms such as modality are redefined.
- *Incompleteness*: Only partial aspects are dealt with, e. g. networking is mostly neglected and the information input and the output side of the human user are not both included.
- *Lack of task orientation*: The user's tasks of information input, processing, and
  output are generally not considered.

Multimedia Taxonomy

In the following a more precise, comprehensive and user and task oriented taxonomy for the interaction of human with multimedia devices is proposed. In order to obtain such a definition human information input as well as information output and the user's task have to be considered. Three terms as part of a three-level concept are used (Table 2):

- *Medium*

To begin with, a medium is a technical means for one or several of the following purposes: Presentation, storage, input, processing, transmission of information for and by the human user (example: screen). The media available are determined by the state of hardware and software technology.

Looking at the media only is not sufficient to describe formally the information exchange between human and machine; two additional terms have to be introduced, representation and modality.

- *Representation*

Representation is the appearance of information, enabling human perception, processing or output of information (examples: text, displayed visually or spoken).

- *Modality*

Modality encompasses human sensor or effector channels for input or output of information (examples: visual system, gesture).

On the first level of this approach technical requirements are addressed by medium and by the next two levels representation and modality, mainly the areas of human perception, cognition, and motoric are concerned.

Level	Definition	Examples	Areas concerned
Medium	Means for presentation, storage, input, processing and transmission of information	Screen, speaker, CD-ROM, network	↕ Hardware, Software
Representation	Appearance of information	Digit, text, colour, icon, table, bar graph, hypertext, tone, speech, virtual reality	↕ Perception, cognition, and motor systems of human user
Modality	Sensor or effector channel for input and output of information	Visual, auditory, and tactile system; mimic, gesture, and voice	

Table 2. Definition of medium, representation, and modality.

As Table 3 shows these three categories are applicable to the human information input and output as well. Examples listed for illustration in Table 3 are not exhaustive. As an important aspect the task of the human has to be mentioned together with its result because use and therefore the design of these 2x3 levels depend strongly on the kind of task to be accomplished by the human user.

These 2x3 levels may be used in a restrictive manner by using minimum numbers of media, representation forms, and modality channels. Multidimensional use offers abundant variety of interaction by multimedia and/or multirepresentation and/or multimodality. However, these three levels are not independent, e. g. the representation image can be displayed with the media paper or screen, but can only be perceived with the modality eye.

Processing Steps	Levels	Examples
Input of Information (Sensors)	***Medium***	Paper, screen, speaker
	Representation	Text; table
	Modality (Sensors)	Eye, ear, tactile sense
Processing of information	Modality and representation specific processing	
Output of Information (Effectors)	***Modality***	Gesture, voice, mimic
	Representation	Text; formal language
	Medium (Effectors)	Paper, key, microphone

Table 3. Formal description of human information input and output by means of medium, representation, and modality.

Representation of Information	Definition	Examples
Coding	System of symbols for single information elements	Digit, text
Organisation	Structure for local, temporal, and semantic arrangement of several information elements	Table, hypertext

Table 4. Subcategories of representation of information: coding and organisation.

The level representation can be divided in two subcategories (Table 4):

- *Coding*

Coding means the use of a system of symbols for single information elements, e. g. visual display of a measured variable such as time by digits (digital code) or by geometric parameters (analog code). If there is a single information element to be presented merely coding is necessary, in the case of a set of information elements an additional mode of representation has to selected, namely

- *Organisation*

Organisation of information describes the representation of several information elements, e. g. arrangement of several numeric values by means of a table, bargraph, etc. Here the presentation of local, temporal and semantic structures are to be distinguished. Hypertext is an example for the last type of organisation allowing reading a text in a non-linear manner according to the contents.

Thus, human-machine communication is not only determined by media but also by representation and modality. We need a three-level model in order to realise the extraordinary abundance of communication modes which the usual multimedia term tries to outline with a single notion. Also for a systematic design of human-machine communication this more detailed terminology seems to be necessary. So the following definition of multimedia is proposed:

Utilisation of media, i. e. several technical means for presentation, storage, input, processing, transmission of information, for the human user in order to permit multiple representation (coding and organisation) of the information which meets the requirements of the human given by his modalities (sensors and effectors), cognition, and tasks.

The proposed terminology is more comprehensive than the existing ones by including human information input, processing, and output as well. New developments can be easily included: new media such as computer networks, new organisation concepts such as hypertext or new interaction modes such as virtual reality.

Figure 3 shows the components of today's multimedia human-machine system. Sensor and effector modalities on the one hand, and displays (visual, auditory, tactile) and controls (manual, vocal) on the other hand, build the interface between human and machine. With these devices information with different forms of coding and organisation can be exchanged. Network connections and other devices like image scanners make additional information available.

Examples

In the following the application of the proposed multimedia taxonomy is shown by means of two examples. In the first application (Table 5), which is based on the task to acquire ornithological knowledge, only the part of information presentation for the learner is considered. The second case concentrates on information output while learning a foreign language (Table 6). These simple examples illustrate the essential multimedia design tasks to be accomplished: choice of media, coding and organisation of information based on human properties of information input, cognition, and output in a task oriented manner.

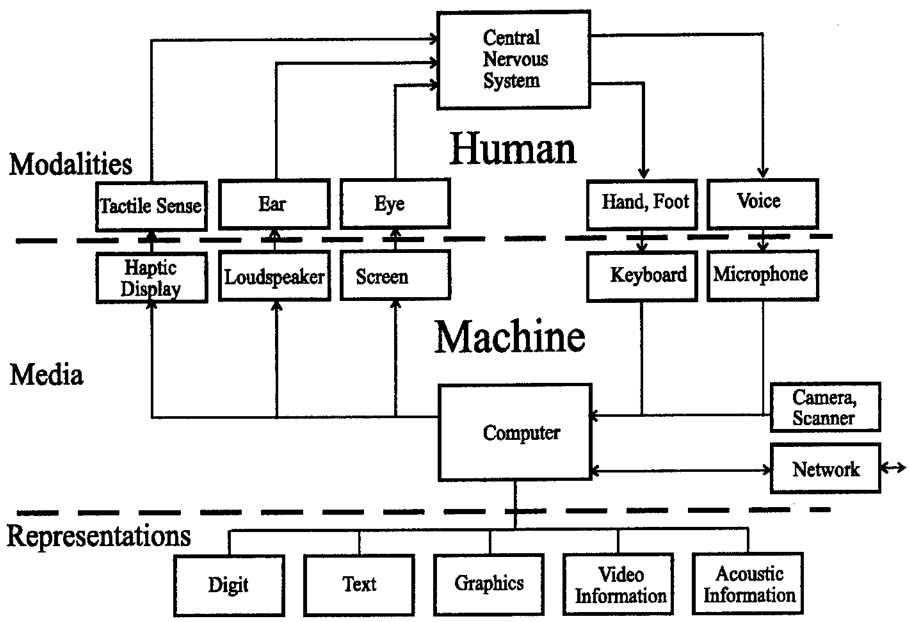

Figure 3. Multimedia human-machine system.

Task	Medium	Representation		Modality (Sensor)
Acquisition of ornithological knowledge		Coding	Organisation	
Name, family		Text	Table	
Dissemination		Graphics	Diagram	
Appearance	Screen	Image	Legend	Eye
Flight behaviour		Image sequence	Time scale	
Song		Analog function	Sonogram	
Actual research	Network	Text	Hypertext	
Song	Loudspeaker	Sound	-	Ear

Table 5. Example for the application of the multimedia taxonomy for human information input.

Task	Medium	Representation		Modality (Effector)
Foreign Language Learning		Coding	Organisation	
Writing	Keyboard	Text	Keyboard arrangement	Gesture
Selecting	Mouse	Text	Hypertext	Gesture
Speaking	Loudspeaker	Speech	Record and playback control	Voice

Table 6. Example for the application of the multimedia taxonomy for human information output.

Relations to other taxonomies

Based on this terminology the area of representation of information both on the input and the output side of the human user must be further differentiated. Several authors propose classification schemes for this level of the proposed multimedia taxonomy (Table 7).

Author(s)	Classification Schemes for Representation (Coding and Organisation)
Arens et al. 1993	Temporal endurance, granularity, baggage, detectability, and media type
Bernsen 1993	Linguistic/nonlinguistic, analog/nonanalog, arbitrary/nonarbitrary, and static/dynamic
Heller, Martin 1995	Elaboration, representation, and abstraction

Table 7. Classification Schemes for Representation (Coding and Organisation).

Five categories are introduced by Arens et al. 1993: temporal endurance, granularity, baggage, and detectability. The first two describe time and resolution aspects, namely permanent or transient and continuous or discrete properties. Baggage is a measure of the user's interpretation effort, and detectability characterises the intrusiveness of a presentation.

Bernsen 1993 suggests a taxonomy of output modalities which should be called representation modes according to the taxonomy proposed in this paper. He applies the categories linguistic/nonlinguistic, analog/nonanalog, arbitrary/nonarbitrary, and static/dynamic.

Heller and Martin 1995 describe a taxonomy which further differentiates the representation level called media expression (Table 8). They allocate three types of expression namely elaboration, representation and abstraction to their four types of media text, graphics, sound, and motion. Elaboration is the unchanged original version of the information, e. g. the medium text may have the elaborations free text, sentences or paragraphs. Abbreviated, stylised modes are called representation (formatted text, drawings, etc.). Finally, abstraction as the third type of expression is based on metaphor and standardised forms. In summary, media expression denotes degree of abstraction, author control, and design effort at three levels.

Media Type	**Media Expression**		
	Elaboration	**Representation**	**Abstraction**
Text	Free text, sentences, paragraphs	Bold, italics, headlines	Shapes, icons
Graphics	Photographs, renderings, scanned images	Blueprints, schematics	Icons
Sound	Speech, audio transcripts	Intensity, tone, inflection	Sound effects
Motion	Raw film footage	Animation, time-lapsed photography	Animated models, highly edited video

Table 8. Media expression (Heller and Martin 1995).

Conclusions

It has been shown that the proposed taxonomy allows a more systematic description of multimedia human-machine interation. However, instead of the extensions described this taxonomy remains incomplete as the area of humian information processing was widely excluded. Obviously, representation and modality influence the ways how users process perceived information and how they generate output information. Therefore a main task in the future development of multimedia will not only be to consider the properties of human sensor and effector channels but also to support cognitive information processing by a suitable choice of medium, representation of information, and modality.

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Comparing Multimedia Concepts by Using Socio-oriented Modelling Methods

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Abstract

This paper presents a method for modeling and comparing different multi-media concepts. The focus of our method lies on a social-oriented evaluation of these concepts. We identified and systematized elementary characteristics of multi-media systems and determined a set of frequently used building blocks to support the construction of models representing concepts of multi-media applications. The models can be used to visualize aspects of the working environment and to support early discussion between different interest groups. To support the evaluation of the different models we developed a procedure consisting of several if-then-rules which allows to find out the weakpoints of multi-media concepts referring to various social aspects.

Introduction

Expecting an enormous variety of multi-media applications, the question arises of how to compare different multi-media concepts and to select the most promising approaches. Multi-media comprises every kind of system which is used to generate, manipulate, dis-

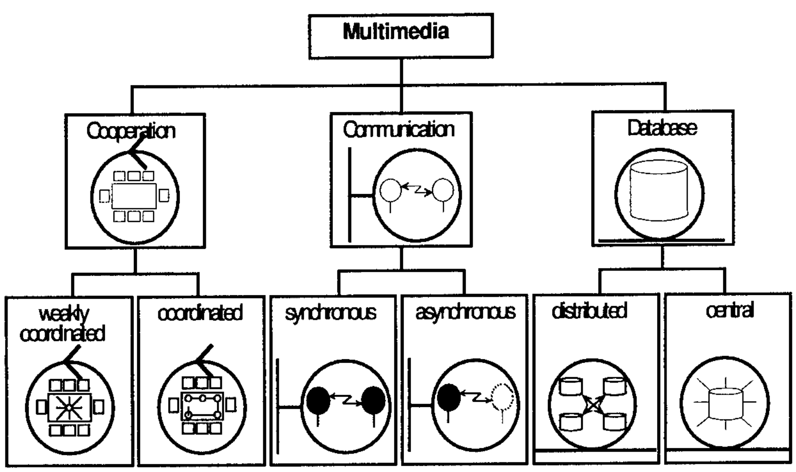

Fig. 1: Stereotypes in multi-media systems

tribute and receive documents or transient data which include pictures (fixed as well as animated), graphics, sound, speech, text, applets, etc. Furthermore these systems can be used to support cooperation and communication; therefore groupware and multi-media will be increasingly integrated. Most important, these systems have to be embedded into an appropriate organizational structure as this is the decisive factor for success. It includes mostly formal as well as informal social aspects. To anticipate the acceptance of multi-media applications, besides costs, their usability and usefulness related to human needs have to be considered. In this paper we present a modeling and evaluation method that is oriented towards those socio-technical aspects.

Stereotypes and socio-oriented components for multi-media applications

To identify and systematize elementary characteristics of multi-media systems we analyzed concepts in the literature as well as prototypes and existing applications. Unlike classifications which are based on the available types and classes of media and documents we concentrated on blocks of typical functionality concerning social interaction. We call those abstract groupings of functionality "multi-media stereotypes". The underlying idea is to use these stereotypes in modeling various kinds of multi-media systems. The six multi-media stereotypes in figure 1 are therefore parts of our modeling notation.

Through the refinement and synthesis of the inspected applications we determined a set of frequently found precise complexes of functionality. We call them building blocks. These "blocks" can repeatedly be used to "build" different multi-media applications. With this method, the set of building blocks can be enlarged if necessary. For example, a multi-media Group Decision Support System is "built" by "blocks" such as *moderation, evaluation, whiteboard, email* and *merging of data.* A subset of elements with social relevance (ref. fig. 2) was identified to supply a basis for the proposed method.

As an example the building block *Authentication* is described in detail. Authentication is related to the social aspect *authenticity of information.* By authentication one can verify the assumed origin of a message or a document. Authentication is based on crypto technology. In principle the sender (res. author) adds an authentication key to the information which can be verified by the addressee using the appropriate test key. The process of

Anonymisation	Data-Protection	Parking
Negotiation	Data-Transfer	Moderation
Authentication	Deanonymisation	Checking-Rights
automatic Reply	Document-Merging	Giving-Rights
AV-Communication	Safe-Payment	Replication
AV-Establishment-Phase	Cipher-Decipher	Tracing
Valuation	Filter	Detour
Call-Back	Group-Lens	Undo/Redo
Data-Request	History	Whiteboard
Data-Supply	Identification	Time-Cost-Control

Fig. 2: Social relevant building blocks

authentication consists of the following steps which can be represented by blocks of our modeling method: exchanging the test key on a safe communication channel where its authenticity can be guaranteed by a trustworthy third party, adding an authentication key to the information to be transmitted and checking the authenticity after transmission. The authentication checking service is started by entering the test key and the pair of authentication key and information. As the result it reports the reliability of the inspected information. It is sensible to describe the complex structure of authentication by a model. One can imagine different concepts being possible to organize authentication and to embed it into multi-media applications. These different concepts can also be modeled.

Modeling multi-media systems for the socio-oriented evaluation

The usage of models is especially intended to compare different concepts of multi-media applications. The comparison is intended to be socio-oriented which means, that aspects of the working environment of users are visualized with diagrams serving as a foundation of socio-oriented evaluation. The method for the socio-oriented evaluation of models is described below.

It must be pointed out that modeling can be constructive and re-constructive. For the purpose of discussing different concepts for the realization of socio-technical systems, a modeling method must be especially designed for the construction of such a system. The representation of social aspects and requirements is helpful to support an early discussion between different interest groups. Therefore we have identified the presented set of socio-oriented building blocks. It is advantageous that the notation and semantics of the models are based on standard software engineering or business process reengineering models to avoid multiple recording of the same facts: existing models can be used for the socio-oriented evaluation and socio-oriented models should be usable to implement a system.

In the following paragraphs we describe which requirements for a socio-oriented modeling notation exist and how to meet them with an object-oriented notation. Object-oriented technology is especially suitable for component-based systems like multi-media systems.

The representations created by modeling methods should comply with ergonomic criteria. This is especially relevant if the models are used for a participatory evaluation of the modeled concepts. Easiness of creation, comprehensibility, communicability for modelers and for recipients must be as good as possible to support the discussion of different realization concepts for the multi-media system.

One approach to develop a modeling method for our purposes is to extent existing methods. However, it might prove that this extension leads to a new method. In this paper we start with a modeling notation which is based on the object-oriented methodology introduced by Ivar Jacobson [Jacobson et al. 1992] and on the extensions for process modeling [Jacobson et al. 1995]. We adapted and extended the notation by adding stereotypes analogous to Jacobson's extensions for business process modeling and using modeling concepts from UML [Booch et al. 1997]. UML is a rising standard for object-oriented modeling and there already exist a mapping from the notations of Jacobson to the UML. With this mappings it is possible to transform models from the usage oriented perspective to an implementation-oriented perspective.

Basically, in a socio-oriented modeling notation, objects, activities, roles and relations must be representable [Herrmann et al. 1997].

Objects means physical objects as well as virtual objects in an object-oriented sense. As multi-media systems are built from components as mentioned above, object-oriented modeling techniques fit properly because of the independence of objects representing these components.

Activities represent the actions of users and participants or system based processes in the socio-oriented system. Therefore it is necessary for the modeling notation to be able to visualize the dynamic aspects of the system to catch the sequences of actions .

Roles are a concept to abstract from real world participants. This is very helpful in modeling socio-technical systems.

Relations between these concepts must be representable to fix all the dependencies between objects, activities and roles. An example of relations is the usage relation between different objects or objects and activities.

The selected modeling methodology from Jacobson et al. (OOSE) includes different types of models. In Use Case Models it is possible to visualize roles, activities and relations between them. The object-model focuses on objects (types) and their relations.

As one extension to the modeling notation we use the presented stereotypes to visualize the abstract functionality of components of the multi-media application (see fig. 3).

When modeling multi-media systems it is especially necessary to visualize the flow of information, as multi-media systems make communication channels available. This flow of information is fundamental for the socio-technical systems. It must be transparent which pieces of information flow over the recognized channels and where the source and destination of this information lie. For this requirement we propose, in addition to the OOSE-Notation, the concept of association classes from UML, which makes it possible to associate types/classes to relations. The associations in the object models are therefore limited to unidirectional relations to prevent the hiding of the flow of information.

It is helpful to start the modeling process with modeling the business with the Use Case Method to figure out the functional requirements for the multi-media system. The design of the application with predefined building blocks can be based on such a model. With regard to the dynamic development in the field of multi-media systems, the presented building set is expandable by adding or modifying building blocks and evaluation rules. For the social evaluation it is even necessary to catch those elements with social relevance. We introduced the socio-oriented components to support that. The modeling process is driven by those elements. Models will be refined until these elements are recognized or until it is obvious that they are necessary or it can be stated that these elements are not necessary anyway.

It is also necessary to note different socio-oriented attributes to the types in the model. They are used for the socio-oriented evaluation described in the following section and for testing the completeness of the model. Therefore we use rules also presented in the following section. The rules for modeling include questions and additions to the current model which make the social necessity of functionality visible (see fig. 7).

As an example we describe parts of the model for an insurance company. In the insurance organization new contracts from sales representatives are first checked by office workers. After the first checking and correction a new workflow process should be initiated. The communication and the transport of new contracts should be supported with a multi-media environment. This business system can be modeled with Use Cases.

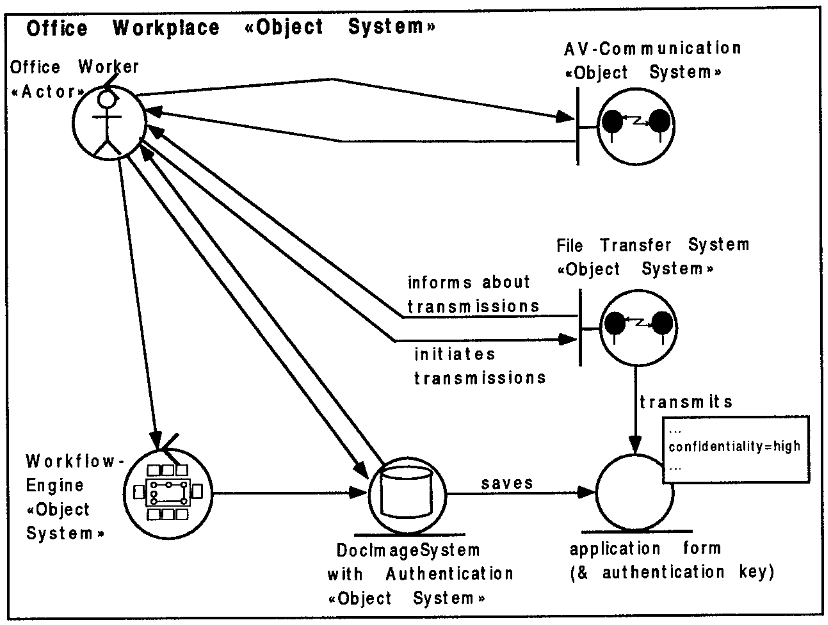

Fig. 3: Insurance Office Example – Workplace Object System

The object model of one possible concept for the multi-media application is shown in fig. 3. It represents the multi-media system from the perspective of the office worker.

First it is necessary to describe the used elements from Jacobson. The notation consists of types visualized by a circle. There are three basic stereotypes for types: control types have controlling functionality on the object system, visualized by an arrowhead, boundary types represent interfaces, visualized by a „T"-adornment and entity types have information storage functionality, visualized by a baseline. The modeling language for business processes consists of different other stereotypes. Especially for participants in the business system Jacobson used special symbols like the case worker stereotype (*Office Worker*). Arrows represent relations in the object-oriented sense.

The object model contains several examples for the usage of building blocks and multi-media stereotypes. The *AV-Communication* building block is used for the communication between the office worker and the sales representative, visualized by the synchronous-communication-stereotype. Another communication channel called *File Transfer System* is used for the transmission of files, especially for the application form. Transmitted forms are stored in a document image system. The document image system has database functionality, represented by the database-stereotype. If necessary the more specialized stereotypes *central database* or *distributed database* could be used. For further processing in the organization a workflow management system, that is based on the document image system for the storage of forms, is used. The basic functionality of a workflow management system, the coordination of the cooperation, suggests using the coordinated cooperation stereotype.

As an example for adding attributes to types, the attribute *confidentiality* is noted to the application form. Attributes are usually invisible in the graphical model. To show the usage of rules the following example may be impressive. We specified the following modeling rule to ensure the social aspect *authenticity of information*:

If the document's confidentiality is *high* **AND** its violation of identity has to be considered **then** check the model for existence of building block "authenticity checking".

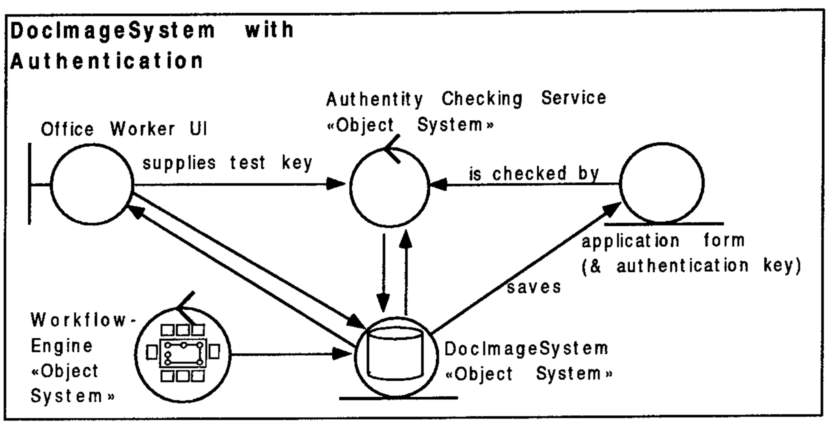

Fig. 4: Insurance Office Example – Document Imaging System with Authentication

The more detailed Object System *DocImageSystem with Authentication* (see fig. 4) consists of a user interface for the office worker *(Office Worker UI)* and the underlying document image system *(DocImageSystem)* that realizes the persistence of the incoming forms. As well we can identify the required building block *Authenticity Checking Service.* Its functionality has been described above.

Comparative Evaluation

We derive a set of if-then-rules referring to the literature in the field of ergonomics and technology assessment [e.g. Herrmann, 94; VDI, 91]. These rules exploit the social aspects to make comparative evaluations between different multi-media application concepts and to find out which of them are more advantageous if various social aspects are taken into account. In addition to building blocks (see fig. 2), we identified structures (see fig. 5) with social relevance by referring to the experience we gained by modeling multi-media applications. By the term *structures* we refer to phenomena which cannot be represented by single building blocks because they are distributed over several blocks or expressed by the relationships between them.

Examples for socially relevant structures: • Choice of communication partner

- Choice of communication means
- Attainability of roles
- Transparency to the participants

Fig. 5: Examples for socially relevant structures

To each socio-oriented building block we added attributes (see fig. 7) which are relevant for the socio-oriented evaluation and which are also used in the if-then-rules.

Examples for attributes:

- personal data included: {yes, no}
- sensibility: {low, average, high}
  these three values mark the intensity of possible negative consequences for individual and for business concerns which can be the result of the publication of data
- confidentiality: {low, average, high}
- universal: {yes, no}
  This attribute relates to the availability of data for all participants.

Fig. 6: Additional attributes for social evaluation

Our method allows a – mostly comparative – evaluation of multi-media applications regarding different social values, such as:

- data protection
- security
- privacy
- authenticity of information
- chances for participation
- reduction of the context
- transparency

There are too many rules to completely present them in this article. To give an example, figure 7 shows a subset of the if-then-rules to evaluate multi-media-applications in dependency of "data-protection".

Examples of if-then-rules for the social aspect *data-protection*:

2. **if** "personal = yes" has been noted at the building block
   then check the existence of following building blocks in the model:
   - making data anonymous
   - coding
   - negotiation
   - tracing
   - identification

4. **if** "sensibility = high" has been noted at the building block
   then check the existence of following building blocks in the model
   - checking the rights
   - coding
   - tracing

9. **if** the building block "Control of costs and time" is part of the model
   then check the existence of following building blocks in the model:
   - making data anonymous
   - checking the rights

Fig. 7: Examples of evaluation rules for the aspects "data protection"

Evaluation-procedure

To evaluate a multi-media concept we suggest constructing a list of weakpoints for the multi-media concepts being regarded. This list allows a comparison of differently constructed concepts on the basis of measurable values. The list of weakpoints can be used to serve three different purposes: it gives hints to improve a concept of a multi-media application, it might contain weakpoints showing that the concept is clearly violating certain social norms, it might become obvious (in relationship to certain aspects) that one concept is more advantageous than another one.

To construct a list of weakpoints, we suggest using the following procedure :

(1) Choose the aspect for the evaluation (e.g. data protection).
(2) Start with the first evaluation rule for the chosen aspect.
(3) For each object and its relationship to others investigate every rule: if it is violated, a hint to this weakpoint is added to the list.
(4) For any further rules proceed the same way as described in step (3)

With this procedure we can construct a values list for every social aspect , which we chose to be part of the evaluation or comparison of the regarded multi-media concepts.

The evaluation rules and the procedure are independent of the used modeling language, if the modeling language supports the concept of building blocks and refinement.

Conclusions

We presented expandable methods for the socio-oriented comparing of multi-media application concepts. Therefore, we introduced building blocks to support modeling of these multi-media concepts and to indicate the socio-oriented aspects. The relevance of the proposed building set has been demonstrated in this paper by an example.

The modeling notation is based on standard methodologies and is independent from the building set concept. The shown object-oriented modeling language is appropriate for component-based systems like multi-media systems. However, additional extensions are still needed to make social aspects more comprehensible. This is especially necessary if the social aspects are related to relationships between objects or to the overall structure of parts of the model.

Also, the evaluation rules and the methods for the evaluation are independent from the used modeling notation. The method for the evaluation leads to a list of ratings supporting a comparison of multi-media concepts and to hints for improving them.

Acknowledgments

The experiences we made on multi-media applications and the gathered data about multi-media concepts in real life are based on the work of a two-semester student project-group (KonMedia) at the University of Dortmund. Thanks to the members of this project-group. Especially we would like to thank Niels Lepperhoff who supported our work with his experience in modeling multi-media applications.

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Virtual Environment for the Simulation of a Tactical Situation Display

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Abstract
Virtual Environment (VE) describes a computer-mediated experience by which an operator perceives a simulated environment by means of special human-computer interface equipment. The human operator interacts with virtual objects in the environment as if they were real. Several operators are able to interact and co-operate in a shared virtual environment, such as a synthetic Tactical Situation Display.

The Research Institute for Electronics and Mathematics (FFM) carries out a research project which has the goal of acquiring methods for three dimensional visualisation of tactical situation data and interaction between the officer in command and the units visualised on the display system.

For fulfilling the operational task several operator look at a three dimensional representation of a landscape using VE-devices like shutter glasses, etc. . The ergonomic research work is to design and evaluate the interactive functions. The important subject is the investigation of different control input devices for simultaneous interaction of operators at a common virtual Tactical Situation Display unit (TSD). An interaction task is e.g. to move and position graphic objects as well as tactical symbols.

The first step to be done is the development of principles for the design of a human-machine-interface which enables the user to handle tactical situation data in a semi-immersive way and to interact with his own units.

The long-term purpose of the realised experimental facility of an Electronic Sandtable (ELSA) is to perform research work with respect to development, performance, evaluation, and optimisation of compliant terrain database, real-time communications, and networking of heterogeneous "Command & Control"-systems computing graphic situation display information.

This paper describes technical challenges and discusses the issue of feasibility of a project started at the Research Institute for Electronics and Mathematics (FFM).

Introduction
Virtual Environment (VE), also popular under the synonyms Virtual Reality (VR) or Cyberspace, describes a computer- mediated experience by which an operator perceives a simulated environment by means of special human-computer interface equipment. The human operator interacts with virtual objects of the environment as if they were real. VE

is conditioned by two factors, which are immersion and interaction (du Pont, 1994). The effect of immersion, the subjective "being there"-feeling of the user is increased by most complete stimulation of the human senses. Interaction is realised by a variety of interaction techniques which guarantee an intuitive behaviour of the operator in case of interacting with virtual objects.

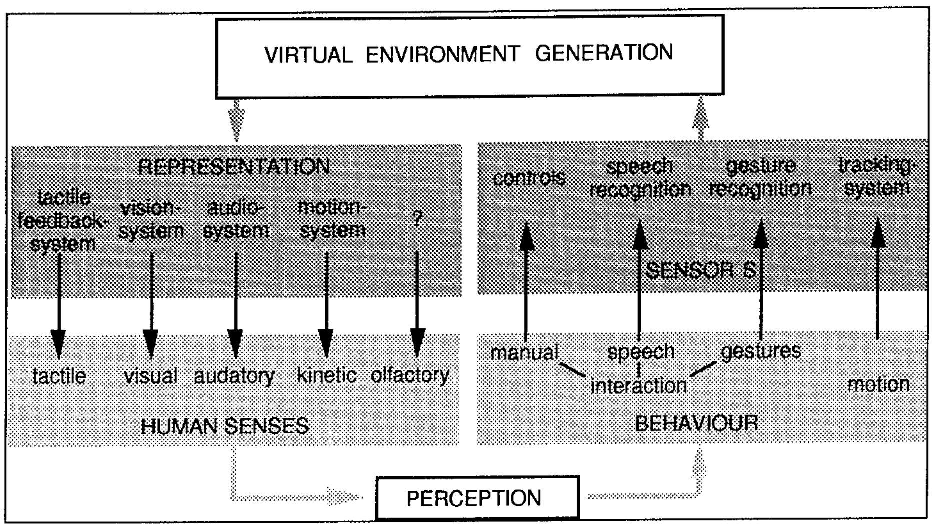

Figure 1: Human-Machine-Interface in Virtual Environments

VE has become popular during the last years due to the rapid development and enhancement of computers, especially in the field of workstations with high graphic power. Powerful tools for generating synthetic environments have been developed and sold, too, and it is only a question of time, until new approaches for the design of human-machine-interfaces (HMI) will have grown up.

Promising ideas of an immersive interaction between human beings and technical systems have been created for the civilian world, e.g. for medical purposes, architecture, education, systems design, etc., and for the military world. But it is well known from the history of technical development, that the promises of new approaches and ideas are often very high and easily made. But after critically studying the techniques differences between promises on the one hand and technique's benefits and risks on the other appear.

Especially for applications connected with high risks for the operator and the environment the consequences of using these new techniques have to be examined very closely. Since the consequences of failures in using or handling such systems are risky or perilous it has to be ensured that the interaction techniques support reliable and safe function of the systems. An important influence on the handling-safety is given by the early involvement of ergonomics in the system design process. By determination of the human machine interface's requirements it is be guaranteed that the system fits the operator which is an important precondition for systems design and handling-safety.

The current state of military commander's workplaces

Before projecting the idea of a virtual Tactical Situation Display (TSD) it should be explained what kind of functions are performed by means of such a device. TSDs are located in operation centres of command posts. They are used to display the current situation of own and reconnoitred enemy troops and facilities, e.g. positions of units, headquarters, bridges, mine barriers, etc. in the operation area to the commander of a unit, e.g. a commanding officer of a tank brigade.

The quantity of displayed situation information depends upon the availability of command and control. Especially communication systems like radio telephony which are used to receive and send situation data at present have high importance. Due to the danger of becoming reconnoitred by the enemy's communications intelligence there are restrictions on the use of communication systems. Furthermore communication links are attentionally jammed by the enemy so that the transmission quality is limited.

Moreover the quality of displayed situation data depends on the accuracy of the own troop's reports about the own situation and the observations made by the soldiers or by technical reconnaissance systems.

Moreover the TSD is used for tactical planning of intended future operations. Quantity and quality of situation data are essential for an adequate operation planning.

At present the paper & pencil technique is used to display these pieces of information. Situation information data are manually noted on the Tactical Situation Display. There is a substantial set of symbology and colours used for the different kinds of information, e.g. for distinction between own and enemy troops, for kinds of vehicles (battle tank, infantry fighting vehicle, etc.), for kinds and states of barriers (prepared, permanent, time-limited) and so forth. Due to this technique it is a time-consuming work to hold this display up to date while receiving actual information from other units. Furthermore the transmission of orders for operations by means of radio telephony takes a lot of time. Due to these facts a situation of high information flow and high workload of the personnel requires the whole operator's capacity and might even lead to states of overload. Figure 2 gives an impression of the situation in today's operation centres.

It is obvious that the form of

- displaying situation information data at the commander's workplace by means of paper & pencil TSD and
- communication mainly made by radio telephony

have not significantly changed for at least 50 years.

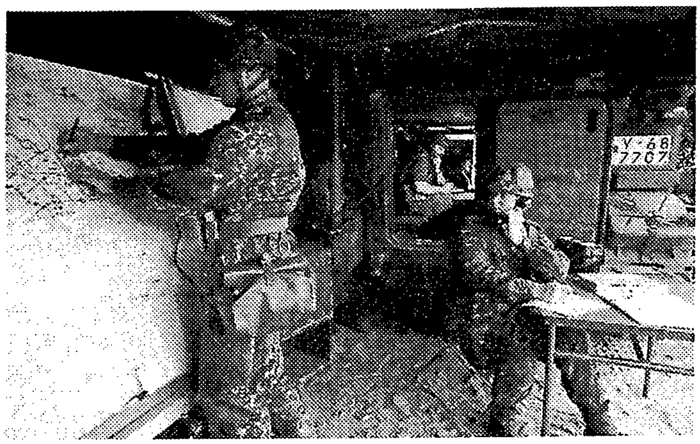

Figure 2: Today's army control centres

Technical developments of C^4I-Systems

The technical environment has developed in recent years and will be improved in future with high speed. This development has taken and will take place in several fields which are usually joined within the expression C^4I-(Command, Control, Communications, Computers and Intelligence) systems:

- Command/Control: Data links between operation centres attached to networks will improve amount and availability of situation information. Furthermore these means will reduce the necessity to use radio telephony for communication.
- Communication: Radio telephony by means of digital transmission reduces the vulnerability of jamming and spying by the enemy.
- Computer: The use of computers for military applications will rise due to low costs and necessity to process huge amounts of data.
- Intelligence: New sensors, e.g. FLIR (Forward Looking InfraRed), improve the quality and quantity of observations.

These developments will influence two factors of the workplace at an operation centre:

- increasing amount of available data,
- non-verbal data reception via computer networks.

Considering the information flow caused by technical developments it can be estimated that current techniques for handling and interpretation of tactical situation data will become insufficient within the next future.

For this reason computer-based command and control information systems (CCIS) have been developed for the services (army, navy, and airforce). In the following CCIS developments for the German army will be discussed. The arguments are likely to be valid for the other services as well.

Examples for CCIS-developments within the German army are the CCISs HEROS (Heeres-Führungsinformationssystem für rechnergestützte Operationsführung in Stäben) for the army command, and ADLER (Artillerie Daten-, Lage- und Einsatz-Rechnerverbund) for the artillery. The current state of CCIS development has its focus on data transmission between units. It is planned and partly realised to connect the army's units via networks so situation information data and orders can be exchanged in non-verbal manner. In order to make these systems "open" for communication with other services of the German Armed Forces, NATO and WEU partner nations protocols and interfaces have been standardised. Figure 3 illustrates the structure of such networks.

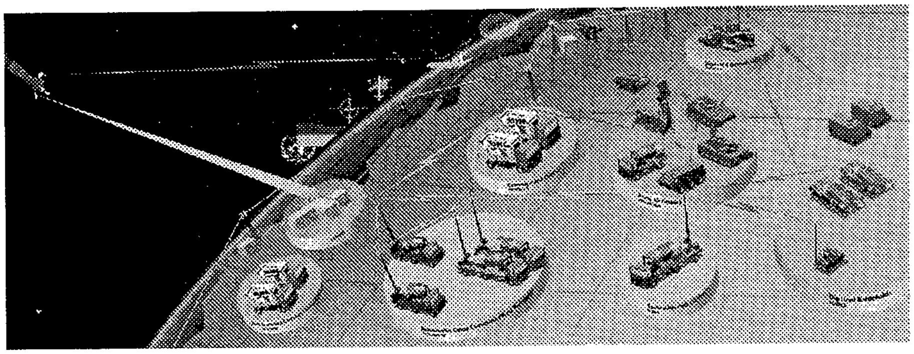

Figure 3: CCIS-scenario (reprint with permission of SIEMENS AG - Sicherungstechnik)

The hardware of the CCISs human-machine-interface has mostly been realized in a conventional way like civilian computer workplaces using commercial of the shelf (COTS) products, i.e. computer displays, keyboards, and additional input devices like mouse or trackball.

Present CCISs visualise the situation information data in a two-dimensional way. The symbology is also similar to the one used with the paper & pencil TSDs. Tools like a march-planner or the display of lines of sight allow the user to take into account terrain shape, cruising speed, etc., when planning a march or checking whether an object is visible to another one. The march-planner is important in rough terrain, display of lines of sight in order to determine acceptable positions of own troops for intended operations. Current CCIS techniques bring along a significant improvement of the situation at the commanders's workplace.

Nevertheless it is obvious that the development will go on in future. This shall be explained by two examples: One disadvantage of two-dimensional representations of three-dimensional data is the necessarity of creating a mental image of the terrain. Although assisting tools are implemented it can be assumed that the availability of three-dimensional Geo-Information-Systems (GIS) with terrain databases like DTED or DHM, and feature vector-databases like DFAD, DCW, VMAP and others means improvement. Other improvements can be made by a perspective view from any location of the scenario into any direction. The operator would be able to see the terrain and objects in the same way a tank commander would do, which might become an important function in some situations.

An important ergonomic requirement of human-machine-interface (HMI) design is to allow an intuitive interaction between the operator and the objects on the display. In present CCIS the interaction with objects of the scenario is not included in a satisfactory way. Instead the operator has to follow various procedures to manipulate objects. Although most of the systems are menu-driven, the procedures take an important amount of time and training for learning to use the systems.

These two circumstances are only examples where lacks of the present systems appear and improvements can be achieved by applying new display and interaction techniques.

Existing visions of future C^4I -Systems describe a combination of new sensors, communication lines and display techniques. The Swedish "Mobile Joint Command and Control System 2010" (ROLF), a vision of a future mobile Command & Control - System, will use a device called AQUARIUM as TSD. The AQUARIUM consists of a large semi-immersive workbench (which will be described later) to enable discussion and co-operation between different operators. The underlying concept of ROLF is variable. It is principally military, but it can be used for civil applications, e.g. supporting the society under severe strain and stress in case of catastophy, too. (Sundin, 1996)

The US-American system of the Naval Research Laboratory (NRL) or the system MIRAGE of the Institute for Simulation and Training (IST) use exclusively workbenches as TSDs (NRL, 1997; IST, 1997). The systems were already tested in military exercises and found very useful and advantageous compared to conventional TSDs. Especially the possibility of displaying "natural features" of three-dimensional terrain in combination with abstract information data (visibility, range of weapon systems, etc.) was found to be very useful (Wilson, 1997). Another important result was that there is special need for ergonomic user interfaces and training to use the new technology and its benefits.

Virtual Environment Systems - A brief overview

In recent years there have been a lot of approaches and ideas for future displays and interaction techniques in the field of Virtual Environments. The devices available on the market are manifold. A good structure of VE-systems is given by use of the degree of immersion, which means "to what extent a user is physically tied in a virtual environment" (Bullinger, 1997).

Simple VE-systems have nearly no immersive effect. Such systems use low-cost desktop-computers and usual monitor-displays. The virtual environment is presented only in two-dimensions. Real three-dimensional navigation or interaction is very limited. An example of these systems are commercial-of-the-shelf software (games, etc.) or VRML-browser on conventional PCs.

Advanced (semi-immersive) systems create a higher degree of immersion. A monitor or projection-plane serves as display and by use of shutter glasses or other techniques three dimensional visualisation is achieved. Interaction devices with 6 degrees-of-freedom (DOF) are often used. Examples for semi-immersive systems are graphic high-end workstations with monitors, projectors or with a virtual workbench. All these systems make the virtual environment and objects become a part of our real world (Bullinger, 1997; Krüger & Fröhlich, 1995).

High-end (full-immersive) systems provoke total visual immersion of the user into the virtual environment. These systems create a virtual world and let the human operator participate in it. Navigation and interaction is possible in three dimensions and three directions. Examples for such systems are the head mounted displays (HMD), special I/O-devices or the CAVE (Cruz-Neira et al., 1993).

Because of the rapid evolution and the variety of VE-systems and devices it does not seem to be useful to put in a summary at this point. To get an impression about the devices available at the market it is recommended to refer to further articles (Bullinger, 1997; Kalawsky, 1993; Grandt & Gärtner, 1997).

The Idea of a Tactical Situation Display using VE-Technology

Decision making is strongly influenced by the information available and perceivable. For this reason the human factor is the most important part to define the needs and goals of an advanced TSD.

TSDs should include a variety of diverse information, which starts at terrain information and position of units and ends at social and political information of the area of interest. The information available should be as complete and actual as possible. These goals are technical and with ongoing improvement of sensors, communications and information-technology it is only a question of time until availability of information is sufficient.

Because of the visualisation of huge amounts of information data the use of virtual environment display techniques has been discussed and found very promising. The real-life appearance of the information is supposed to create a high situation awareness, which will make decision making easier for the human operator. Moreover VE has been found very useful for visualisation of huge amounts of complex data in several other research studies.

Additional benefits for using VE-technology as TSD is the possibility of including assisting functions for preliminary decision making and assessing the effects of an intended operation. Such functions might be the visualisation of the range of weapon systems, visualisation of the range of units for transportation, information about the current airspace situation above a terrain, lines of sight, visibility and others. Such functions would make the TSD an assisting tool for tactical situation assessment.

Moreover co-operation is very important at operation centres. A battle commander should have the possibility to discuss his decisions and alternative ideas with his staff. Although there are some thoughts about "virtual staff centres", yet real co-operation cannot take place in full-immersive Virtual Environments due to unknown co-operation techniques and social problems. Instead the virtual world should become a part of the real world where staff meets as real persons, not as avatars or virtual agents.

For this reason it was decided to use a virtual workbench. The workbench looks like a conventional cardtable and by using shutter glasses it is possible to create three-dimensional images on its horizontal projection plane. This way virtual objects become a part of the real world. Especially co-operation and interaction with the graphic objects is more natural than it would be by using full-immersive systems.

The Electronic Sandtable (ELSA) - Facility at the FFM

The Electronic Sandtable (ELSA) at the Research Institute for Electronics and Mathematics (FFM) has been designed as an advanced experimental three-dimensional display system for tactical information. It is planned to equip the system with additional functions to extend the passive display system to an assisting system for staff members in command centres (Alexander et al., 1997).

To get a comparison to conventional TSDs the ELSA-project has been designed according to the following demands:

- display of tactical information of existing CCIS,
- use of standardised tactical symbols according to ZDV 1/11,
- use of military geographic data (AMilGeo, 1996),
- reference to the usual scale of military paper-cards.

As it can be seen in figure 4 the structure of the display-system can be divided into two main parts.

Part 1 works offline and creates the static scene-database to be displayed. Geographic data (terrain, feature and satellite data) and detailed objects (CAD-generated objects like houses, tanks, cars) are merged and converted into polygon data. At the following step tactical information of a CCIS is included giving information about number, kind, and starting position of military units at the field of interest. This information is linked to dynamic objects and included in the final scene-database for visualisation.

The second part works online in real-time. Here the scene-database is displayed on a virtual workbench and interaction with the database is possible. For post-brief all the actions are written into a protocol file. As the dynamic objects are linked to information from the CCIS their position may change and the display has to be updated.

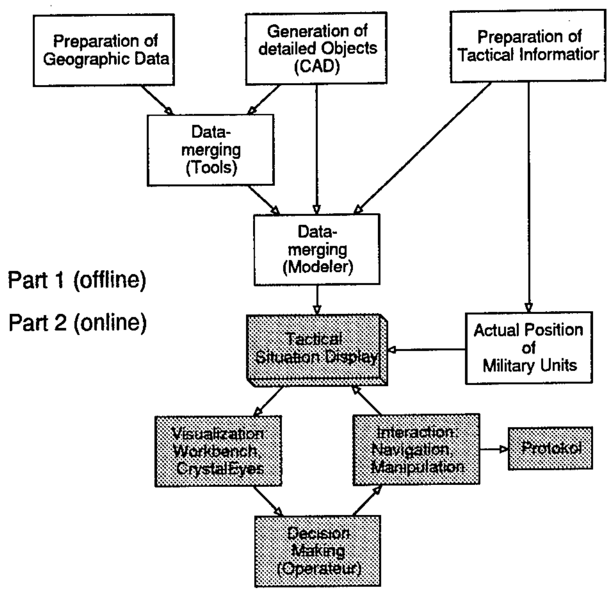

Figure 4: Brief structure of the Electronic Sandtable (ELSA)

The hardware of the systems consists of a graphic computer (Onyx2 Infinite Rality 2 of Silicon Graphics Inc.) and a virtual workbench with shutter glasses. The scene-database is created using EasyT-Software by Coryphaeus Software Inc. and DLMS (Digital Land-Mass System) data (AMilGeo, 1996). The visualisation software uses IRIS Performer graphics library (Silicon Graphics Inc.). With multichannel-option one channel is used for the display on a supervisor's monitor and the second channel drives the workbench of the Electronic Sandtable.

The virtual workbench is shown in figure 5. It is based on the ideas and studies of Krüger (Krüger & Fröhlich, 1995). A projector puts different frames for the left and the right eye time-multiplexed via a mirror onto the projection plane. The operators wear shutter glasses, which are synchronized with the projector. Synchronization works by using IR-emitters and IR-sensors on the glasses. An interface for connectiong different I/O-devices to the computer system exists.

The view geometry is calculated for a single operator. His eye-position is assumed fixed at the moment and perspective error grows with distance to this position. An achievement is expected by tracking the eye position and updating the displayed geometry if the position changes.

Topics of Research

Since applicability and limitations of VE-techniques in connection with CCIS are mostly unknown, there are questions arising about the human operator using VE-interaction devices and VE-TDS.

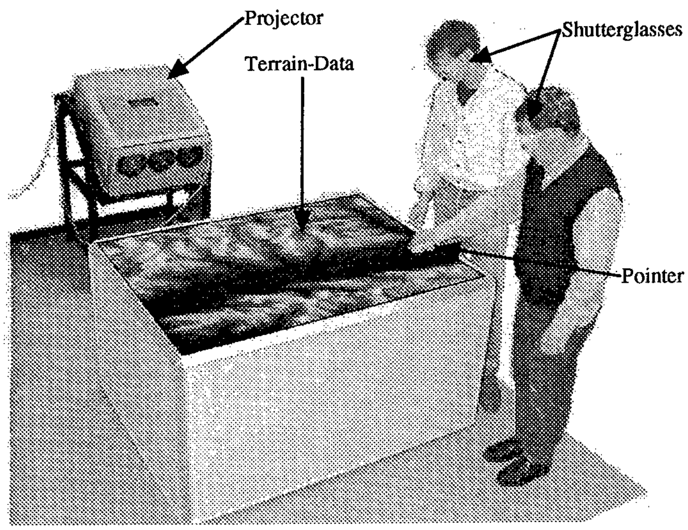

Figure 5:Experimental facility of the Electronic Sandtable (ELSA) at FFM

Generally spoken, interaction devices have to fulfil several ergonomic requirements connected with the human operator's abilities and limitations. These are:

- Aspects of the human perception with different human senses. Especially if information is displayed in a three-dimensional way attention should be paid on depth perception of the visual sense;
- Aspects of the usability of devices (e.g. weight, adaptation to all kinds of protective clothes) in order to achieve a comfortable use for long duration.

Software-ergonomic requirements have to be determined in order to assure high situation awareness, acceptable operator workload, and sufficient handling safety and reliability while taking advantage of a three-dimensional representation of the scenario. Questions on these deal with

- adequate information presentation,
- intuitive manipulation of objects embedded in the virtual scene,
- ability for the operator to build up a mental model of the system's functionality,
- implementation of error-tolerant behaviour of the system,
- implementation of user support.

Applying VE-techniques to a TSD brings along a lot of questions. VE-techniques are defined as an "intuitive perceivable and experienceable scene of a natural or abstract environment" (Bullinger et al., 1997). The software-ergonomic requirements are still valid, but a simple adoption of the results for conventional two-dimensional computer-interaction will lead to the loss of nearly all benefits of VE-systems This means that new ways of visualisation and interaction have to be evaluated, tested and optimised.

The main focus of research lies in the following areas:

Visualisation: Human visual perception plays the important role for defining requirements of future visual displays. Monocular and binocular depth cues like perspective, shadowing or stereoscopic parallax have different effects on individual's depth perception. Studies about quantification of the effects of modelled depth cues in virtual environment scenarios with a large scale is not known. For visualisation of geographic data a simple model of the view geometry is not enough because of large scales. Instead view geometry has to be modified in order to create a better depth effect. This will be made by using un-real eye-to-eye distances. This procedure is also used for photogrametric or reconnaissance purposes.

Interaction: A main goal of VE-Systems is the natural representation of virtual objects. This leads to natural interaction with virtual objects. Interaction in VE-systems means both: navigation in virtual worlds and manipulation of virtual objects. Procedures of navigation in virtual environments and databases are evaluated and hardware devices are tested with regard to their practical use. Because view geometry of the Electronic Sandtable is "god's eye" from direct above, navigation is roughly two-dimensional (horizontal and vertical scrolling). This can be controlled by conventional two-dimensional I/O-devices. Manipulation of virtual objects (picking, moving, etc.) requires interaction with more degrees of freedom (normally 6 DOF). Because of this 6-DOF interaction devices like the space mouse or virtual pointers will be used.

Co-operation: A multi-user VE-TSD offers the possibility of co-operative work and virtual discussions at military staffs. From the technical point of view multi-user systems bring along new problems. For example, view geometry has to be calculated for more than one eyepoint, which reduces the framerate of time-multiplexed display systems. Multi-user interaction techniques have only roughly been developed and simple problems like giving an object to another user brings along a lot of problems for software developers. Another question is whether all users should have the same interaction abilities. Is it better if each user has the same rights to manipulate objects or should there be a hierarchy of manipulation rights? These topics are of major interest for TSDs as there is a military hierarchy in reality which should have effects on virtual command hierarchy.

Distribution: Yet co-operation is only possible if staff members meet at the same place. By use of distributed simulation this might change. Real persons will meet in a virtual environment as representations (so called avatars) and have their staff meeting virtually. This future vision sounds very promising, but do remember that co-operation, discussion and brainstorming meetings are events in the real world. There are sociologic, psychologic and individual factors involved in real world which cannot be simulated. Because of this the benefits of distributed TSDs have to be quantified and examined very carefully.

Conclusion

Virtual Environment technology brings along a lot of new ideas for military TSDs.

Especially the natural way of presenting complex data, the possibility of including assisting functions and the high actuality when connected with electronic CCIS are huge benefits for the use of such systems.

Nevertheless the human factors have to become the main points of interest to define needs and requirements for an integration of VE-systems. If this does not happen, the benefits will change into disadvantages and human operators will not be assisted but confused by visualisation of the information data flow.

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Multimedia Approaches in Management Information Systems

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Abstract

Modern multimedia decision support systems are characterized by continuously changing conditions regarding technology, task and user profiles. As a consequence of this heterogeneity a huge amount of information items of different data types has to be managed and processed. From a human factors point of view there is a need to bridge the gap between general ergonomic design principles (e.g., suitability for the problem, flexibility, controllability) and concrete implementations. Solutions have to be found to provide *homogeneous user interfaces* with consistent access and evaluation capabilities for different data types. Another problem is the *dynamic aspect of information flow*. One has to take into consideration that - especially in hierarchical management information systems (MIS) - information items may change their data type during processing steps. E.g., a broad range of textual input details may be aggregated and transformed to other presentation categories to support decision processes at a higher management level. To achieve those goals integrated information systems require problem solutions depending on *document-oriented working styles* instead of traditional program-oriented solutions.

In client/server environments the data management concept should be developed independently from data types used in the operational system. It can be stated that good, clear process models are the key to design the core of an information system. Efficient *CASE technology* allows for breaking down the major processes into lower-level processes step by step. During this top-down process software generators may be used to create applications and interfaces with respect to ergonomic styleguides to ensure consistent interaction techniques even in multimedia applications. Another approach to meet the ergonomic requirements in complex MIS is to make use of modern object-oriented concepts (e.g., COM, CORBA). This takes into account that nowadays the ability to *integrate* different generic software components is of greater importance than developing specific applications. Several basic principles to achieve this integration will be addressed in this paper.

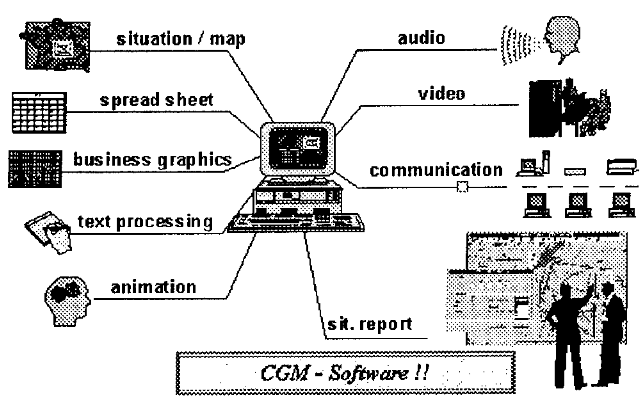
Introduction

Our research efforts are directed towards the development and application of human engineering methods and criteria to the design and evaluation of complex man-machine systems in all phases of system development and acquisition. Multimedia communication is ubiquitous in those domains. When humans converse one another, they utilize a wide range of media to interact. Some media of communication are more effective than others for certain situations, users or contexts. A multimedia document which includes text, tables, graphics, speech, video, may effect several human senses to process the incoming information. This interaction occurs over time. Therefore, it is necessary to account for the processing of discourse, context shifts, and changes over time. Whereas humans have a natural facility for managing and exploiting multiple input and output media, computers do not. Human abilities should be amplified by using computers, and the synergistic utilization of multiple media can support this amplification. If appropriate media are utilized for human computer interaction, there is a potential to increase the bandwidth of information flow between human and machine. To achieve this goal requires a deep understanding of information characteristics, how they relate to characteristics of media, and how they relate to models of tasks, users, and environments. Understanding these principles will not only result in better interactive devices, but also leads to new tools for context-sensitive multimedia interfaces, and intelligent agents for multimedia information retrieval, processing, presentation, and authoring.

Two approaches dealing with multimedia information processing are covered in this paper. First, it is illustrated how actual tendencies in software development technologies can be utilized to design user- and task-oriented multimedia systems which allow for document-oriented working styles. Second, it is shown how integrated CASE-technology can be applied to meet general ergonomic requirements in complex database management systems.

A modular workstation

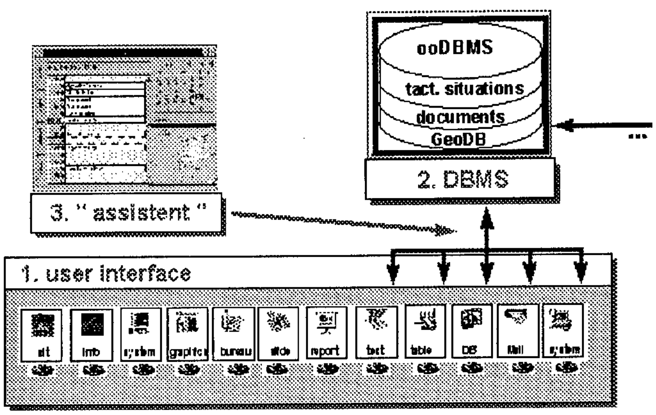
Modern workstations designed for complex information systems must support a wide range of functionalities. In our application domain these are military situation display, geographic information processing as well as text processing, spread sheet applications and business graphics. The incorporation of video and audio will be standard in the near future to realize multimedia presentations for situation reports. Those workstations are embedded in heterogeneous communication networks where the combined use of commercial, government, and military software products (CGM-software) is ubiquitous. Workstation design means to use and integrate specific characteristics of different products which can be considered as independent „components". In such a modular environment state of the art is a program-oriented workstyle. This means that operators use different tools for different tasks. The aim is - however - to construct homogeneous user interfaces based on complex documents which consist of different building blocks processed by distinct tools.



A modular workstation for command and control information systems

Model-View-Controller

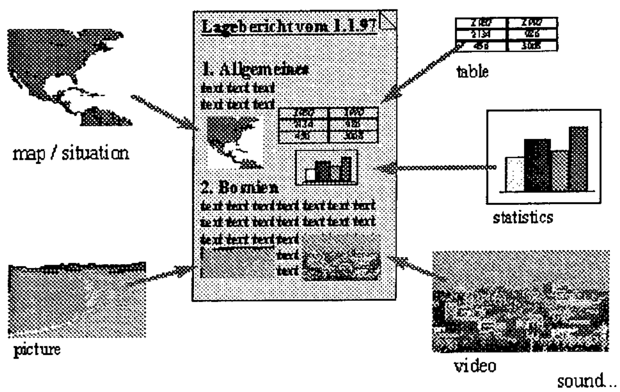
In order to use efficient tools for the management of multimedia data the before mentioned „components“ should not be responsible for data storage and organization. According to the „model-view-controller“-concept (MVC) known from Smalltalk, information container should be realized in separate databases. This separation of multimedia database (model) and user front ends (views) gives the chance to implement powerful algorithms for data evaluation and aggregation across different data types. These algorithms can be implemented independently from specific user interfaces and can be adapted to actual task requirements. On the other hand „intelligent“ agents can be developed to interpret user needs and control the information flow between database and user front end(s). E.g., a situation display can present data on a geographical map as well as in a textual form or in a tree structure if appropriate. While the model represents the actual situation in a formal description, different views can be applied to present the data in a task-oriented way.



System architecture with separate modules: (1) views, (2) model, (3) controller

Compound document

The mentioned MVC-concept gives the freedom to implement different accesses to the various data sources. The aim is to design a task-oriented man-machine-interface without overloading the operator with a huge amount of functions of different programs. A solution is the integration of objects in a single document to ensure that the user can concentrate on his work. Object Linking and Embedding (OLE) is a method used by Microsoft's Windows products to integrate the output of one program (server task) as data into another (client task) - for example, a drawing into a word processing document. The appropriate server program is automatically run to edit the data when the OLE-object is activated. The newer version 2.0 of OLE supports in-place-editing, so that rather than opening or moving to a new window, it lets you edit the embedded object without hiding the rest of the document. Clicking starts the server application and changes only menus and toolbars. Competing approaches like Apple's OpenDoc and IBM's System Object Model SOM work in a similar manner. The difference between Object Linking and Embedding and conventional copy-and-paste-strategies is that with OLE, the data may be edited within the client document. Documents that contain links to the output from other applications are called „compound documents". The underlying „Componentware"-technique can be applied to configure the user interface according to actual situation specific needs. The figure shows such a compound document consisting of portions like map display, table, picture, graphics and embedded video sequence.



Compound document as integrated interface to different tools

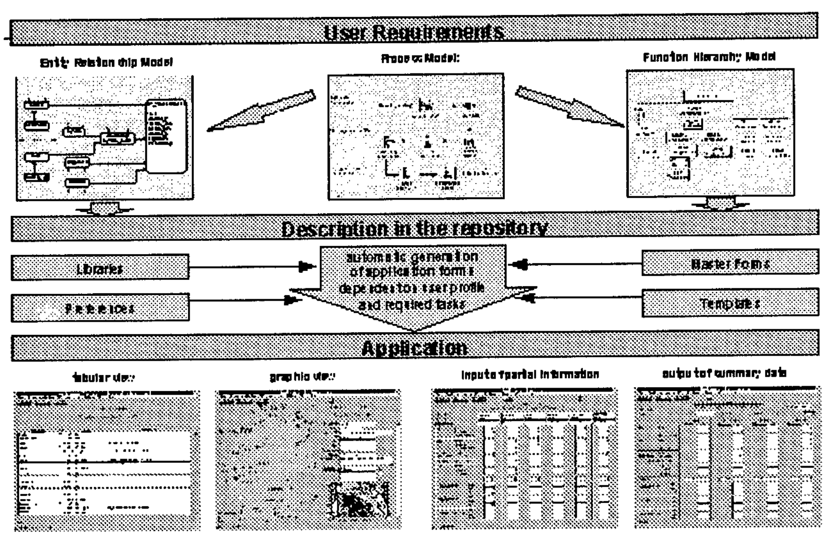
OLE allows to initiate a program-to-program-connection manually. Furthermore is it possible to create automatic connection between application by using, e.g., OLE custom controls (OCX). The link from one application to another is installed permanently and can be activated whenever the user wants to do this. These automatic links may be used to combine the features of different programs in a given context. E.g., a display system may be applied to present a situation in front of a geographic map. Using OCX-techniques an agent may be instructed to read additional background information from a database and present this text in word processing program. Other techniques called „visual programming" may be used to configure a graphical user interface independently from data processing components. Those components can be linked dynamically to interface commands such as menus items, toolbars and buttons to invoke the required functions.

Multimedia database applications

In modern client/server environments the mass of information is stored in central archives. CASE technology (computer aided systems engineering) can support the process of generating large databases and complex applications based on multimedia data sets. Graphical design tools assist developers defining the application domain by process and system models. The description is hold in a central repository. Automatic generators create basic prototypes with consistent look and feel as well as consistent behavior of the application system. The automatic generation process can be controlled by supporting components such as libraries, preferences, master forms, and templates. This can be used to direct the system generation in a way that ergonomic know-how is implicitly incorporated in the design process. Libraries define the functionality (procedures) for different user interfaces in a consistent manner. Preferences specify general adjustments about the layout of applications, like window behavior. Templates hold exact information about common parts of the layout, color settings, etc. Master forms are used in an object-oriented way to develop application specific forms.

Because routine work is performed by CASE tools, the system developer can concentrate on the design of the interactive user interface. According to the MVC-concept this interface is not directly influenced by the central data management system. Therefore it is possible to develop different interactive access components based on the same data model. The figure gives an example to illustrate the development process from „user requirements" to „multimedia applications" based on CASE technology:

- user requirements are analyzed and modeled in a formal language
- process and system model are managed in the central repository
- additional components control the system generation process in a predefined way
- interface prototypes are optimized to ensure an optimized presentation of data (e.g., tabular views to display data records, graphic views to show maps, videos,..)



CASE-technology used to bridge the gap between general ergonomic requirements and actual systems design

Conclusions

Flexible and intelligent multimedia interfaces promise to enable systems and people to use media to their best advantage. They can increase the bandwidth of information flow between human and machine. New technologies can help to solve the structural problems coming along with the combined use of enriched media. They can also help that human abilities are amplified, not impeded, by using computers. The introduction of a document-oriented working style helps that users can concentrate on their goals. Controlling the software generation process enables new facilities to incorporate ergonomic know-how into the design procedure.

Simulation-Supported Analysis and Development of Tactical and Lower Level Ground Battle Units

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Abstract

Modern warfare requires a comprehensive understanding of effective decision making, clear-cut command and control procedures, and high-capacity communication systems. At the tactical and lower unit levels this understanding is decisive, because lack of insight in these issues can cause severe consequences for the intended outcome of future operations, and ultimately, unnecessary loss of life.

In this work, we developed a framework for analysis, modeling, and evaluation of the combat skills of low-level ground forces, commander combat resource management, and overall unit performance. This framework originated from various sciences: control theory, quality control, certain behavioral and human factors areas, operations research, and statistics. The integration of these well- proven research areas, together with advanced high-performance ground combat simulation, into a novel concept of Combat Efficiency Analysis (CEA), facilitated simulation-supported, unambiguous and comprehensive military unit evaluation and assessment.

Two full-scale studies of mechanized infantry units against a realistic adversary were carried out. The subsequent CEA provided a powerful aid for understanding combat essentials and for requirements generation based upon hard facts. The described analysis and modeling approach made it possible to identify various limiting factors for combat success of ground forces.

Introduction

Unclassified research, regarding the specific kinds of skills and properties that is needed for optimum performance at the battalion, company and platoon levels of modern tactical forces, has been rarely published. The striking properties of such forces can be characterized in brief as constantly increasing mobility, lethality and level of protection. Corresponding enhancements are made concurrently in tactics and intelligence. These dynamic properties raise a demand for novel solutions to several of the eternal warfighting problems: Individual and team situation awareness and decision making, commander and soldier combat resource management, and combat endurance of the units and systems engaged in the mission. Determined and forward exploitation and control of these belligerent system dynamics are vital for success. Soldier/operator and commander skills in managing and mastering these dynamics have decisive impact on all decisions and selections of action, the battle course of events, logistics, the number of casualties, and many other vital components of war or severe crisis.

Worm (1996) developed a set of methods and tools for modeling, analysis, and evaluation of ground forces and their abilities at the battalion and lower levels: Combat skills, commander combat resource management, and overall unit performance. The central point of this project was the integration of a number of methods and tools, used for many years in trade and industry as well as in military systems development, into a multi-discipline mission and unit evaluation and assessment technique. To facilitate this integration, a set of concepts were introduced in order to analyze and evaluate the accomplishments and shortcomings of various military units in an unambiguous and comprehensive way. The concepts were:

- Control theory-based conceptual modeling of dynamic and complex combat systems and processes, and of their states and state changes.
- Identification of mission and unit state variables, and of different action and decision making mechanisms as a combat process regulator.
- Within-mission Combat Efficiency Analysis of fully manned and equipped company units against a realistic opposing force.

The rest of this paper is set out as follows. In the next four sections we describe the development of a dynamic system model of tactical missions. The following section elaborate on mission and unit state variables identification, and on regulating combat processes. The last sections describe the Combat Efficiency Analysis technique applied in a case study. Conclusions and an outline of future work concludes the paper.

A Dynamic System Model of Tactical Missions

By *system* is meant, in control theory, an object, driven by external input signals $u(t)$ for every t and as a response produces a set of output signals $y(t)$ for every t. From the work of Ashby (1956), Brehmer (1992), and Ljung and Glad (1995), it is well known that most complex systems have *real-time, dynamic properties,* i.e. the value of the output at a given time is not only dependent of the input value at this specific time, but also on earlier input values. The difficulties of maintaining situation awareness in such dynamic environments cause specific problems. Endsley (1995) developed a comprehensive theory of individual operator, commander, and team situation awareness in dynamic environments. In this work, an extended system terminology was used. In the domain of modern and future military combat, and military command and control, Worm (1996) defined three main system components:

1. **Technological Systems**, e.g. weapons, vehicles, communication-, reconnaissance-, decision support-, or command support systems, along with system operators.

2. **Command and Control Systems**, i.e. information structures, command structures, and decision structures, built up by technological systems, intelligence acquisition systems and directly involved decision makers, arranged in command hierarchies and chains of command. A few examples of command and control systems are:

    - Tactical Military Command and Control Systems
    - Fire Support Command and Control Systems
    - Emergency Management Command and Control Systems
    - Logistic Command and Control Systems
    - Transportation Command and Control Systems

3. **Units**, i.e. organizational aggregates, whose structures consistof one or several technological systems, soldiers/operators, commanders, command and control systems, staff functions, support functions, and other special services.

The Mission Control Problem: Definitions and Properties

According to Ljung and Glad (1995), modern control theory formulated the control problem as follows:

"Given a system (S), with available measurement (y), determine the controller output (u), so that a control signal (z) follows a reference(r), despite the influence of external disturbances (w), measurement errors (n), and system variability, while keeping controller output values within reasonable limits."

This definition is illustrated in figure 1.

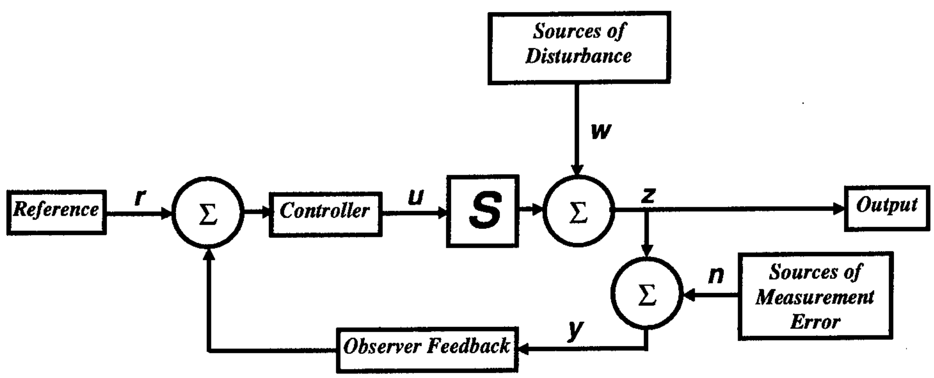

Figure 1: A general feedback control system.

The Basic Concepts of a Generic Combat Mission Model

The *System* is the own military and/or civilian unit, defined above.

The *Controller Output* to the system consists of a flow of information. The information components are orders, intelligence, and other control components, transmitted via available communication systems.

The *System Reference* is constituted by the missions, objectives, goals, and the required system status of the unit.

The *System Process* is in this case the battle which is strongly dynamic and non-linear, i.e. changes in the process can give non-proportional, unpredictable or even chaotic consequences.

The *Combat Environment* (i.e. the enemy, his systems, the terrain, and other battlefield components), and its impact on the own unit and the combat conditions, are treated as *disturbances*.

The *Controller* compensates for the disturbances. The controller function consists of the planning, decision making, orders, and actions of commanders and soldiers within the own unit.

Measurement are all values that can be registered, measured, and processed. There are also *Measurement Error* that must be handled. The Measurement Error consists of a number of components, of which two of the most important was identified this far (Worm, 1996). Those are *Incorrect or Insufficient Situation Awareness*, and *Insufficient or Misleading Intelligence.*

The *System Output* is the *Influence on Battle Course of Events,* and *Influence on Enemy Decisions, Actions, and Planning*.

Feedback: If you use the system output to determine the system input (closed-loop control, feedback control), there is only a limited need for knowledge on system dynamics. You can then continuously make necessary adjustments by measuring the deviation of the system output from the reference value.

The Combat Mission Model

Combat missions can be described as clusters of processes, arranged in a dynamic system model aggregate, depicted in figure 2.

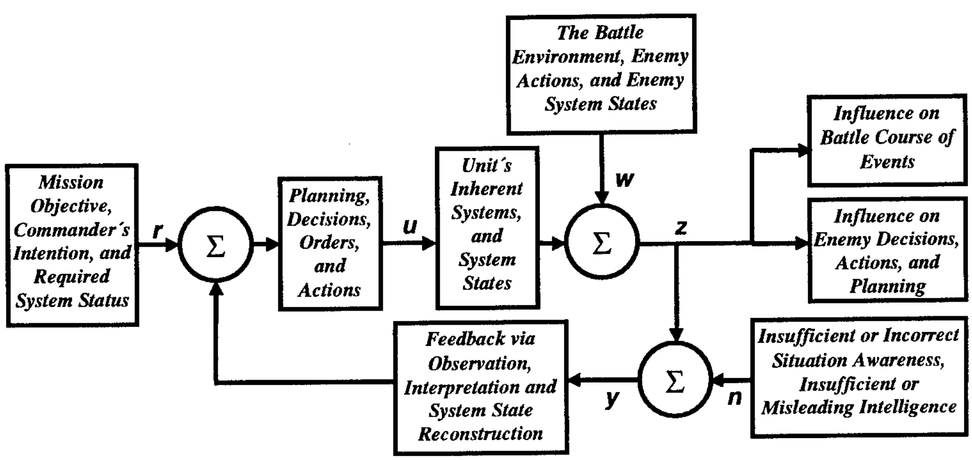

Figure 2: A simple combat model.

Description and Determination of Mission and Unit States

With the *System State* at a given time is meant a set of information, e.g. variable values that makes it possible to determine future system output if future system input is known.

Before the battle, the unit has an *initial unit state* that is continuously affected by all actions and events occurring in the combat environment. Correspondingly, the mission has an *initial mission state* that is influenced by all maneuvers and outcomes of the coming battle. When the activity, function, status or mission objective of the unit changes, due to any cause, a *state change* takes place. Initial unit and mission states are primarily determined by the following factors:

1. The status of soldiers and operators concerning:
    - individual and team skills
    - combat experience
    - physical capacity and injuries
    - psychological resistance to trauma and stress
    - psychosocial capacity
    - motivation
2. Commander's support and improvement of unit's status concerning:
    - confidence in subordinate commanders
    - fostering a good unit spirit
    - practicing and encouraging good leadership
    - good personal judgment
    - caring for subordinated personnel
    - evaluating experienced combat situations together with all personnel involved
    - assigning appropriate mission tasks
    - continuous training and adaptation of mission tactics and procedures
    - well-functioning maintenance, logistics, and medical services within the unit
    - sustaining good physical and psychological performance
3. Materiel and ordnance status concerning
    - technical availability
    - tactical availability
    - damage assessment and maintenance requirements
    - depleted resources
    - replenished resources
4. Information status concerning
    - operations orders and mission objectives
    - the reliability, availability and diagnosticity of intelligence and information
    - access to and utilization of intelligence/information acquisition resources
    - reporting from own and adjacent units

Case Study: Mechanized Infantry Combat Efficiency Analysis

The integration of the system models, concepts, and components above now leads to the definition of the *combat efficiency* measure, that will be applied in the case study in the following sections. The definition of combat efficiency and its determinants is depicted in figure 3, next page.

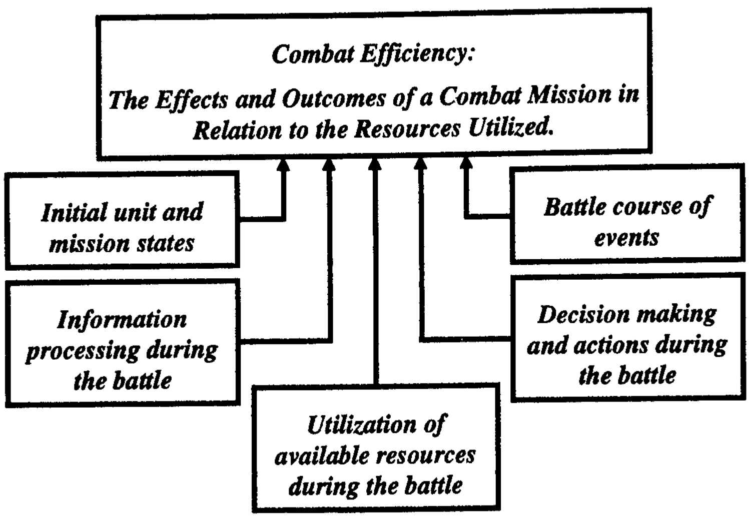

Figure 3: Definition and determinants of the combat efficiency measure.

The Mission: Attack Enemy Airborne Assault

In this case of unit evaluation and assessment, the unit at study was a reduced mechanized infantry company, transported in armored personnel carriers, and equipped with man-portable anti-tank missile systems as its main armament. The unit also had access to indirect fire support, i.e. artillery and mortars, and anti-tank mines. The mission of the mechanized infantry company were to locate and attack enemy airborne landings in either of three geographical sectors, designated sector A, B, and C.

The opposing force in this particular situation was a special unit, organized and composed by uniquely equipped and trained mechanized platoons, with tactics, mobility, and firepower equal to a hypothetical, modern, enemy air assault unit. The mission of the air assault forces were to seize and defend a number of vital crossing points in order to support following airborne landings.

The combat environment and the effects of major weapon systems were simulated in the MIND simulation environment, (Jenvald, Morin, Worm, and Örnberg, 1996). The MIND system, which is an integrated simulation and data collection system for instrumented force-on-force battle training, is currently used by the Swedish Army in its Combat Training Center, at which the described case study took place.

The Combat Efficiency Analysis was based on aggregation and evaluation of expert observations, registered combat events, and After Action Reviews (Rankin, Gentner, and Crissey (1995) of two consecutive battle training sessions, in which the mission and combat requirements were close to identical. The participating units were the same, and the operations orders were adjusted to compensate for learning and transfer effects. Information lost (if any) due to technical failure were not able to take into consideration, but judging from the consistency of the results of the two sessions, this fact did not affect the data compilation and analysis in any decisive way.

Initial Mission and Unit States

Status of Soldiers and Operators: Individual and team skills were limited because basic training was not completed; only 6.5 months of a total of 10 to 12 months were carried out. This induced limitations in the unit's ability to correctly handle unforeseen situations, not yet experienced by the unit, and this was taken into consideration in the analysis. The fact that the unit was slightly reduced caused no significantly limited availability of personnel and materiel in battle training sessions as short as in this study.

Commander Sustainment and Improvement of Unit's Status: Main limiting factors were that commanders had not yet performed any evaluation of experienced combat situations together with all personnel involved and, consequently, were not able to train and adapt mission tactics and procedures associated with the battle to come.

Materiel and Ordnance Status: Unit had good logistic preparedness. No materiel lacked, and supplies of fuel and ammunition were full.

Information Status: Tactical operations orders were understood and disseminated into clear, straightforward operations orders. Preparations orders were issued and executed. The limiting factor was terrain knowledge, and also intelligence, which was uncertain, unconfirmed, and several hours old.

Battle Course of Events

The outline of the mission, preparations, enemy approach to landing zone and acquired intelligence prior to engagement are briefly depicted in the mission timeline in table 1. From the time of landing and engagement of the air assault forces the course of events were followed by expert observers and controllers, most of which were experienced combat training officers in active duty. They reported combat events supported by a computerized tool for structured activity reporting (Jenvald and Morin, 1997), which allowed automated processing of the very large quantity of information acquired.

Battle course of events were violent and expeditious. Approximately sixty minutes from the landing of the assault forces at time T, the combat activity culminated and the session stopped sixty minutes later, in order to let both sides handle disengagement and preparations of reengagement, and to take care of the simulated casualties and wounded, thereby increasing workload of the logistics function. At the After Action Review, commanders and soldiers of both sides, together with the mission training officers, concluded that the opposing air assault forces, despite large losses at one flank, were able to break through or avoid the mechanized infantry units at the other flank, and accomplish their mission.

Table 1: Mission Timeline

Time	Own unit events	Opposing force events	Time
1900	Session start. Tactical operations orders issued: Prepare location and attack of enemy airborne assault in sector A, B, or C.	Session start. Tactical operations issued: Prepare airborne assault in sector A, B, or C.	1900
0600	Company operations orders issued: Locate and attack enemy airborne assault in sector A, B, or C.	Company operations orders issued: Commence airborne assault in sector A. Bomber sorties launched.	0500
0630	Air defense warning issued: Air attacks east Skövde city, sector A and B.	Assault preparations. Air strikes in sector A and B. Assault unit boarding.	
	Air defense warning issued: Air attacks Karlsborg city westward, sector A and B.	Last bomber sorties launched. Assault forces launched.	
	Air defense warning issued: Air assault Karlsborg city heading Skövde city.	Assault forces approach landing zone in sector A.	
0725	Battlefield intelligence reports: Air assault landing in sector A.	Time T: Assault units landing.	0725
	Indirect fire support authorized.	Assembly of units after landing.	0745
0800	Maneuvering towards enemy location. Visual contact. Engagement.	Time T + 35 minutes: Advance towards target zone. Engagement.	0800
1030	Session stops. Preparations for After Action Review.	Session stops. Preparations for After Action Review.	1030

Information processing during the battle

The flow of information and intelligence within and between the units engaged during the session indicated grave inaccuracy and misconception. Intelligence was communicated slowly between the different levels of command, and was not properly acquired, compiled, and interpreted. This led to information time delays that caused the mechanized infantry company commander to have an incomplete intelligence support in his situation assessment, and hence, his situation awareness deteriorated. Communication systems caused information loss due to bad sound quality, units out of range or partial technical function losses.

Decision making and actions during the battle

Altogether, the insufficient intelligence support and the communications difficulties constituted the major part of the inconsistencies in the unit's shared situation awareness, and the inaccuracies and misjudgments of the mechanized infantry company commander's decisions. The company commander did not realize the need for reconnaissance patrols for potential enemy sector surveillance, nor did he identify the necessity of indirect fire forward observers in the potential landing sectors for immediate response to enemy actions. Both of which showed later to be of crucial importance to the fulfillment of the mission. This led to feedback delays in decision making and to actions that caused severe consequences for the unit's ability to fight in a coordinated and timely manner. The results were consistent with Brehmer and Allard (1991), who addressed the issue of time delays in real time decision making.

Utilization of available resources during the battle

During the battle training sessions the mechanized infantry company had an almost unlimited amount of simulated indirect fire support available, with capability of combating both soft and hard targets. Much of the indirect fire was unobserved, which led to low hit probabilities and waste of exclusive fire-and-forget anti-tank ammunition. A great number of anti-tank mines were hardly used at all in the battle, which caused difficulties in blocking terrain not possible to cover with troops. The units used unnecessary short firing distances of their medium-range anti-armor weapon systems. The units also primarily used firing positions towards the enemy's front. All this caused low terminal weapon effects, low effects of surprise and of holding a well-prepared firing position, and high risks of detection and counter-attack, with large losses as a consequence. The mechanized infantry company did not accomplish its mission, to efficiently locate and attack air assault forces within its perimeter. The unit suffered from gravely reduced combat sustainment and reengagement capability after the first engagement. *This rendered the mechanized infantry company low combat efficiency.*

Conclusions

The integration of various well-proven research domains, such as control theory, several behavioral and human factors areas, quality control, operations research, and statistics, together with extensive utilization of the MIND system, turned out to be a successful approach. Applied in a context of ground force battle training, combined with advanced medium and high fidelity combat simulations, and the systematic use of domain expert knowledge, this novel approach facilitated comprehensive military unit evaluation and assessment. From the performed Combat Efficiency Analysis we concluded, that in this particular case, the following factors limited and constrained the unit's ability to execute its mission with its available resources:

- The ability to rapidly and accurately determine the identity and location of enemy targets and of own units, and to evaluate the battlefield terrain.
- The access to and use of a battle information structure which supports and improves real time information and intelligence acquisition, and permits mission-relevant information and intelligence to reach the intended decision maker in a timely manner.
- The access to and use of robust, wide-band communication systems that permit fast and accurate transfer of data and speech.

To be able to objectively and reliably identify the limiting factors of a specific unit, system, or operating procedure, and to assess the magnitude of influence of these factors on unit's overall combat performance, a series of within-mission Combat Efficiency Analyses in will have to be performed in each typical case. In force-on-force battle training situations, most factors except the ones studied can be held constant to the greatest extent possible, which makes the validation of results easier. Also actual combat missions can be analyzed in the same way. However, the extreme risk exposure, and the reduced reliability, diagnosticity, and availability of information and intelligence obtained in armed conflict or other hostile situations, makes validation more cumbersome.

Future Work

There are several areas in which further development and refinement of the Combat Efficiency Analysis technique could be of vital importance. A few examples are: *military training* (especially training tactical decision making and combat resource management), *battlefield intelligence* (using the Combat Efficiency Analysis technique, a new perspective of the capabilities and limitations of the enemy can be obtained), and *development of tactical units , procedures, and systems* (particularly within the command and control domain). We also see possibilities to develop the Combat Efficiency Analysis technique into a generic mission evaluation tool for activities other than those of warfare, e.g. crisis management and emergency response. However, the potential risk of a workload increase has not yet been fully investigated. If workload actually increases significantly in a way that would endanger the outcome of an actual combat mission, this must be taken into consideration before launching a within-mission Combat Efficiency Analysis. If this should be the fact, the Combat Efficiency Analysis technique will perform very well in a post-mission debriefing situation as well, judging from the successful Army Combat Training Center achievements.

Acknowledgments

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Biography

Arne Worm (Captain, Army) is a member of the MIND system group at the National Defense Research Establishment, where he performs systems development and systems integration. Mr. Worm is also engaged in modeling, simulation, development, integration and design of future computerized command, control and intelligence systems of the armed forces. His research interests include command and control science, military and emergency management training, human factors, control theory and systems engineering issues. Mr. Worm holds a M.Sc. in Mechanical Engineering and Computerized Automation from Linköping University. He is a Ph.D. candidate at the University of Linköping and the National Defense College, at which he is currently employed.

Human Factors, an emergency situation, and the Automated Highway System

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Abstract

Twenty subjects drove a normal car and an Automated Highway System (AHS)-car in a high fidelity driving simulator. The AHS-vehicle was driven in three conditions; at 1 second time headway, at 0.25 s. time headway and as platoon leader. In the final condition when they were driving as platoon leader, the front sensor of the automated vehicle failed to detect a merging car in time, leading to a critical incident (but not an accident). Ratings of mental effort, activation, risk, safety and acceptance were collected and the driver's ECG was continuously registered.

Results show that normal driving is more activating and effortful than automated driving. When driving in AHS mode drivers prefer a large time-headway to vehicles-in-front. Risk ratings are highest for the emergency situation, followed by driving at 0.25 seconds in automated mode. The emergency situation was surprising for most subjects, and the majority did not respond or responded late to it (drivers could avoid the critical situation by pressing the brake).

Introduction

In the Automated Highway System (AHS, e.g., Sussman, 1996) "intelligent"cars will be guided by the road infrastructure and will control their own lateral and longitudinal position on the road. Traffic on an automated lane will drive in platoons, i.e. in rows of cars driving at short headway. The ultimate aim of AHS is to increase road capacity and to eliminate driver error (Congress, 1994). However, for at least several years after initial AHS implementation, Safety Boards will require that the driver 'stays in the loop'. The driver will be strongly encouraged or perhaps even legally requested to monitor the AHS and other vehicle systems during the journey, to ensure that all functions are working properly (Alicandri & Moyer, 1992). For reasons of liability the user has to stay alert in the AHS facility all the time, just in case manual control needs to be resumed (Congress, 1994). This is similar to an aeroplane pilot who, monitoring autopilot functioning, resumes control whenever deemed necessary. However, driving a car entails higher frequencies of actions and lower time constants, i.e. it will be much more difficult to take over car control than aeroplane control in case of acute emergency.

Only after system reliability is ensured and driver liability is ruled out, driver attention to the system will become formally superfluous. One of the basic questions then in AHS, in due course, will be whether driver intervention with vehicle and system operation in an emergency situation should be allowed or not (Tsao et al., 1993). If the driver is expected to intervene, training will be required. If s/he is not supposed to intervene, one of the questions raised then is whether s/he will try to do so anyway (Tsao et al., 1993). Finally, will it be acceptable to the driver to be totally without control. The question whether drivers are going to give over control is the question whether AHS is accepted. Research indicates that drivers prefer warnings to actual take-over of control (Nilsson & Alm, 1991, Hoedemaeker, 1996), with the exception of driver emergency situations (e.g., in case of an acute health problem or when falling asleep, Petica & Bekiaris, 1996). Shifting the driver 'out-of-the-loop' may lead to reduced responsiveness to critical events, which has been reported as pre-crash factor in aviation (e.g., Ward, 1996). Automation may also increase reaction time. In case of continuous monitoring, reaction time to events in a driving task can be restricted to something like one second, while if more than one functions have to be monitored and other tasks are attended to, awareness of the situation has to be refreshed with increased frequency and the malfunction and its origin have to be determined which might take many seconds. In this way, an attempt to reduce workload is actually very likely to lead to increased workload (Hancock & Parasuraman, 1992). The classic goal of automation is to replace human manual control, planning and problem solving by automatic devices. However, these systems still need human beings for supervision and adjustment. It has been suggested that the more advanced a control system, the more crucial is the contribution of the human operator (Bainbridge, 1983).

The point made by Bainbridge (1983) is as follows: normal operation is performed automatically, abnormal conditions are to be dealt with manually. Unfortunately, as a result of automation, experience is limited, while in case of abnormal conditions (i.e., something is wrong with the process) unusual actions will be required. Also, human problem solving is not optimal under time-pressure. Monitoring of (present) automatic processes is based on skills that formerly manual operators have, and that future generations of operators (/drivers) cannot be expected to have (Bainbridge, 1983). Pilots also indicated that although automation reduced workload, it also had a negative effect on flying skills. They considered manually flying of a part of every trip important to maintain these skills (McClupha et al., 1991).

The aim is free of faults functioning, but it is obvious that there is no way of guaranteeing that a car or any other part of the system will not fail in the AHS (Hitchcock, 1991). When a system fails to work or is in a state that failure is possible, feedback should be provided in order to let the driver know that s/he can not rely on the system. The main reason for this is that automated systems can and will lead to what has been called 'complacency' (Wiener and Curry, 1980). Complacency is an attitude of (over)reliance on an automated system. This and other forms of behavioural adaptation or compensation as it is called in a wider field, are factors that should be taken into account when investigating the conditions for introduction of AHS (Verwey, Brookhuis & Janssen, 1996).

The new AHS-driving task will bring the driver in an unknown situation, for the which the demands, limits and preferences are not yet determined. Questions of major importance in this respect are:

- What is the driver's opinion about this altered task, what is the level of acceptance?

- Is there an effect of driver alertness level on task performance and acceptance?

- Are there any differences in driver behaviour and risk ratings for different following distances in a platoon of cars?

- Are there any differences in driver behaviour and risk ratings when driving as platoon-leader compared with driving inside the platoon of cars?

- What happens in case of system failure in an emergency situation, will the driver (try to) take over control?

Bringing the driver into the real AHS condition is not yet possible, reason to investigate driver's behavioural changes and feelings in a driving simulator. Another reason to carry out AHS studies in a driving simulator is an ethical one, any emergency, any system or driver failure must be without any (physical and/or material) consequences.

Method

Twenty subjects drove the advanced driving simulator of the Centre for Environmental and Traffic Psychology (the former Traffic Research Centre, Van Wolffelaar & Van Winsum, 1995). All subjects drove the simulator in the automated mode where lateral and longitudinal position was regulated by the system, as well as in the 'normal' mode (as if in an ordinary hand-shifted car). Subjects completed two sessions in the simulator, one in the morning (between 9 an 12 AM) and one in the evening (between 9 and 11 PM). In the evening, subjective driver alertness can be expected to be lower (Monk et al., 1983, De Waard et al., 1997) which could be a nonoptimal state for monitoring. The order of the conditions was balanced across subjects.

In the AHS conditions drivers drove (or actually only sat in) a car in a platoon. The car drove at high speed. Three conditions were part of the experiment: driving in the platoon at 1 second time headway to the car-in-front, driving at 0.25 seconds headway, and driving as platoon leader. The experimental following times that were used have been proposed in the USA by Bloomfield (1995). The driver was not able to control lateral position, i.e., steering is not possible. The only way to overrule the AHS was by applying the brake.

During the rides physiological measurements (ECG) and self-report ratings were collected. These measurements provide information on mental effort, activation and experienced risk and safety. Failure of the AHS can and was tested only once, in the final session at the end of the experiment when they were driving as platoon leader, in order to prevent negative effects on the rest of the experiment and the simulator in general. The emergency was a failure of the AHS front-sensor to detect a merging car. The car merged extremely close in front of the AHS vehicle (leaving 0.1 metres of space between the cars). Failure of the AHS did not lead to an accident, but the situation was such that in normal driving an alert subject would apply the brake.

Before the actual experiment, subjects were asked to read a description of the AHS and were trained in driving the simulator, both in normal and in AHS mode. The order of these conditions was balanced across subjects. Per visit, subjects drove under the following conditions:

N: Normal, conventional driving, distance to a lead car is self-chosen

A1: AHS, supervisory, distance to car-in-front = 1 second, speed = 100 km/h

A.25: AHS, supervisory, distance to car-in-front = 0.25 seconds, speed = 100 km/h

F: AHS platoon leader, supervisory. This condition was only part of the experiment during the first session (visit).

F*: AHS failure to respond. In this condition the subject's car was platoon leader, and a car merged from the emergency lane to subject's path. This condition was only part of the experiment during the second session.

In the middle part of the N, A1 and A.25 conditions the lead car slowed down, in the AHS conditions the system reacted appropriately (i.e., also slowed down). The order of conditions was balanced over subjects. The following measures were sampled at 5 Hz: lateral position, steering wheel position, time headway, speed (all for conventional driving) and brake pedal position. Changes in driver alertness are preferably measured from alertness related physiological measures (see Brookhuis & De Waard, 1993). As physiological measure subject's heart rate was registered. From these measurements average heart rate and heart rate variability, in particular in the frequency domain, were calculated. Variability in the Blood pressure band (0.07-0.14 Hz, "the -0.10 Hz component") reflects mental effort (see e.g., Mulder, 1992, Brookhuis & De Waard, 1993).

Before each session subjects completed questionnaires on sleepiness (Stanford Sleepiness Scale and a rating of tiredness, see De Waard, Van der Hulst, & Brookhuis, 1997). Before the first test ride on the first day and after the last ride on the second day acceptance of the AHS was assessed by a standard ATT acceptance checklist (Van der Laan, Heino & De Waard, 1997). After each condition (i.e., after A1, A.25, N and F) a self-rating of mental effort (Rating Scale Mental Effort, RSME, Zijlstra, 1993), a rating of activation (Bartenwerfer, 1969), a risk rating (Heino, 1996) and a safety rating on a 5-point Likert scale were collected. Subject's ECG while resting was measured at the start and end of each session.

At the end of the second session subjects again completed the acceptance checklist under the instruction not to take into account the condition where the system failed. A preferred AHS-time headway was also indicated.

Results

Average age of the subjects was 29.8 (*sd* 6.0), 20 % was female. Their average mileage was 16 000 km/year and, on average, they had held a licence for 8.6 years (*sd* 5.7). Effects of time-of-day were limited to subjective tiredness, which was higher in the evening. As other effects of time-of testing (and subjective alertness level) were absend, no further attention will be given to this factor.

Average speed in the 'normal-driving condition' was equal to the lead car, 100 km/h. Average time-headway was 2.2 seconds (*sd* 1.4), well above the AHS time headways of 1 and 0.25 seconds.

What happened in the emergency situation in the final trial is illustrated in. At t=0 the experimental AHS vehicle (E) is within viewing distance of the car that will merge (M), which is still standing still on the emergency lane. At t=7 seconds, the M-car accelerates, while at t=9.7 s the M-car blinks and starts to merge in front of E. At t=14.7 s the manoeuvre is completed, and if the subject did not brake, the distance between the two vehicles would be no more than 0.1 metres.

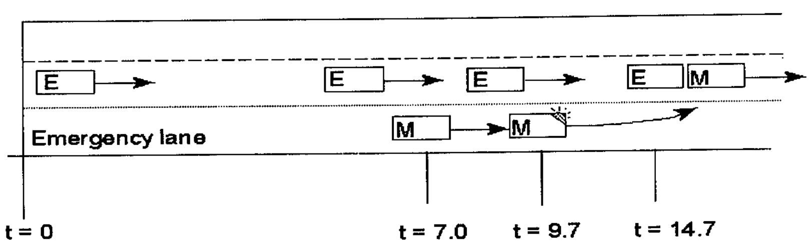

Figure 1. Emergency situation (F)*

In Table 1 subject's behaviour during this trial is classified on the basis of braking-response, the only means to interfere. As much as 50% of the subjects did not react at all, whereas 15% braked after the car had merged close in front.

Table 1. Subject's response during the emergency situation

Response		time (t =)	Proportion subjects
No reaction		∞	50 %
Braked	late	> 14 s	15 %
Braked	middle	9-14 s	30 %
Braked	early	< 9 s	5 %

After each conditions self-ratings of mental effort, activation, risk and safety were collected. In Table 2 averages of these ratings are summarised. Statistical tests (the reader is referred to the technical report, De Waard et al., 1997) indicate that normal driving is rated as more effortful and more activating. The short-headway AHS condition requires more mental effort, is more activating and riskier, and judged to be less safe. The emergency situation is considered to be the riskiest and the least safe. There were no significant effects of being inside or in front-position of the platoon on any of the subjective ratings.

Table 2: Averages of self-ratings. The following ranges apply, from low(effort, risk etc) to high: Effort (RSME): 0-150, Activation 0-270, Risk 0-6 (7 point), Safety 1-5 (5-point). Session 1 is the first visit and test, Session 2 the second visit, thus on another day.

Condition	Session	Effort	Activation	Risk	Safety
Normal	1	41	136	2.0	1.6
	2	32	119	1.5	1.6
AHS 1 s	1	12	85	1.1	1.4
	2	13	79	1.0	1.4
AHS 0.25 s	1	21	101	2.2	2.3
	2	18	96	1.7	2.0
Lead (F)	1	16	80	1.1	1.5
Emergency (Lead F*)	2	28	110	2.9	2.9

If the AHS conditions are taken together and are compared to normal driving, a significant effect on the 0.10 Hz component of heart rate variability is found. During normal driving the 0.10 Hz component is more supressed than during automated driving, which indicates increased mental effort during normal driving. All heart rate parameters differ significantly from rest during driving. More details on heart rate can be found in the technical report (De Waard et al., 1997).

Driver acceptance of AHS was measured using standard ATT acceptance items (Van der Laan, Heino & De Waard, 1997). Before the actual tests, drivers were asked to judge the AHS system, and after the second session the same was done with the explicit instruction not to take into account the emergency trial. Reason for this is the interest in general AHS acceptance, and the unlikeliness of acceptance of an ill-functioning system. Usefulness of the AHS is slightly positive (0.5 on a scale from –2 to +2), in terms of being satisfying the overall opinion is slightly negative (-0.3). Acceptance ratings did not change significantly after experience with the system and are comparable to the evaluation of an autonomous intelligent cruise control (see Van der Laan, Heino & De Waard, 1997), i.e. relatively low scores due to take-over of control.

75% of the subjects preferred the long (1 s. time headway) following condition to the short (0.25 s. time headway) following condition. The other 25% did not prefer one condition to the other.

In addition to driver acceptance in terms of usefulness and satisfaction, questions were asked whether the driver agreed with various positive and negative aspects of the systems, which were explained in one or two sentences. Table 3 shows the percentages of the drivers who agree on four of the statements about the Automated Highway System (AHS) before and after the tests.

Table 3. Percentages of AHS opinions.

		Before	After
positive:	It enhances traffic flow	80%	65%
positive:	I don't have to be attentive	45%	45%
negative:	No control of driving	55%	75%
negative:	No fun of driving	75%	75%

The Wilcoxon Signed Ranks test shows that the increase in 'No control of driving' is significant. Much more drivers disliked the fact that they had no control of driving when driving in the AHS system after experience with the system. On the other three items drivers did not change their opinion after experience with the system, or in the direction of a less positive opinion.

Conclusions

In the present experiment differences between automated driving and normal driving were found on mental effort and activation. More effort is required for normal driving, as is indicated by self-reports of invested effort and heart rate parameters. Driver activation is also higher during normal driving compared to automated driving. The results on these self-report scales are in line with expectations with respect to an altered driving task; during conventional driving the driver has to be active, during automated driving the task is supervisory. Risk and safety ratings differ to a lower extent and depend upon the time-headway of the AHS. At the close headway of 0.25 s. the average risk rating is comparable to normal driving whereas safety during the automated drive is judged to be lower. At the larger headway of 1 second these differences disappear, and risk is actually rated lower during the automated ride compared with the normal ride. When asked to indicate a preferred AHS following distance the majority chooses the large headway, while none of the subjects prefers the short headway (25% does not have a preference). One of the advantages of AHS is an increased road capacity per driving lane. This effect is enhanced by shorter time-headways, but, driver acceptance of this is a prerequisite. In addition to the preference as indicated directly by the subjects, the higher risk ratings for the short following conditions also give a clue that introduction of short time headways in platoon driving may be stopped by low user acceptance. Similar effects were found in studies by De Vos (De Vos et al., 1996, De Vos & Hoekstra, 1997), drivers dislike short time headway. De Vos and coworkers expected increased ratings of comfort when driving at very close distances from the vehicle-in-front, but did *not* find them. Their hypothesis was that even though at short headways the chance of collision may be high, the collision energy (and thus damage) is low due to small speed differences when colliding. Perhaps for most people this positive implication is difficult to imagine.

The emergency situation at the end of the experiment was a surprise for most, as many did not react or responded fairly late. In most instances where the front-sensor failed to work, the tested situation would have led to a collision. Complacency may be the reason for no response, after the experiment a subject stated that "you either trust the system and sit and relax or don't trust the system and are continuously alert and stressed". One should be aware of the fact that subjects were tested in a driving simulator, which may have had an effect on their behaviour. The effects on motivation of driving in a simulator opposed to on-the-road tests have been described in the literature (e.g., Smiley & Brookhuis, 1987). The actual risk of collision in the present experiment was nil and may have made subjects less inclined to take over control.

Driver opinion on different Automated Vehicle Guidance systems indicates that drivers expect the systems to have as much negative as positive effects when introduced into the traffic system. In general it can be concluded that drivers are positive about the effects on traffic safety, but they see also negative effects like loosing control of driving and attention reduction. This result is in accordance with the results of an earlier study with this questionnaire (Hoedemaeker, 1996). Driver acceptance of a well-functioning AHS is neutral in terms of satisfying and usefulness. This means that such a system is not refused after experience in a simulator. It is, however, obvious that an AHS should be fail-safe and that drivers should be able to trust on accurate functioning of the system.

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A Model of Individually Acting Drivers with Cognitive Capabilites for Microscopic Traffic Simulation

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Summary

When assessing novel car technologies like driver assistance systems or route guidance systems it is desirable to predict the effects of these technologies on vehicle-driver-environment interaction already during the development phase. Due to the complexity of the issue computer simulation is the most appropriate means for such an evaluation. As human factors play an important role in the performance of the entire system, the need of reliable conclusions implies an appropriate modelling of human decision making and driving behaviour.

In this paper a model of individually acting drivers which have cognitive capabilities like planning, decision making and goal directed acting is outlined. The model presented is based on a production system, which can be extended by the instrumentality of Artificial Neural Networks and Fuzzy Techniques to describe psychological knowledge about motivation, information processing capabilities and motor control. The behaviour of one or more drivers in typical traffic situations is simulated. This includes also the modelling of inter social relations.

The driver model is implemented and run in a driving simulation environment. Some selected examples are presented and discussed.

Introduction

Traffic accidents are frequently caused by perceptual flaws or mutual misunderstandings of drivers in quickly emerging critical situations, especially at high speeds. Microscopic traffic simulation that focuses on individual behaviour of the human as well as the driver-vehicle interaction could help to gain more insight into the origination of accidents and the means how to prevent them as well as predict the effects of driver assistance systems and influence their development in an early stage. We therefore concentrate on modeling and simulating of human cognitive capabilities and performance in a typical dynamic situation considering social interaction with other road users.

Driver behaviour is determined in a decisive way by accessible information about the current situation, experience and skill as well as motivation. The necessary *information* about the environment is gathered by means of the human sensory apparatus which cannot reproduce quantities like relative velocities or distances with great accuracy. *Experience and skill* in car driving manifests in the capability to judge the significance of available information about the actual driving situation and the existence of highly trained complex motor programs like parking or overtaking. Together with *motivation* which is a central factor in the entire cognitive process, these factors influence the internal setting of goals, judgment of a situation, the decision process and the way of executing actions. Goal directed acting in an environment populated by other agents implies moreover the evaluation of the consequences of one's decisions and actions and hence anticipation of the behaviour of other traffic participants.

We conclude that a driver model for microscopic traffic simulation which can be used to simulate individual behaviour in critical situations has to embody human perception characteristics and motor processes as well as motivation, decision making and goal directed acting.

Other Driver Models

To simulate driver behaviour it is most common and often sufficient to model the driver by means of control theory where driver behaviour is described by a single, basically linear differential equation with time shifting operations and possibly a nonlinear part. The individual attributes of a driver are encoded in the structure of the differential equation and its parameters that can be adjusted such that „careful" or „daring" driver behaviour can be simulated in a given situation (Wiedemann,1974). Intrinsically human characteristics like goal directed action that is not a mere stimulus reaction, but a result of planning and decision making influenced by particular motivational factors cannot be modelled that way, though. To achieve the objective to model individual behaviour, psychological and physiological knowledge about human cognition has to be incorporated into the model.

In cognitive psychology production systems in which knowledge and behaviour are represented in the form of IF - THEN rules are commonly used to model task performance and knowledge representation. Proved program systems like Soar und ACT-R (Newell, 1990; Anderson, 1993) which are based on psychologically motivated problem solving procedures and algorithms have already been used for the implementation of cognitive driver models (Aasman, 1995). As the process of problem solving which is equivalent to the decision process in our case is part of the program design of the above mentioned program systems, we believe that a specially designed program better serves the purpose of getting some insight particularly into the relevance of motivation and social interaction on decision making.

Another approach of to model driver behaviour is that of hybrid modelling (Jürgensohn, 1997). The idea is to combine different modelling tools like Fuzzy Techniques, Artificial Neural Networks, production systems or control theory in order to take advantage of the particular qualities each method can contribute to the modelling of human behaviour (Wolter et al., 1997; Jürgensohn & Willumeit 1997). A comprehensive survey of existing driver models was presented by (Willumeit & Jürgensohn, 1996).

Description of the driver model

Individual behaviour is defined through motivational factors, overall goals, specific conflict resolution strategies, estimation qualities, driving skills and given declarative and procedural knowledge about traffic rules, vehicle operation as well as driver specific motor programs.

Perception, decision making and the execution of movements or motor programs all involve processing times which can play an important role especially in dynamic situations at high speeds.

The program is structured in the sense of object oriented design by means of data structures and corresponding methods. Driver behaviour is then described by element functions which can contain rules like production systems but also parametric functions and programs. This conception can be found especially for multiagent systems (Huhn, 1991).

In figure 1 the realized model structure is sketched in principle. It should be noted that the separate blocks with the denoted functionalities cannot be interpreted in a way that these functions are independent from each other, although from the viewpoint of computer implementation it makes sense to treat them as seperate modules.

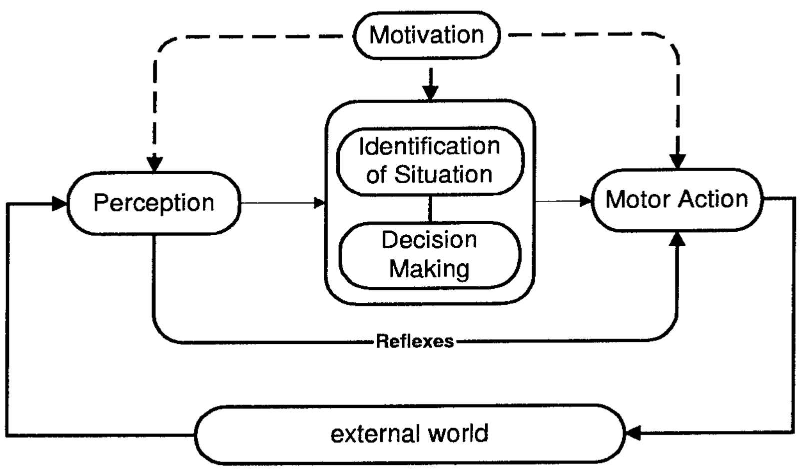

Figure 1 : Model Structure of the Cognitive Driver Model

Coordination of Subtasks

The driving task in an environment populated by a number of other agents can be considered to be composed of several subtasks which have to be to be handled simultaneously as well as consecutively during driving. Some obvious subtasks of car driving which are relevant for the present investigation are listed below :

Sensation of environment (expressed by state variables $\Delta x, \Delta \dot{x}, \dot{x}, \ddot{x}$)

Identification and interpretation of traffic situations

Decision among several alternatives of action through evaluating of resulting consequences

Motoric execution of an action

Regulation of the action after comparison with estimated outcome

Communication with other traffic participants

Coordination of subtasks

For the coordination of the subtasks some assumptions about human resources in information processing and motoric executions are necessary. It is presupposed that perception, decision making and motoric action can be executed simultaneously, bottlenecks occur only when similar tasks are to be performed. Therefore the main criterion for subtask coordination is chronological order and consideration of time constants for the respective execution. This simple approach is certainly not valid for a comprehensive cognitive modelling, but simulation results of multiple-task performance in the field of human-computer interaction assumptions match well with observed behaviour (Kieras & Meyer, 1992).

Perception

Drivers have only limited access to important state variables of the environment stored in the public database, limits being due to human sensory characteristics. The state variables listed below are presumed to describe the driver's world and therefore are made available to the model:

- Width and course of the road
- own velocity and position
- type of neighbouring objects
- distance, relative velocity and acceleration to neighbouring objects
- steering movements and movement characteristics (smoothness) of neighbouring objects
- Braking, blinking, flash of neighbouring objects
- traffic rules
- additional information from guidance or driver assistance systems

In the model important characteristics of human sensation should be reflected. This was realized by processing the quantities read from the database in a particular way to account for the following features:

- limitation to visual information gathering only
- limited visual field (objects are eventually not visible)
- erroneous estimation of relative distances, velocities and accelerations
- finite processing time for object perception
- objects perceived peripherally imply information insufficiency and further delay in perception due to required eye movements

Errors in estimating distances etc. are affected by the driver's expertise and by motivational factors. The resulting vagueness of perceived values is modelled by adding noise to the database quantitites.

Reported processing times for visual perception vary between 50 and 250 ms. These differences reflect specific processing speeds for different visual resolution (peripheral vs foveal) on the one hand and the influence of the test environment on the other hand.

Identification of Situation

For the driver model the state of the world is represented by the aggregation of a limited number of state variables relevant for the driving task like position or velocity, which are continuously changing with time. In cognitive psychology the term „situation" is understood as a kind of category which encompasses a certain range within the state space and is closely related with a corresponding action. This is modelled in such a way that the identification of the situation is performed by a *classification* of the current variables of state. Classification here means that a continuous state vector is mapped onto a number of discrete situational categories.

The identification of a situation can also be considered as a kind of pattern recognition, a typical field of application for Artificial Neural Networks (ANNs). Previous work shows that ANNs are well suited to model humanlike identification of a situation with subsequent estimation of action urgency (Jürgensohn et al., 1994; Jürgensohn & Willumeit, 1997; Jürgensohn 1997).

We chose to classify a situation by providing the driver model with declarative knowledge about traffic rules and individual safety margins that are influenced by motivational factors. The model compares the perceived variables of state with its rule base and the identified situation with an internally desired state. If the deviations are above a certain margin, a drive to change the current situation a specific way to approach the desired state is created. As there may be several action alternatives that are able to transfer the present state into a more favourable one a decision process becomes necessary to evaluate the alternatives and make a choice.

Decision making

Concurring action alternatives require a decision. In order to evaluate distinctive actions the action sequences have to be planned first, in a next step consequences due to reactions of other traffic participants have to be taken into account and evaluated with respect to own goals and security. Goals are evaluated through estimation of benefit and cost (risk). For this purpose the individual needs some knowledge about implications of other traffic participants' behaviour and signals they possible convey to him. Additionally the model will have to make some assumptions about the reactions of other traffic participants on own behaviour, which are deduced from observing the driving style of other drivers or from their communications.

The presented model has only two action alternatives to choose from: following and overtaking. The decision will be largely influenced by motivation factors, that is how the benefit of overtaking compares with the risk of an accident due to the driver approaching from behind. The risk estimation itself will also depend on motivation and driving skills of the model.

If a decision has been made, the situation changes and thus the possible actions the driver can perform. In the state of following there are the possibilities to approach or brake, in the state of overtaking there are the possibilities of regulating the manoeuvre e.g. by accelerating or stopping the manoeuvre.

To prevent the system from moving between different actions very often, the currently selected action is given high priority which can be overrun only by very urgent situational requirements.

Motoric Execution of an Action

The chosen action sequence can either initiate an operation like steering, braking, stepping on the gas pedal or handle blinker and flash or a more complex motor program according to the theory of generalized motor programs (Schmidt, 1976, 85). Motor programs like lane change or overtaking are actions composed of a well defined sequence of discrete operations. Usually these motor programs have been internalized by the driver through long time training and are executed in such a way that movements are time optimal. Nevertheless the driver controls execution and regulates if the result of the action does not conform to his expectations. In fig. 2 a typical diagram of the lateral deviation for a lane change with corresponding steering wheel angle and steering wheel rate of a well trained driver is shown (Jürgensohn, 1997).

Motor programs and discrete actions have a finite duration and cannot be interrupted arbitrarily. If there is the need to switch to an action that is more urgent than the current action, though, the preferred action cannot be started immediately, but only after a somewhat delayed interruption of the actual motor program due to neuromuscular lag. While in general actions are selected by explicit considering the alternatives, some actions are executed skipping the decision process, for example emergency braking in panic (reflex action).

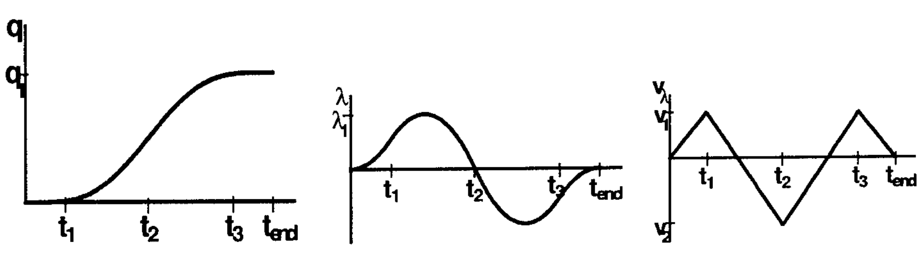

Figure 2: Schematic motor program of steering wheel angle λ, steering wheel rate v_λ and the resulting lateral deviation q for lane change

In order to have the model act in a way similar to human drivers, the driver model is supplied with simplified parametric motor schemes which have been observed at real drivers. Parameters are current speed, acceleration and relative distances. Both of the two action sequences available to the driver model are complex motor programs composed of other motor programs and several single vehicle operations. „Following“ includes „approaching“, “braking“ and „keeping the distance“ as sub-procedures. „Overtaking“ is composed of „change to left lane“, „acceleration“ and „change to right lane“.

Motivation

As already mentioned, the psychological state of the driver is relevant for every stage of the cognitive process. In the presented driver model only a limited number of motivational factors are accounted for, namely

- hurry
- competence
- daring

While plausible assumptions how these attributes are connected with human behaviour are quite self-evident, valid quantitative interdependences will be almost impossible to formulate. Here a fuzzy-like description using linguistic variables could be considered, but it is also possible to presume simple functional relationships. (Dörner & Hille, 1995) employ very elementary functions to simulate the influence of emotion and motivation on human acting in „artificial souls" and are able to produce reasonable behaviour.

For example, the desired speed (the overall goal) will increase with the individual's hurry, its estimate of own driving skills, the degree of boldness and last but not least the type of vehicle. It is further assumed that estimation of safety margins and even perception of e.g. relative speeds are dependent on motivational factors. Because the evaluation of benefit and risk is also subjective, the decision process is thus very sensitive to the disposition of the individual.

Intersocial Behaviour

Intersocial behaviour can show itself in communication activities like operating blinker or flash or driving characteristics like jostling. In any case intersocial behaviour will give drivers hints about other driver's intentions and a means to communicate own plans. Usually drivers observe other traffic participants carefully in order to predict their future actions and be able to react in an appropriate manner. This need for anticipation requires that the driver model be able to infer other drivers' current goals and intentions from observed actions, in other words, it should be able to generate an internal model about the mental state of other road users. As a typical example of internal models the frequent classification according to distinctive features into categories like „speedster", „slowcoach" or „dare devil" which possess typical driving patterns can be mentioned.

The Simulation Environment

The drivers move in an artificial environment consisting of the road and fixed or moving objects herein. The course of the road is constructed by joining discrete street segments together. Objects can be positioned along the road and be assigned velocities and trajectories to move along. The whole environment can be configured for different driving situations by defining the course of the road and the participating objects with their characteristic movements. In addition it is possible to incorporate a human driver into the situation. The simulation environment becomes then a driving simulator and can serve to validate the driver model.

Vehicles are manipulated by the driver model by operating gas, brake, steering wheel, blinker and flash, whose current values are fed into a single track model of the vehicle to calculate relevant variables of state like position, velocities and acceleration (longitudinal and transversal) for each time step.

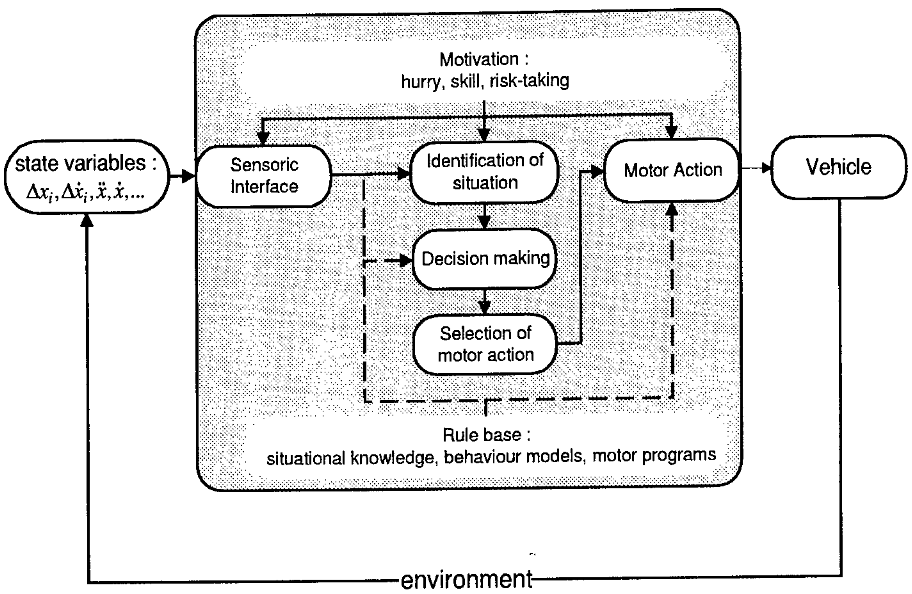

Figure 3 : Schematic representation of the simulation program

Example Driving Situation

The driver model is specified for the investigation of the situation „overtaking on a dual track highway", see figure 4. At least 4 vehicles are necessary to describe this situation, which do not need the same degree of model accuracy, though. The following assumptions and simplifications are made for the described driving situation:

- the leading vehicle (F1) drives at fixed speed on the rightmost lane,
- the second vehicle follows F1, but starts overtaking with a given probability,
- the third vehicle (EGO) contains the discussed cognitive driver model. EGO decides according to the perceived traffic situation, its motivation and its estimation of the behaviour of the other drivers between two cardinal driving programs, following or overtaking. Both driving programs consist of a complex set of action sequences (e.g. lane change or keeping a constant distance). If a situation rated as dangerous emerges (e.g. sudden swerve out of the previous vehicle or close drive up of the car behind) the overtaking manoeuvre can be eventually interrupted. There is social interaction with vehicle F4 that approaches quickly from behind on the left lane.
- the vehicle on the left lane (F4) approaches the column from behind at high speed. According to its motivation the model cooperates with EGO or not. Decisions are possible only with respect to speed choice and communication, lane change has not to be considered.

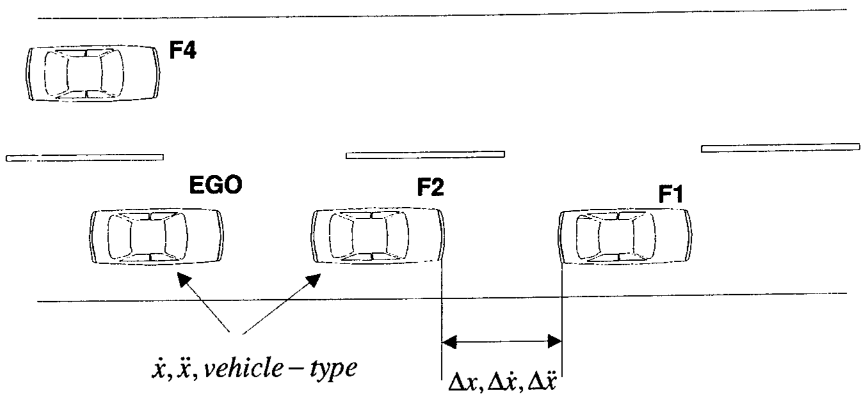

Figure 4 Investigated traffic situation

The described driving situation allows the simulation of many traffic situations due to different initial conditions and driver characteristics. The following constellations were considered quite illustrative for the behaviour of the driver model:

(1) large distance between F2 and EGO, EGO not motivated to drive fast

(2) medium distance between F2 and EGO, F2 is driving slowly, both EGO and F4 are motivated to drive at maximum speed in sport cars

(3) same as (2), but EGO driving a slow car

Discussion of Results

In constellation (1) EGO chooses not to overtake, but first accelerates until the safety distance is almost reached, then the regulation program „follow in constant distance" is started and continued.

Figure 5 shows the simulated following behaviour plotted in the $\Delta x - \Delta\dot{x}$ - plane. The parabolic parts of the curve reflect the rule that whenever the model chooses to approach or to brake, it does so with constant acceleration or deceleration of the vehicle respectively. The irregular distribution of turning points is due to the stochastically varying perception of relative distance and velocity. Observed car following behaviour results in curves like those displayed in figure 6, which are in principle similar to the calculated ones.

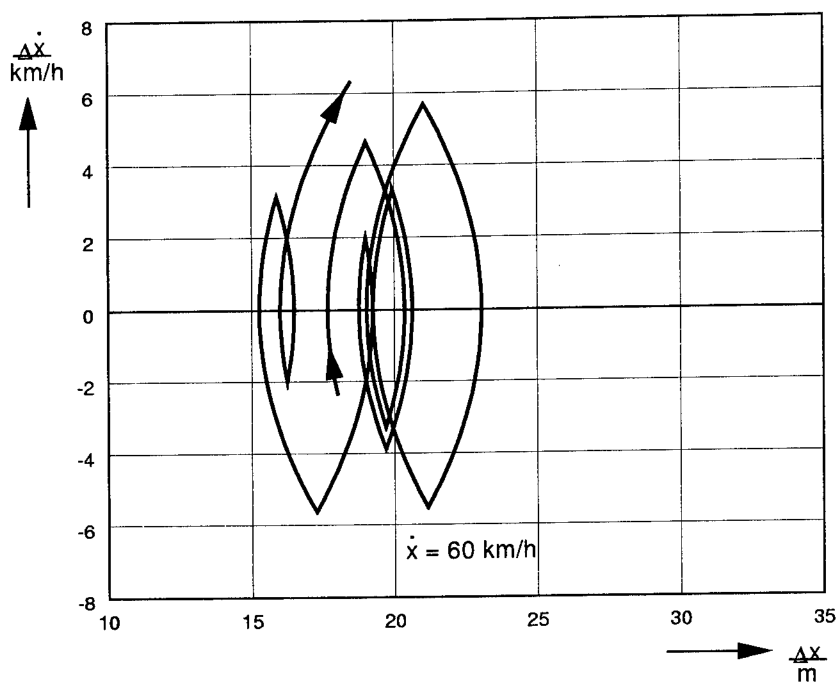

Figure 5 : Simulated Following Behaviour in the $\Delta x - \Delta \dot{x}$ *- plane*

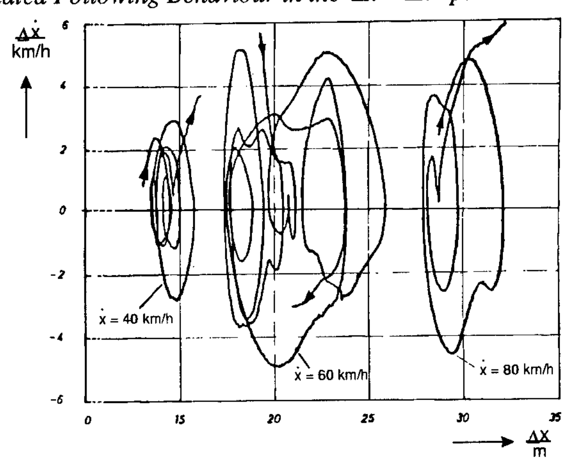

Figure 6 : Observed limit cycles of car following in the $\Delta x - \Delta \dot{x}$ *- plane (modified after Hartwich, 1971)*

Constellation (2) is more interesting with respect to decision making. EGO first approaches and then decides to accelerate with maximum gas for overtaking in order to be able to achieve the desired speed and avoid the conflict with F4, who is approaching quickly and operating the flash. Due to the stochastic component which is introduced through perception errors further development of the situation is not definitely determined. If the estimation of relative speed and distance to F4 was on the safe side, overtaking can be finished. If not so, or if F2 suddenly swerves out, an accident can occur.

The third case demonstrates the anticipation of other traffic participants' behaviour. Although the circumstances are equal to that of the previous example, F4 brakes much earlier and more vigourously supposing that EGO shows no inclination to yield and that the maximum speed of EGO's vehicle is very much under F4's speed.

Conclusion

A cognitive driver model that accounts for motivation, decision making and goal directed acting as well as human perception characteristics and motor processes with emphasis on decision making has been developed in order to simulate critical traffic situations. The assertion that the motivational disposition of drivers affects traffic situations to a great extent could be confirmed. First results show that the chosen modelling method using a modified production system is suitable for the purpose to simulate individual car driving behaviour.

For an assessment of novel technologies like driver assistance systems, however, a more realistic modelling of perception and information processing will be necessary. For this objective modelling tools like ANNs or Fuzzy could be employed.

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Online Traffic Simulation Based on Cellular Automata

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Abstract

Saturated capacities in traffic systems evoke increasing interest in simulations of complex networks serving as laboratory environment for developing management strategies. Especially for urban areas questions concerning overall traffic control have to be considered with regard to their impacts on the whole network. Modelling traffic flow dynamics using cellular automata allows to run large network traffic simulations with only comparative low computational efforts. We present a traffic simulation tool for urban road networks which is based on the Nagel-Schreckenberg Model. Arbitrary kinds of roads and crossings are modelled as combinations of only a few basic elements. Furthermore parking capacities are considered as well as circulations of public transports. The vehicles are driven corresponding to route plans or at random depending on the available data. The application of this network simulation covers investigations on the field of traffic planning as well as online simulations based on real-time traffic data as basis for dynamic traffic management systems.

Introduction

While for global aimed questions in the field of traffic management like dynamic vehicle routing it is self-evident to be considered on the whole network, even local aspects like changes in priority regulation at single crossings have to be investigated on large scales to avoid undesired global effects due to mutual correlations. Testing control strategies in realtiy is usually infeasible or at least extremely demanding in time and costs; therefore the application of simulation tools as laboratory environment is desired. Designing a simulation tool for network traffic requires to find an overall compromise: To enable collection of individual vehicle data like travel times or number of stops due to priority rules a microscopic approach is appropriate. In addition one is engaged to minimize running times, since e.g. for checking out different vehicle routing or traffic light control strategies complex scenarios have to be simulated again and again such that large computation times are very cumbersome and inefficient. Furthermore for online simulations based on real-time traffic data run speeds of at least real-time are a necessary requirement.

We present a microscopic simulation tool for vehicular traffic in urban road networks [1], which was developed in the framework of the Northrhine Westfalia Cooperative FVU (Forschungsverbund Verkehrssimulationen und Umweltwirkungen) [2]. The underlying traffic flow dynamics is based on the cellular automaton introduced by Nagel and Schreckenberg [3]. This approach has proved as very efficient: Meanwhile it is possible to simulate even the whole German autobahn network in real-time [4,5] and within the project TRANSIMS [6] microscopic traffic simulations are carried out for the Dallas / Fort Worth area [7].

The Cellular Automaton Model

The Nagel-Schreckenberg model [3] was originally defined on a single-lane road. The road is subdivided into cells, which can be either empty or occupied by one vehicle. Every vehicle has a non-negative integer velocity. For one update of the road the following four steps are performed simultanously for all vehicles:

1. Acceleration: $v = \min(v + 1, v_{max})$
2. Avoiding crashes: $v = \min(v, gap)$
3. Randomization: if rand() $< p$ then $v = \max(v - 1, 0)$
4. Update: Each vehicle is advanced v cells.

Here gap denotes the number of empty cells in front of a vehicle and v_{max} the maximum velocity. The randomization (Step 3) takes into account, that individual driving behaviours for different vehicles result in non-deterministic dynamics of vehicle motions in reality. The resolution is taken to be 7.5m per cell representing the average space a vehicle takes in a jam, but can be suitably adjusted with regard to the considered problem [8]; using this cell width each time step in the simulation corresponds to one second in reality. For modelling traffic on multi-lane roads a set of rules for lane changes is added to the fundamental rules [9,10,11].

Detailed investigations showed that despite its simplicity the cellular automaton model is capable to reproduce macroscopic traffic flow features including realistic lane changing behaviours [9,12]. Also a continuous extension [13] of the basic discrete model and a modified set of rules resulting in more realistic breaking and accelerating behaviour [14] was developed to enable modelling of additional more detailed vehicle features (e.g. exhaust emission).

Network Simulation Tool

The road network is described as composition of nodes and edges representing crossings and roads. To avoid misunderstandings: Whenever we use the expression "edge" we refer to directed edges representing one direction of motion on a road; i.e. one road usually consists of two (oppositely directed) edges. The basic idea is to define different types of edges. This approach causes arbitrary complex crossing types to be represented as combinations of at most three basic edge types: On *single-lane edges* simply the basic cellular automaton is applied. In addition there can be connected turn pockets for each direction at the end of the edge. Especially at the end of multi-lane roads the lane changing behaviour strongly depends on the desired driving direction. For this purpose, *multi-lane edges* are subdivided into different regions. Finally also highways play an important role for a realistic description of urban traffic. Therefore an additional element is incorporated to simulate highway drive-ups and also crossings with large spatial extension. *Transfer edges* are one- or multi-lane edges which merge in a destination edge.

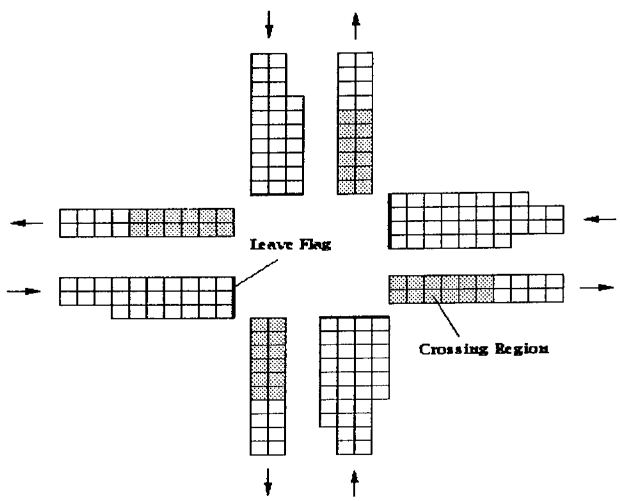

Figure 1: Representation of a node as combination of different edge types.

Fig.1 shows a crossing as combination of different edge types. The numbers at the end of the edges represent signal groups of the corresponding traffic lights and will be used below. Optionally the first cells on a edge can be defined as crossing section (shaded in the figure) to model the spatial extension roughly. In this case for each possible direction it is predefined if vehicles entering the edge are put onto the first cell of the edge or beyond the crossing section. This also allows to consider cases of jammed crossing regions in combination with priority rules.

One striking feature of urban road networks is the high density of intersections, which causes essential correlations among traffic streams on different edges. It is important for the simulation to have realistic throughputs at the crossings, which again requires to consider complex priority rules and especially traffic lights in a realistic manner. Each edge in the network has a driving-direction-dependent leave flag at its end, by which vehicles may be prevented from advancing any further. Traffic lights are realized by switching these flags corresponding to predefined time tables. In addition a hierarchy can be defined to consider crossings where special directions are controlled by more than one light (e.g. occasionally active green-light arrows for right turns). To facilitate handling of traffic lights the simulation tool contains an editor for setting green and red phases within a switch matrix.

Priority rules are realized by switching leave flags depending on vacant cells on other edges. In reality turning vehicles are often hindered in driving further e.g. by pedestrians crossing the destination road, which can reduce the throughput at certain crossings essentially. This effect is in case considered by blocking turning vehicles, for which driving on is allowed by traffic lights and priority rules, with predefined probabilities.

Furthermore no-stop and stop priority rules are distinguished; for the latter it is additionally checked if vehicles had zero velocity standing on the last cell of the edge for at least one time step before they are allowed to drive on.

One of the fundamental questions with regard to network traffic simulations concerns the question how the vehicles are guided through the network. In a randomly driven simulation at each crossing destination directions for the vehicles are choosen at random corresponding to turn counts. Running the simulation route plan driven means that each vehicle makes its turning decision corresponding to individual route plans, which are derived from origin-destination information. In the simulation the guidance mode is specified for each vehicle separately. Combination of both for example allows to check routing strategies on random background traffic representing typical traffic states.

The vehicles are characterized by their maximum speed, length (number of occupied cells) and a probability for carrying out risky lane changes (i.e. lane changes without considering safety distances). In the actual version the deceleration probabilities are not individual, but attributed to the edges to tune throughputs at the crossings. There are two special kinds of vehicles: Vehicles can be guided periodically along predefined routes following time tables to simulate public transports. Additionaly bus respectively tram stops are defined, where these have to wait for a certain time and in case are taken out of the network for that time. The second type covers hindrances like accidents or road works. These are represented by vehicles of special length and zero maximum velocity.

An essential characteristic of urban traffic is the fact that there are no predefined sources and sinks; rather vehicles are allowed to enter or leave the network at nearly every arbitrary position. For that reason sources and sinks can be linked to every cell in the network. At sources vehicles are characterized by type, guidance mode (see section Vehicle Guidance) and -- if necessary -- additional information like if the vehicle follows a dynamic routing system or not. They are inserted corresponding to source rates or trip plans; the latter means that at the beginning a list of vehicles with departure times, vehicle characteristics and route plans is prepared. In addition flow check points as source-sink combination can be defined. These can be located everywhere in the network to adjust the number of vehicles to counting loop data. For these check points statistics covering number of added and deleted vehicles are collected separately. Route plan driven vehicles are taken out of the network after reaching the destination node. Probabilities for leaving the network at the next node are attributed to every edge for randomly driven vehicles.

Especially for urban areas the consideration of parking capacities is desired. In the simulation these are considered as special source-sink pairs, which are filled up with regard to predefined capacities and from which -- as far as they are not empty -- vehicles can enter the network. This allows to develop strategies for parking control systems. It is also possible to define parking-lanes on the roads, which are used as usual lanes and in addition vehicles can be put on them marked as parking. This feature allows to consider capacity reduction of roads due to parking vehicles.

A necessary requirement for traffic management systems is information about the traffic state. For this purpose, three instruments are incorporated in the simulation: At measure points local data like number and average speed of vehicles are collected separately for different vehicle types and averaged over predefined time intervals. Edges can also be grouped together representing measure regions , by which global measurings are carried out. The individual travel time is measured for every vehicle in the network. For more detailed information it is possible to guide vehicle probes through the network. This allows to collect additional point to point data for special routes (e.g. data with regard to the driving comfort like number and duration of stops due to priority rules and traffic lights). Furthermore overall network data like number of vehicles, average speed and edge usage are stored.

The overall simulation tool consists of two principal processes. The master controller maintains the overall coordination: it checks static and dynamic network data read from the database for consistence and initializes the scenarios. During the simulation it receives and updates time dependent data like turn counts, handles the simulation output including in case updates of the graphics and if necessary provides dynamic data to the routing module, which updates route plans for the vehicle guidance system. The actual network dynamics is carried out by the micro simulation process; i.e. vehicle motions, source and traffic light updates and data collection for statistics.The advantage of this subdivision is twofold: On the one hand it speeds up the simulation, since in addition the micro simulation can be parallelized independently. Furthermore in practice it facilitates overall handling, because it is possible to rearrange e.g. graphical output or data formats without caring about the complex structure of the micro simulation.

Simulation of the Duisburg road network

Currently traffic simulations for the inner city of Duisburg are developed applying the simulation tool. Here we focus on presenting the present traffic state using online traffic data stemming from induction counting loops provided by the traffic control center of the municipality and updated every minute.

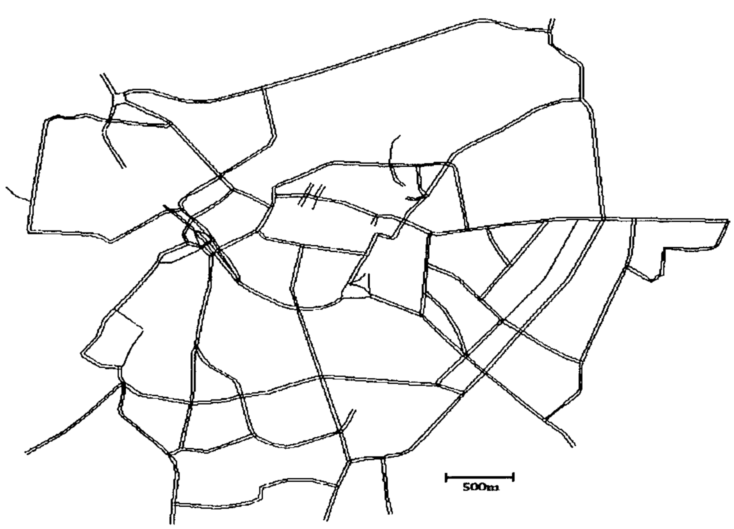

Figure 2: The simulated road network of Duisburg.

Fig.2 shows the considered network covering 107 nodes, 280 edges; the total lane length amounts to about 165 kilometers (22059 cells). Inclusive online source and turn count updates, priority regulation and data collection for statistics it is possible to simulate in 20 minutes on a PC (Pentium P133) a whole day of typical traffic.

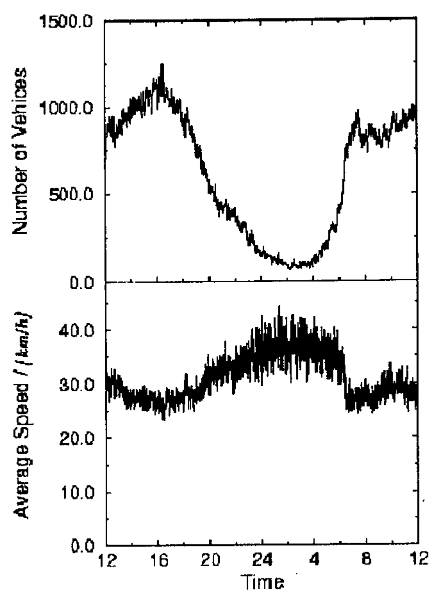

Figure 3: Number and average speed of vehicles in the Duisburg network during an online simulation.

Fig.3 shows the number of vehicles and the average speed during an online simulation for the time interval from 12.23am on the 1st until 12.22am on the 2nd of April in 1997. The extended minimum in the night and the two maxima at about 8am and 5pm are well dicernible. Due to missing origin-destination information with appropriate time resolution the simulation is driven randomly, while turn counts are derived from real-time traffic data. The present traffic state for the city of Duisburg is presented in the Internet [15].

Conclusions

We presented a simulation tool for urban traffic. The microscopic dynamics based on the Nagel-Schreckenberg cellular automaton allows to simulate large networks in multiple real-time. Within the network model complex crossings inclusive realistic traffic lights and priority rules are considered as well as parking capacities and circulations of public transports. In combination with real-time traffic counts this tool serves as useful laboratory environment for designing and checking dynamic traffic management systems.

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Intelligent Speed Adaptor (ISA)

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Summary

This manuscript concerns a study on the effects of a prototype intelligent speed adaptor (ISA) in actual traffic. Twenty-four subjects were included in a test of effects of feedback on speed behaviour, mental workload and acceptance. Subjects drove an instrumented vehicle in normal traffic on various types of roads with different speed restrictions and in a driving simulator, interacting with other traffic as well as under different speed restrictions. Subjects completed both test parts twice, half of the subjects receiving feedback in the second trial (experimental group), half of the subjects not (control group). The groups differed in several ways, the most important being adaptation of their behaviour under feedback. Subjects in the experimental group behaved more according to traffic rules, in particular speed limits, than subjects in the control group. No differences in workload were found. Several types of feedback were tested to acceptance and rated differentially.

Introduction

The Dutch Ministery of Transport and Public Works ('AVV', Transport Research Centre) has initiated a project ('Automatisering Rijtaak', automatizing the driving task) whose objective is to delineate standardized test methodologies for assessing safety effects of advanced transport telematics (ATT). This report presents a study in which the general methodology, as proposed by Verwey, Brookhuis and Janssen (1996), is followed to investigate the effects of feedback on speed behaviour, mental workload and acceptance of telematics applications developed to regulate speed.

As put forward by Kuiken and Heijer (1995) in their theoretical considerations regarding driver support systems and traffic safety in general, this type of systems aims to facilitate driving performance. One of the functionalities of such a system may be to facilitate the task performance of drivers by providing real-time advice, instruction and warnings. The latter type of systems are usually also described by the term 'co-driver systems'. Co-driver systems may operate in advisory, semi-automatic or automatic mode (e.g. Rosengren, 1995), which concern, for instance, speed regulation systems. Speed regulation as driver support system per se is different from speed regulation in (fully) automatic form, such as in autonomous intelligent cruise control (AICC) which is especially developed for and useful on motorways. In advisory mode a speed regulation system is suitable for any environment and situation.

According to Kuiken and Heijer (1995) the underlying assumption behind presenting drivers with specific information about the driving environment or supporting them in performing certain aspects of their tasks, is that their behaviour will change for the better. For example, if you warn a driver that his/her speed is too high, s/he will decrease the speed (see De Waard et al., 1994, De Waard and Brookhuis, 1995a). Thus far, little is known about the effects of driver information and support systems on traffic safety. Kuiken and Heijer (1995) recommended to develop, at the first stage, guidelines that will allow a systematical assessment of current and future in-vehicle support systems. In assessment procedures developed so far (Verwey, Brookhuis and Janssen, 1996) the human driver is considered in relation to the traffic environment, in terms of their capacities and limitations, terms of the tasks that need to be performed, and in terms of the errors (i.e. traffic rule violations) they might make.

Violation of traffic rules is obviously unwanted because of its relationship to accident causation. Well-known deviations from the norm, related to accident causation are close following, driving while intoxicated, speeding, running red traffic lights and neglecting stop signs (cf. Smiley and Brookhuis, 1987, Rothengatter, 1991). Speeding has a relatively well-known relationship to accident involvement. Salusjärvi (1981) reported an almost linear relationship between change in number of accidents and change of mean speed in Finland. Joksch (1993) found that the probability that a driver is killed increases with increased speed fits regression models with exponents as high as four, meaning that each km/h faster exponentially increases fatality risk. An average reduction of as little as 2 km/h to 5 km/h could lead to a reduction of 10% up to 30% in injury accidents (for a more elaborate overview, see Rothengatter, 1993). However, these effects seem less evident on motorways where the maximum speed (120 km/h in the Netherlands) is allowed than on, for instance, rural roads where a speed limit of 80 km/h is imposed (Wegman et al., 1991). One approach to influencing unwanted traffic rule violations, in particular speeding, is embedded in a project in the European DRIVE (Dedicated Road Infrastructure for Vehicle safety in Europe) initiative, the DETER (Detection, Enforcement & Tutoring for Error Reduction) project. DETER is concerned with the development and testing of prototypes of on-site, in-vehicle and integrated monitoring, tutoring and enforcement systems, among which Intelligent Speed Adaptation (ISA, see also De Waard and Brookhuis, 1995b).

Intelligent Speed Adaptation (ISA)

Through recent legislation in the Netherlands, the maximum driving speed is restricted by a speed limiter in the heavier types of lorries and coaches. As a consequence of this legislation the number of heavy vehicles in which the maximum driving speed is restricted will only increase in the coming years (Alink, 1992). The effect of these devices on fuel consumption, noise, air pollution, wearing of the tires and traffic safety is expected to be mainly positive (e.g., Almqvist et al., 1991, Van der Mede, 1992). The obvious restriction of the speed limiter as mandatory now, is that it only prevents driving above the maximum allowed driving speed of heavy goods haulage vehicles, and is independent of local limit in a specific road environment. An intelligent speed adapter (ISA) takes into account local restrictions, and adjusts the maximum driving speed to the posted maximum speed. When it comes to restriction of driving speed of *private* vehicles, the use of intelligent speed limiters is to be preferred due to further differentiation of speed limits for private cars compared to heavy goods vehicles. A non-intelligent speed limiter is set at the maximum allowed driving speed for motorways (120 km/h), while the majority of a speed limiting system's safety benefits can be attained on 'A'-class roads (limit 80 km/h) and in built-up areas (50 km/h).

Intelligent speed limiters require vehicle-infrastructure communication. For exchange of information about the road class or local restrictions, one option is to equip traffic signs with transmitters, beacons or tags. At the moment a car passes such a sign, the new speed limit is to be conveyed to the vehicle in one way or the other. Examples of experimental car-infrastructure communication can be found in Sweden (Nilsson and Berlin, 1992, Palmquist, 1993, Persson et al., 1993) and the Netherlands (De Waard and Brookhuis, 1995a,b).

In general, a standard speed limiter is an intrusive system that restricts speed control, i.e. the device sets the maximum possible driving speed. An intelligent speed limiter is able to set this maximum speed in accordance with local posted legal limits. A less intrusive device is a system that provides the driver with feedback about local limits, for instance, on the accelerator. An active gas pedal increases the counterforce if the driver is driving too fast (Godthelp and Schumann, 1991). In principle, such a speed limiter leaves the driver in control, while the feedback provided in case of a speed violation is highly compelling. Moreover, the feedback is provided in the tactile modality, i.e. the same modality through which action has to be undertaken to observe the rules again. Feedback could also be presented in the visual modality, e.g. a warning light or message in the dashboard, or auditory, an acoustic signal or vocal message. On the one hand this type of feedback seems less intrusive than the feedback an active gas pedal provides because these warnings can easily be ignored. On the other hand, it might be that the social effect of being warned in the presence of other passengers is a more severe chastisement and therefore less preferred. Anyway, acceptance of the feedback type systems can be expected to be higher than of a strict, standard speed limiter, because behaviour is less restrained. Results from a questionnaire survey demonstrate that a slight majority of people consider an indicator of speed-limit violations useful, while only 35% of the respondents were of that opinion with respect to a speed limiter (Hagen and Fokkema, 1990). Another advantage of the feedback systems opposed to the speed restricters, is that speed violations can sometimes be advantageous for traffic safety, e.g., there are instances in which a (perhaps misjudged) critical overtaking manoeuvre is faster and safer performed if the limit is exceeded.

Development of a prototype intelligent speed adaptor

An effort is now undertaken in the Netherlands to develop a prototype intelligent speed adaptor that leaves the driver in control. For a start, this resulted in the development of a continuous feedback display in close proximity of the speedometer indicating the current speed limit, quite similar to the CAROSI system (Nilsson and Berlin, 1992). Central part of the CAROSI (CAr ROadside SIgnalling) system is the instrument panel, which includes not only standard displays such as the speedometer, but also contains sections on which roadside information is displayed. Amongst these is the posted speed limit, which is displayed below the speedometer. Major advantage of giving feedback by displaying the speed limit inside the car is that this information remains continuously visible instead of only being visible at the moment a sign is passed. This might reduce speeding because of general unawareness of the limit, which is not uncommon in the Netherlands (e.g., Steyvers et al., 1992, De Waard et al., 1995).

A special version of the latter type of feedback display is developed for implementation in an experimental test-vehicle. Whenever the speed limit is exceeded the colour in which the speed limit is displayed changes from green ('normal/neutral') to amber, or yellow, ('warning'). In case the speed limit is exceeded by 10% the colour changes from amber to red ('violation'), and then an additional, auditory warning message is issued (see also De Waard et al., 1994, De Waard and Brookhuis, 1995ab). The systems are integrated in the existing DETER system (see De Waard and Brookhuis, 1995a), which is developed as an open system to integrate driver monitoring and feedback (sub)systems. In the present experiment this set-up is tested, letting subjects drive the test-vehicle with and without the feedback systems.

Additionally, an active gas pedal is tested as a medium for haptic feedback in case of speed limit violations, exceeding by 10%, in a driving simulator with the same subjects, in a cross-over design. All modes of feedback are studied to effects on behaviour, mental workload and acceptance.

Method

Subjects

Twenty-four subjects were selected from the TRC subjects' pool. They were paid for their participation in the test on effects of feedback concerning speed restrictions and violations in the institute's instrumented test vehicle and driving simulator.

Experimental design and procedure

Upon arrival at the institute, subjects were first informed about the purpose of the study in general terms, and more specifically what was expected from them. Heart rate electrodes were fixed at appropriate places on the chest. Then a general questionnaire concerning personal data, such as driving experience and their ideas about speed restriction systems, was completed after which half of the subjects drove the instrumented test vehicle over a fixed route and then performed the simulator test, half of the subjects vice versa. Each of the test-rides consisted of two parts, first the baseline measurement, then after a short break, either the test ride with feedback or the control ride. Half of the subjects received feedback, half were in the control condition. The subjects were instructed to drive as they would normally do, in their own cars, and were told in the second ride that behaviour with respect to law compliance was monitored and feedback was possibly given.

The test rides in the instrumented test vehicle were in normal traffic, under various conditions. Subjects were guided by sampled vocal route guidance messages that were triggered by the investigator for reasons of proper timing. They were led over a varied route that included sections of motorways, A-roads and built-up areas, with speed restrictions of 50, 70, 80, 100 and 120 km/h. The test ride in the simulator was a copy of the situation used for the DETER experiment (De Waard, 1995a), other traffic being present, speed restrictions being 50, 80, 100 and 120 km/h.

After each of the (four) test rides, subjects were requested to complete questionnaires concerning perceived workload and subjective driving quality. At the end of the whole test, subjects completed a general questionnaire again, asking for their ideas with respect to speed resticting systems again.

Test vehicle

For the test rides on the road, the instrumented test vehicle (a Renault 19 RT) was used (for a description of the instrumentation, see Kok and Brookhuis, 1995). Data regarding speed and steering wheel movements were sampled on-line at 10 Hz by an industrial PC with a Pentium™ processor and were stored on harddisk. Information regarding speed limits and stop signs were conveyed to the car by means of a microwave system adapted, not especially developed, for this specific purpose, by an electronics manufacturer. An antenna (MIDS SAA-4S) / reader (MIDS V1) combination was installed on top respectively inside the vehicle, while traffic signs were equipped, at the back side, with tags (labels, MIDS ML20). This microwave system operates at a frequency of 2.4-2.5 GHz. Positioning of the tags at the back side of traffic signs ensured that information regarding local speed limits did *not* enter the vehicle *too early,* i.e. not before a speed limit zone actually was entered. In this way it was avoided that drivers were 'accused' of speeding by the system when the new restrictions had not taken effect yet in geographical sense. Feedback about local speed limits was provided only to subjects in the experimental condition during feedback trials (i.e., the second series of trials). On the road the display indicating the speed limit in green (when keeping to the limit), amber (when exceeding the limit but less than 10%) or red (when exceeding the limit by more than 10%). The vocal message 'You are driving too fast, the local limit is ...' was given at the instance the display's colour changed from amber to red. Headway feedback was not given in this experiment.

Simulator

Subjects performed two rides in the insititute's driving simulator (Van Wolffelaar and Van Winsum, 1992, Van Winsum and Van Wolffelaar, 1993). Subjects drove in the same condition as in the on-the-road test, i.e. subjects in the control condition did not receive feedback regarding detected violations. Subjects in the experimental condition were provided with haptic feedback about the (posted) speed limit when exceeding the limit, but this feedback was given in the second trial only. Haptic feedback consisted of a continuous counterforce on the gas pedal. The counterforce was dependant upon the extent to which the limit was exceeded, and was equal to: 4 x (speed - speed limit (both in m/s)) Newton. If the speed limit was exceeded by more than 10% the same vocal message was given as in the on-the-road trials. The same testbed as described in De Waard et al. (1994) was used with one exception: in the previous simulator experiment the last 3 minutes of driving of each trial consisted of tedious dual-carriageway driving.

Subjective measures

During the whole test, performance parameters and subjects' heart rate were registered as measures of workload, whereas after each ride the self-report scale RSME (Rating Scale Mental Effort, see Zijlstra and Meijman, 1989) was completed. In previous tests, both performed in the simulator (De Waard et al., 1994) and on-the-road (De Waard and Brookhuis, 1995a,b), results showed that the tutoring messages increased driver mental load in a moderate way. Both reduced heart rate variance and increased self-report scores indicated increased effort.

A subjective driving quality score (driving quality scale, see Brookhuis et al., 1985) was also derived to check on subject's personal impression about driving circumstances.

Before entering the experiment and after the whole session, a score on nine items regarding acceptance of tutoring and enforcement systems (Van der Laan et al., 1997) was derived from the subjects. After the test rides more detailed questions about acceptance of the different feedback systems were posed.

Results

A total of 24 subjects participated in the test rides. Eleven subjects were female, average age 34.6 (*sd* 8.7), average mileage 10.000 km/year (*sd* 9.000), thirteen were male, average age 34.7 (*sd* 10.7), mileage 21.000 km/year (*sd* 19.000). On average, both males and females had held a drivers' licence for 15 years. Five subjects did not (fully) complete the test due to simulator sickness, but were as much as possible included in the analyses.

Although the number of detected violations during the second (feedback) series of trials is lower in the experimental group, this effect does not attain statistical significance (Group x Trial interaction: $F(1,18) = 1.33$, NS). The difference in the number of speed violations between the two test facilities is significant ($F(1,18) = 25.4$, $p < 0.001$), drivers more frequently violated the speed limit on-the-road. The extent to which the speed limit was exceeded was higher in the simulator ($F(1,18) = 24.3$, $p < 0.001$). During the feedback-trial the extent to which the limit was exceeded was on average lower (with the exception of the second on-the-road trail for the control group), but this effect is not significant (Group x Trial interaction $F(1,18) < 1$, NS, Group x Trial x Testfacility interaction, $F(1,18) = 2.7$, NS).

During the test rides it was noted that some of the subjects in the experimental group obviously 'played' with the feedback display to test its behaviour or use it to stay in the marginal area (amber). It was therefore decided to determine a new parameter, the proportion of time violating the limit. This parameter does not discretely sum up the number of times the limit is exceeded, but reflects the time the driver is not complying. Two parameters were determined, the proportion of time driving above the limit, i.e. the time the display was or would have been amber or red, and the proportion time driving above the limit + 10%, i.e. the time the display was or would have been red and an auditory message was or would have been issued. The `would have been'-condition is for the control group, the experimental group actually received the described feedback. From figure 1 it is clear that as much as 20 to 25% drivers are speeding in the strict juridical sense. Between 5 and 10% of the time they are driving faster than the speed limit plus a 10% margin. The effect of the feedback system is only significant for the latter parameter

(Group x trial interaction: $F(1,22) = 1.50$, NS for amber/red display, $F(1,22) = 9.39$, $p<0.01$ for red-display feedback).

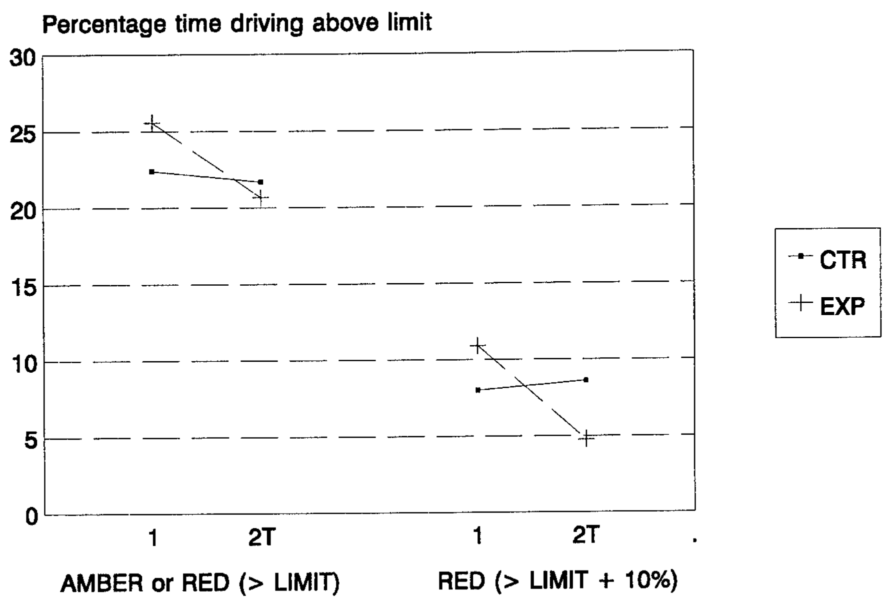

Figure 1 Time driving above the limit and above the limit plus a 10% margin per group and Trial (on-the-road data only). 1 = Trial 1, 2T = Trial 2 (T = Tutoring feedback, provided to subjects in the experimental group only).

Workload

Task performance was measured by the vehicle parameters *SD* of the steering wheel movements (on straight sections in the road), average lateral position on the road and *SD* of the lateral position on the road. During the second simulator trial swerving as measured by the SD of the lateral position increased in both groups ($F(1,18) = 7.59$, $p<0.05$). No significant changes in task performance parameters as a result of the feedback system were found.

Self-report ratings on the Rating Scale Mental Effort (Zijlstra and Meijman, 1989) show a clear effect of test environment ($F(1,17) = 26.6$, $p< 0.001$). Previous comparison of trials between on-the-road driving and simulator tests had also shown increased mental effort for task performance in the simulator (De Waard and Brookhuis, 1995a). There is a tendency to evaluate the amount of invested effort in the second trial as lower ($F(1,17) = 4.04$, $p<0.10$). The interaction Group x Trial approaches significance for the car data only ($F(1,22)= 3.98$, $p<0.06$).

One physiological measure was registerd, the subjects' heart rate, or ECG. Data were off-line checked for artifacts. Different problems varying from simulator sickness to cable problems led to incomplete data sets, four subjects had to be deleted from the car data set, eight subjects from the simulator set. ECG analysis resulted in parameters: IBI (inter-beat-interval) and variation coefficient (normalized heart rate variability in the time domain). Both parameters are sensitive to general arousal and effort. There were no effects of feedback on any of the heart rate parameters. Only self-reported mental effort during the trials performed on-the-road are indicative for a slight increase in mental workload. Physiology and task performance did not reflect any changes as a result of feedback.

Control variables

Control variables for driving performance are self-report ratings about driving quality and average and *sd* of driving speed. After each trial subjects were asked to compare their performance to normal driving on the driving quality scale (Brookhuis et al., 1985). The scale has a range from -100 ('I have driven exceptionally poorly') to +100 ('I have driven exceptionally well'), while a rating of '0' stands for 'I have driven normally'. Analysis shows an interaction between trial and testfacility ($F(1,17) = 9.1$, $p < 0.01$). Rated driving quality decreases slightly in the second on-the-road trial, while it improves during the second simulator trial. Probably due to relatively low familiarity driving quality in the simulator is rated lower than in a real car ($F(1,17) = 17.8$, $p < 0.001$).

Speed was determined on the motorway (speed limit 120 km/h), on a rural 50 km/h speed-limit road (both on-the-road) and in the simulator on a dual carriageway (speed limit 100 km/h). The difference between trial 1 and 2 is significant for both average speed ($F(1,17) = 6.0$, $p < 0.05$) and variability in driving speed ($F(1,17) = 10.4$, $p < 0.01$).

The control variables show that rated task performance as well as average driving speed on high speed roads increase with time-on-task (i.e., trials). Driving speed and variability (sd) in driving speed decrease mostly in the second trial, in particular in the experimental group.

Ratings on the acceptance items (Van der Laan et al, 1997) did not differ significantly between the control and experimental group ($F(1,22) < 1$, NS), nor did they differ between before and after-test measurements ($F(1,22) < 1$, NS). Usefulness of a speed compliance feedback system is rated negatively, -1.04, on a scale from -2 to +2. Such a system is rated slightly positive in terms of being satisfying (+0.16) on a scale with the same range.

After the test rides, subjects from the experimental group were asked to rate the effect the feedback system had had on their speed choice. Evaluation in terms of good/bad and pleasant/not pleasant are given in table 1. All drivers had been asked whether they would accept the different types of systems The display-only turned out to be the best accepted system, followed by haptic pedal feedback (experimental group) and auditory feedback (control group).

Table 1. Evaluation of the different types of feedback systems (N=11).

Feedback	'Good' ↔	'Not Good'	'Pleasant' ↔	'Not pleasant'
Auditory (car)	73%	0%	21%	54%
Visual (Display) (car)	91%	0%	82%	0%
Auditory (simulator)	73%	0%	27%	36%
Haptic (simulator)	40%	10%	20%	50%

In table 2 the 'preferred system' is given in order of preference of the group who had experienced the systems (the experimental group). The feedback display is clearly favourite, followed by pedal counterforce.

Table 2. Preferred feedback system

	Control	Experimental
Display	42%	42%
Pedal counterforce	8%	17%
Voice + pedal	0%	17%
Voice + display	33%	8%
Voice	8%	8%
Display + pedal	8%	8%

Discussion

In fact this is the third experiment on the road in which feedback in one way or the other was given to subjects about violations of traffic rules, in this case primarily speed. Similar to the first two experiments (De Waard et al., 1994, De Waard and Brookhuis, 1995a), effects of feedback are present again, but not as large as in previous experiments and slightly different. Specifically the effect on number of speed violations was much lower in the present study. The main difference, and probably largely explaining the lower effects, in driving condition for the subjects this time was a continuous feedback on (posted) speed limits *and* rule compliance, as opposed to incidental warnings in case of violations in the first two studies. A clear reduction in speed in the experimental condition in those cases where subjects clearly tended to violate the limit, i.e. in the 50 km/h zones, was found. Furthermore, from the data on percentage of time driving above limit (see figure 1) it is clear that, at least some subjects used the continuous feedback to keep their speed in the margin of 'limit to limit+10%' (amber).

From the acceptance data (see tables 1 and 2) it follows that acceptance very much depends upon feedback system, continuous feedback was accepted best of all means of feedback by far. The ratings for the continuous visual feedback were unusually high and can maybe even considered as (highly) appreciated. The system that is most proximate to an actual speed-restrictor, haptic feedback, is according to the subjects, surprisingly enough not the most influential on behaviour. Differences between the two test environments (simulator <==> car) make a comparison of effects on actual behaviour of haptic versus visual display feedback difficult (confounded).

An new, unexpected effect of the compound feedback was found, a significant reduction in speed variation. One of the reasons is the earlier mentioned use of the amber to stay in the margin of 'limit to limit+10%'. The implication of this finding is that less variation in driving speed could help to harmonize traffic, which is one of the candidate tools to reduce the number of accidents (see also Brookhuis and Brown, 1992).

No effects on workload were found in this study, again contrary to the first two experiments as mentioned. However, in the latter studies the (slight) effects were marginally significant, while in the present data the (slight) effects demonstrated in either of the two measures of mental load did not attain significance. The implication of these findings, in line with Verwey, Brookhuis and Janssen (1996), is that before implementing telematics systems, in principle workload effects should be measured, just to be sure, but the type of systems tested so far are not implying alarming effects.

Finally, the conclusions of this study can be summarized succinctly in three statements:

- Giving feedback about speed limit compliance/violation is effective
- Giving continuous *including* compliance feedback is effective and appreciated
- Giving continuous *including* compliance feedback could help harmonizing traffic

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Simulation and Control of Traffic Flow on Large Motorway Networks

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Abstract

Motorway networks are important facilities to handle high demand of traffic flow and transportation. In overloaded situations or in cases of incidents efficient, operative control means are necessary to save the operability of the motorway network. The most effective control means are ramp metering at the entries of the motorway network, variable speed limitation on individual sections of the motorway and diversion of traffic flow using variable message signs.

In this paper a macroscopic simulation model for traffic flow is used to find optimal control strategies for traffic responsive control means. First the traffic model allows a forecast of the traffic evalution on the motorway network. Further it is used for an offline-optimization of the control means in certain traffic load situations. Therefore an optimization problem for the control variables is formulated with a suitable performance criterion for the traffic flow. The *offline* optimization results are compared with the developed *online* traffic responsive control law in some simulation studies.

Introduction

Congestion on German motorway networks have become a common phenomenon especially within the holiday period. It leads to considerable delays, reduced traffic security, increased fuel consumption and air pollution.

Traffic control systems are important facilities to preserve the capacity of the motorway network and to avoid congestion. They require intelligent traffic responsive control strategies.

In this paper a traffic responsive control concept in motorway networks is presented. As control inputs we take into consideraton:

- ramp metering at the on-ramps of the network by traffic signalization,
- variable speed limitation imposed on individual sections of the motorway,
- traffic flow diversion to alternative routes by variable message signs.

The concept of a traffic responsive closed loop control is illustrated in Fig. 1.

Actual traffic data are collected from appropiate locations. These sample data are extended by estimation techniques (e.g. as proposed by Cremer, 1976). The values of the state variables are then mapped by a short control algorithm into the actual control inputs which respond best to the given traffic load.

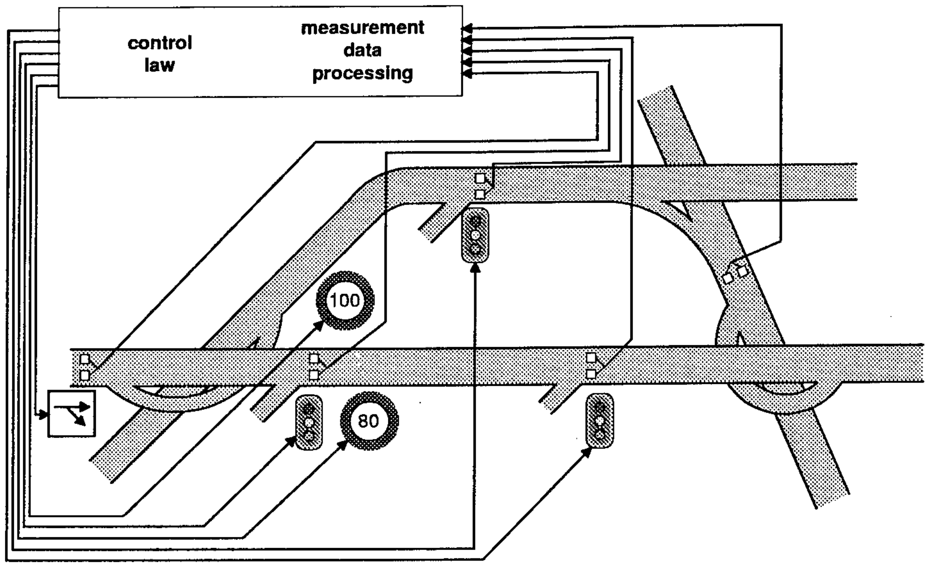

Figure 1: Structure of a feedback control system for a small network

This paper is organized as follows: In the following chapter a dynamic, macroscopic model for the traffic flow in a motorway network is introduced. In chapter 3, an optimal control problem for open loop control of traffic flow is formulated. This nonlinear, large scale optimization problem is solved by particular heuristic optimization algorithms. Using these results a closed loop control law is designed in chapter 4. The efficiency of the control law is underlined in chapter 5 by a simulation of a critical case. Finally a summary with some conclusions is given.

The simulation model of traffic flow

To simulate traffic flow in a large network a macroscopic, time discrete model is used which was first introduced by Payne (1971) and later improved by Cremer (1979).

To present the model equations briefly, let us consider a section of a motorway, which is spatially divided into subsections of a length between 400 and 600 meters.

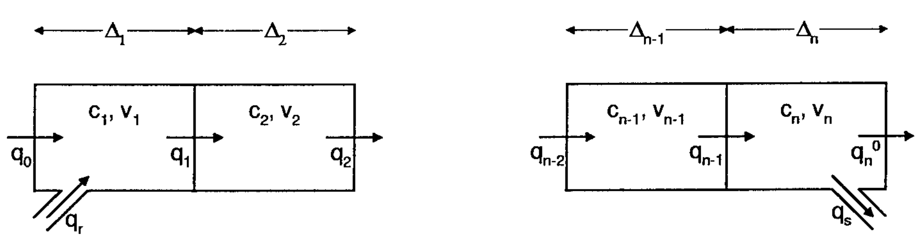

Figure 2: Section of a multilane motorway with subsections and model variables

Let T denote the time step width. Then for each subsection j (j=1, ..., n) the following variables of the time discrete model are introduced:

$c_j(k)$ *traffic density* in subsection j at time kT [veh/km]

$v_j(k)$ *mean speed* of the vehicles within subsection j at time kT [km/h]

$q_j(k)$ *traffic volume* from subsection j into subsection j+1 during the time interval $kT \le t < (k+1)T$ [veh/h]

$q_r(k), q_s(k)$ entering or leaving *ramp volumes* during $kT \le t < (k+1)T$ [veh/h]

Now we can formulate difference equations for the state variables $c_j(k)$ and $v_j(k)$:

$$c_j(k+1) = c_j(k) + \frac{T}{\Delta_j}\left[q_{j-1}(k) - q_j(k) + \delta_{1j}q_r(k) - \delta_{nj}q_s(k)\right] \quad (1)$$

$$v_j(k+1) = v_j(k) + \frac{T}{\tau}\left[V\left(c_j(k), u_2(k)\right) - v_j(k)\right] + \frac{T}{\Delta_j}\left[v_j(k)\cdot\left(v_{j-1}(k) - v_j(k)\right)\right] - \frac{\nu}{\tau}\cdot\frac{T}{\Delta_j}\left[\frac{c_{j+1}(k) - c_j(k)}{c_j(k) + \kappa}\right] \quad (2)$$

Equation (1) is a simple balance of vehicles and equation (2) was derived from empirical considerations. The first term in brackets on the right hand side describes a retarded adaptation of the average speed to the stationary speed-density characteristic $V(c, u_2)$. The second term represents convection of spatial speed profile in the downstream direction and the third term models drivers anticipation of a density variation as seen in downstream direction.

For the volumes between the subsections the following approximate expression taken from hydrodynamical relations is meaningful:

$$q_j(k) = \alpha\, c_j(k)v_j(k) + (1-\alpha)\, c_{j+1}(k)v_{j+1}(k) \quad (3)$$

The model parameters $\alpha, \kappa, \tau, \nu$ and the speed-density-characteristic (see below) have to be calibrated by real measurements. For German motorways the calibration was performed in Cremer and Papageorgiou (1981). For the time step T a value of 10 sec has shown to be a suitable value. Care has to be taken that the maximum speed does not exeed the ratio Δ_j / T.

The influence of speed limitation is modelled by the control variable u_2. Based on investigations of the effect of speed limitations on German motorways (Zackor, 1972) the following relationship for a stationary speed-density characteristic has been formulated:

$$V(c, u_2) = v_f \cdot u_2 \cdot \left[1 - \left(\frac{c}{c_{max}} \right)^{l(3-2u_2)} \right]^m \tag{4}$$

where v_f is the average free flow velocity, c_{max} is the maximum density at full congestion and l and m are positive real numbers. The control variable u_2 has the following correspondences:

- $u_2 = 1$: unlimited free speed
- $u_2 = 0.82$: speed limitation to 100 km/h
- $u_2 = 0.65$: speed limitation to 80 km/h
- $u_2 = 0.5$: speed limitation to 60 km/h

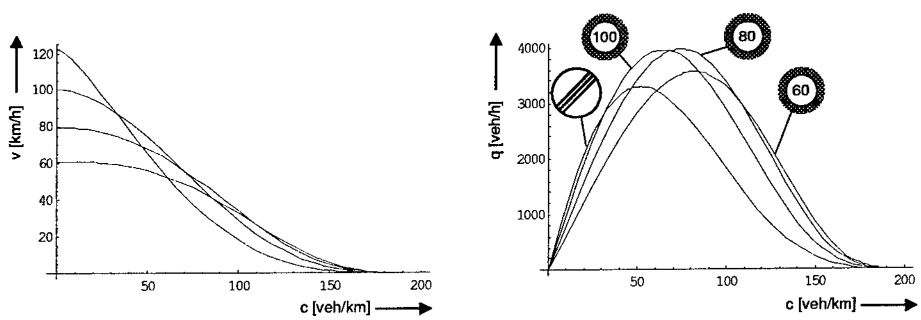

Figure 3: Speed-density characteristic and volume-density characteristic for different speed limitations

Ramp metering by control input u_1 is modelled by the following equation:

$$q_r(k) = min \begin{cases} q_r^{max} \cdot f(c_1(k)) \\ q_r^{max} \cdot u_1(k) \\ q_d(k) + q_w(k) \end{cases} \tag{5}$$

Thus, the entering volume is either limited by congestion on the motorway (function $f(c_1)$) or by the green time quota u_1 of the ramp metering signal or by the number of waiting (q_w) and arriving (q_d) vehicles.

To model the leaving ramp volumes at intersections or off-ramp some knowledge about the origin destination pattern is necessary. For simplifying reasons we assume constant local OD-quotas $(0 \leq \varepsilon \leq 1)$:

$$q_s(k) = \varepsilon \cdot q_n(k)$$
$$q_n^0(k) = (1-\varepsilon) \cdot q_n(k) \tag{6}$$

If diversion of traffic flow due to congestion or an incident on the main route is recommended by the control variable $u_3 \in \{0,1\}$, the off-ramp volume is increased by an additional trafficstream $q_a(k)$:

$$q_a(k) = u_3(k) \cdot \varepsilon_a \cdot (1-\varepsilon)\, q_n(k)$$
$$q_s(k) = \varepsilon \cdot q_n(k) + q_a(k) \tag{7}$$
$$q_n^0(k) = (1-\varepsilon) \cdot q_n(k) - q_a(k)$$

ε_a denotes the divertable portion of the traffic flow. The diverted traffic flow has to be balanced separately on the alternative route in order to secure correct origin destination flow. For this reason density and volume have to be calculated separately for the diverted flow in Eq. (1) and (3). The average speed (Eq. (2)) has to be calculated by taking the total density.

The control variables u_1, u_2 and u_3 are defined at several places in the network and can be changed after a period of T_u seconds which should be chosen not too small for reason of acceptance. We have chosen a value of $T_u = 5$ min.

Optimal control problem

In order to determine optimal controls for a given traffic demand pattern we need a suitable performance criterion by which the impact of the control variables on the traffic flow can be quantified. Several objective functions may be found in literature (e.g. in Isaksen and Payne (1973) or Cremer and Fleischmann (1987)). A meaningful objective is to minimize overall travel time within the network during the time period under consideration. The only disadvantage is that the effects of the control actions can reach beyond the chosen period and are therefore not accounted properly.

The *total delay time* in the network is closely related to the overall travel time and avoids the mentioned disadvantage (Cremer and Schoof (1989)). Total delay time is calculated as a function of the model variables by taking a sum of three different terms:

- delay time from the waiting queues on the i-th on-ramp:
  $$L_1^i(k) = T^2\, q_w^i(k) \tag{8}$$
- momentary delay time in subsection j of the motorway:
  $$L_2^j(k) = \Delta_j c_j(k) T \left(1 - \frac{v_j(k)}{v_f}\right) \tag{9}$$
- delay time caused by driving on the deviation route:
  $$L_3(k) = T q_a(k) \frac{l_a - l_m}{v_f} \tag{10}$$

  where l_m and l_a are the lenghts of the main route and the alternative route.

Total delay time is then the sum over time and space of the momentary terms:

$$P = \sum_{k=1}^{K} \left[\sum_{i=1}^{I} L_1^i(k) + \sum_{j=1}^{J} L_2^j(k) + L_3(k) \right] \quad (11)$$

With this performance criterion we can now formulate an *optimization problem*:

Given a time discrete model for the traffic flow through a motorway network as nonlinear differential equation system:

$$x(k+1) = x(k) + f\big(x(k),\, u(k),\, q_0(k)\big) \quad (12)$$

with known initial state $x(0)$ and known entry flows $q_0(k), k = 1, \ldots, K$.

Find sequences for all control variables $\{u_1^i(k), u_2^j(k), u_3(k)\}$ over a chosen time period K which minimize the total delay time P (11) under the following constraints:

$$\begin{aligned} &0 \le u_1^i(k) \le 1 \\ &0.5 \le u_2^j(k) \le 1 \\ &u_3(k) \in \{0,1\} \end{aligned} \quad (13)$$

Values can be changed after a period of T_u seconds (e.g. 5 min.).

This problem can be classified as a large scale, nonlinear, mixed integer optimization problem. To solve such a complex problem, several optimization techniques have been tested. The best results were achieved by the method of „Threshold Accepting“, which was developed by Dueck and Scheuer (1990).

In one optimization step a complete simulation of the traffic evolution in the network is necessary, so the performance of the simulation model is very important.

Traffic responsive control law

The optimization procedure is only suitable for an offline-control of the traffic flow, because of the complexity and the computational effort.

For an online-control-system as shown in Figure 1 a simple control law is needed, which maps the actual state variables into new control decisions. From typical case studies and analysis of the static traffic control problem a new control law for the online traffic control problem in urban traffic corridors was derived (Schoof (1991)).

We present the control law briefly adapted for motorway networks:

1. Determination of the on-ramp control values $u_1^i(k)$ for the i-th section

In stationary state of traffic flow the ramp metering control variables can be calculated by a simple linear optimization scheme. In case of congestion a special algorithm is necessary to reduce the congestion.

In the i-th section the following constraint has to be fulfilled (see Fig. 4):

$$\overline{q}^{i-1} + u_1^i \cdot \overline{q}_d^i \leq q_{off}^i \quad (14)$$

The incoming static traffic volumes are given at the network boundarys or can be calculated successively.

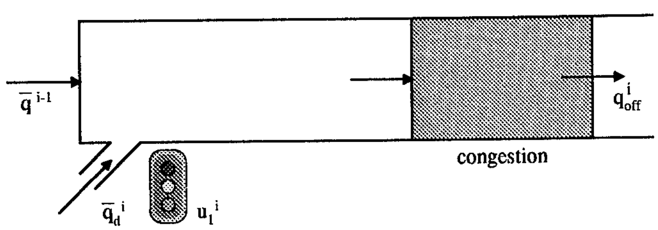

Figure 4: Necessary constraint for congestion reduction

From this the values u_1^i can be determined as follows:

$$q_{off}^i = \begin{cases} q_{cap}^i & \text{no congestion (e.g. } q_{cap}^i = 4000 \text{ veh / h for 2 lanes)} \\ \min\limits_j \{q_j^i\} & \text{in case of congestion (} \max\limits_j \{c_j^i\} \geq c_{crit}) \end{cases}$$

$$u_1^i = \begin{cases} 0 & \text{for } q_{off}^i - \overline{q}^{i-1} < 0 \\ \left(q_{off} - \overline{q}^{i-1}\right) / q_r^{max} & \text{otherwise} \\ 1 & \text{for } q_{off}^i - \overline{q}^{i-1} \geq q_r^{max} \end{cases} \quad (15)$$

If the reduction of the incoming traffic volume is not sufficient, other upstream onramps have to be closed.

2. Determination of the speed limitation values $u_2^i(k)$ for the i-th section

The influence of speed limitation to the stationary speed-density characteristic $V(c,u_2)$ is formulated in Eq. (4). With $Q(c,u_2) = c \cdot V(c,u_2)$ and $\frac{\partial Q}{\partial u_2}(c,u_2) = 0$ the optimal speed limitation u_2^* for a stationary density $\overline{c}$ can be calculated. The functional correspondence $u_2^* = U_2(\overline{c})$ is depicted in Fig. 5.

To obtain a characteristic density value in the section, a weighted average density $\overline{c}^i$ is calculated with heigher weight to the heigher density values:

$$\overline{c}^i = \sum_j w_j \cdot c_j^i(k), \quad \sum_j w_j = 1 \quad \text{and} \quad u_2^i = U_2\left(\overline{c}^i\right) \quad (16)$$

If congestion is detected ($\max\limits_j \{c_j^i\} \geq c_{crit}$) , speed limitation of $u_2^i = 0.65$ (80 km/h) is recommended. If other upstream onramps must be closed, speed limitaion in the upstream sections are set to 80 km/h respectively.

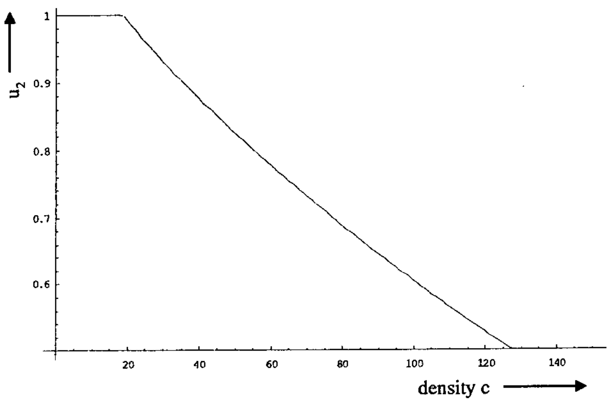

Figure 5: Stationary control characteric $U_2(c)$

3. Determination of the route diversion decision $u_3(k)$

For calculation of the route diversion decision it is necessary, to estimate the influence of the decision to the performance on the main route and on the alternative route. In stationary state of traffic flow the delay time in the i-th section can be determined by:

$$\overline{L}_2^i(\overline{q}^i) = K \cdot T \cdot l_i \left(C(\overline{q}^i) - \frac{\overline{q}^i}{v_f} \right) \qquad \text{with } \overline{c}^i = C(\overline{q}^i) \approx c_{crit}\left(1 - \sqrt{1 - \frac{\overline{q}^i}{q^i_{cap}}}\right) \tag{17}$$

and l_i denotes the length of the i-th section.

The delay time caused by driving on the deviation route is in this case:

$$\overline{L}_3(\overline{q}_a) = K \cdot T \cdot \overline{q}_a \left(\frac{l_m - l_a}{v_f} \right) \tag{18}$$

If $\overline{q}^i < q^i_{cap}$ for all sections i, recommendation of the route diversion can be determined by calculating:

$$\Delta_1 = \sum_{i \in I_m} \left(\overline{L}_2^i(\overline{q}^i) - \overline{L}_2^i(\overline{q}^i - \overline{q}_a) \right) - \sum_{i \in I_a} \left(\overline{L}_2^i(\overline{q}^i + \overline{q}_a) - \overline{L}_2^i(\overline{q}^i) \right) - \overline{L}_3(\overline{q}_a) \tag{19}$$

If $\Delta_1 > 0$, set $u_3(k) = 1$. (I_m denotes the set of sections on the main route, I_a the set of sections on the alternative route respectively).

The revocation of the route diversion can be determined by calculating:

$$\Delta_2 = \sum_{i \in I_a} \left(\overline{L}_2^i(\overline{q}^i) - \overline{L}_2^i(\overline{q}^i - \overline{q}_a) \right) + \overline{L}_3(\overline{q}_a) - \sum_{i \in I_m} \left(\overline{L}_2^i(\overline{q}^i + \overline{q}_a) - \overline{L}_2^i(\overline{q}^i) \right) \tag{20}$$

If $\Delta_2 > 0$, set $u_3(k) = 0$.

If $\overline{q}^i \geq q^i_{cap}$ for a section i, the route diversion is determined with the aim to avoid congestion. For a detailed algorithm see Schoof (1991).

Results

To demonstrate the efficieny of the traffic responsive control law, a topology like Fig.1 was chosen. The length of the main route is 5 km to node 1, then 15 km to node 2 and another 5 km. The length of the alternative route between node 1 and 2 is 20 km.

The simulation period is 1 hour, and on the main route an incident occurs from min. 17 to 33 by which one of two lanes is blocked.

Fig. 6-8 show the evaluation of the density at the main route in case of no control, traffic responsive control and optimal control. In case 2 the route diversion is recommended from min. 20 to 40, in case 3 from min. 15 to 30.

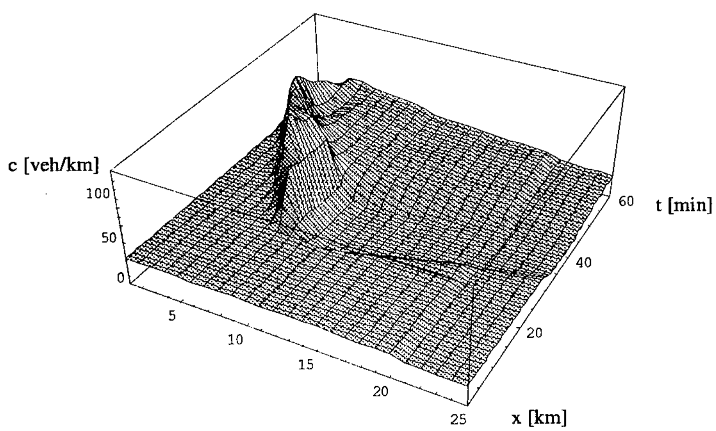

Figure 6: Time space diagram of density on the main route without control

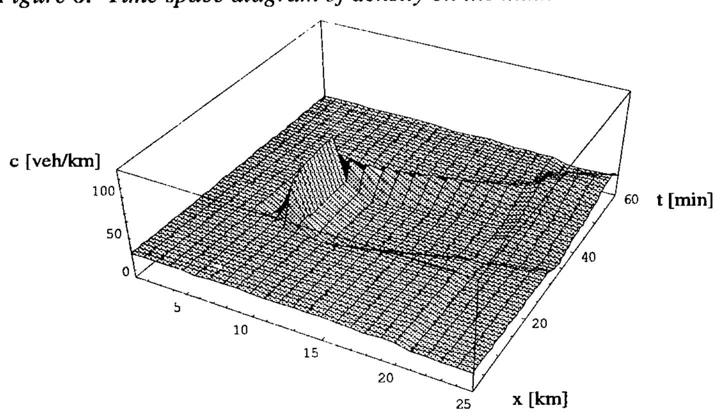

Figure 7: Time space diagram of density on the main route with traffic responsive control law

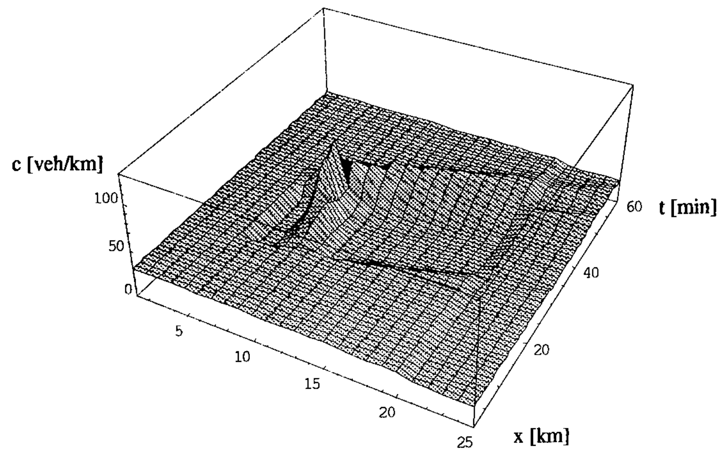

Figure 8: Time space diagram of density on the main route with optimal control

The performance index for the overall network in the three cases is shown in the following table:

	performance index [veh h]
no control	396.2
traffic responsive control	303.5
optimal control	285.4

Conclusions

In this paper a traffic responsive control law is presented to determine optimal control sequences for traffic flow in a motorway network. The control means are ramp metering, speed limitation and route diversion.

First a dynamic macroscopic model for the traffic flow in a motorway network as a simulation tool is introduced. Second an optimal control problem was formulated. To solve this large scale, nonlinear, mixed integer optimization problem special optimization techniques, e.g. the method of „Threshold Accepting", are necessary.

For an online-control-system a traffic responsive control law is necessary, which was derived by investigation of the stationary state of traffic flow. The efficieny of the control concept is demonstrated by the results of a case study.

Future work is directed to extend the control law for multiple alternative routes with conflicting requirements. Other research tasks are a sensitivity analysis or the reduction of the measured information.

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False yield and false go decisions at signalized left-turn intersections: A driving simulator study

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Abstract

The possible errors drivers can make interpreting different traffic signal/sign combinations at signalized intersections fall into two error categories: False yield and false go responses. In order to understand better the possible reasons for false yield and false go responses, younger and older drivers had to interpret different signal/sign combinations while operating a driving simulator. The combinations of traffic signals and signs were selected such that the elements in those combinations either conveyed a yield response, a go response, or both, to different degrees. The percentage of errors drivers made was the dependent variable. We predicted that the percentage of errors would vary systematically with the compatibility of the messages implied by the sign and signal. The predictions were consistent with the observed errors in the majority of combinations. Thus, we are able to predict which particular signs will be most effective with a given signal. Theoretical and practical gains clearly follow from this capability.

Introduction

Drivers have to react to different signals, one of which is the traffic signal at intersections. Oftentimes the design and location of these traffic signals does not allow their efficient interpretation by drivers (Bonneson and McCoy, 1994; Williams, Ardekani, and Asante, 1992). This leads to errors, where drivers sometimes go when they should yield (false go), and sometimes yield when they should go (false yield). Williams et al. (1992), for instance, conducted a mail survey, in which different pictographic designs of signalized intersections were sent to hundreds of drivers in Texas. Drivers had to decide whether a left turn was allowed during the presented signal interval, and if so, whether it was permitted or protected. Based on a sample of close to 900 responses, the authors concluded that the simultaneous presentation of a red globe and a green arrow on a horizontal five section head should be avoided since this combination produced a great many false yield decisions. False yield responses were also found in a similar survey conducted by Bonneson and McCoy (1994). In their survey, the authors tested how well motorists understood whether a signal design indicated either a protected left turn (green arrow and red globe), a permitted left turn (green globe, i.e., drivers can turn left if there is no oncoming traffic), or an overlap condition (i.e., left turn green arrow for left turn indication and green globe for through indication). They found that the overlap indication was least understood (i.e., false yield responses for about half of the respondents), and permitted and protected indications were understood equally well. Regarding sign use, a significantly higher correct response rate occurred without the use of signs. The sign used was "left turn yield on green (symbolic green globe)". It improved driver understanding only in the permitted indication (green globe) whereas during overlap and protected indication it appeared to confuse drivers, a result also consistent with other studies (Hummer, Montgomery, and Sinha, 1990; see also Williams et al., 1992).

In addition to false yield responses, false go responses have also been observed. For example, Staplin and Fisk (1991) ran an experiment in which subjects were shown a series of still frames representing the approach to an intersection. Cars were positioned in the opposite lane of the intersection. Upon the onset of an auditory signal subjects had to press either the brake or accelerator pedal to indicate either a no go or go decision as a response to the depicted traffic signal and sign. Staplin and Fisk found that if the signal was a green globe the percentage of false go responses ranged from 13.1% to 30.4% for younger adults, and from 44% to 64% for older adults depending on the accompanying sign. For example, if a green globe was presented with the sign "left turn yield on green (symbolic green globe)", 13.1% of younger, but 44% of older adults indicated that it is safe to turn left. If the signal was a green globe and the sign was "protected left on green arrow" 30.4% of younger, but 64% of older adults made a false go response.

The reviewed results indicate that the presence of an auxiliary sign can help as well as impair driver understanding. Furthermore, it appears that understanding of the traffic signal and sign depends on whether both elements convey the same message. For example, in Staplin and Fisk's (1991) experiment, more errors were made when the green globe was accompanied by the sign "protected left on green arrow", than when the sign was "left turn yield on green (symbolic green globe)". Since the latter sign and signal both imply that the driver should yield if making a left turn, whereas the former sign and signal imply different actions (go and yield, respectively), drivers may respond correctly more often to the combination for green globe and "left turn yield on green (symbolic green globe)" sign than they do to the combination of a green globe and "protected left on green arrow" sign.

In an attempt to investigate the possible reasons for incorrect responses as well as to replicate the results of the previous studies we tested drivers under realistic driving conditions on a driving simulator. Drivers approached a 4-way signalized intersection and had to decide whether it is safe to turn left in the presence of oncoming traffic in the opposite lane of the given intersection. We expected that, in general, fewer errors would be made in our study compared to the reviewed studies because subjects could interact with and take into account approaching traffic when making a response. We further theorized that errors would vary with the degree of compatibility between the conveyed messages of the traffic signal and the sign. Thus, in conditions in which a protected left turn status is conveyed by the signal (i.e., a green arrow with or without a green globe), a compatible sign that conveys verbally the same status [e.g., "protected left on green arrow"] should allow better understanding than an incompatible sign that conveys a "yield" message [e.g., "left turn yield on green (symbolic green globe)"]. The possible errors drivers can make for those signal/sign combinations implying a protected left turn status are false yield responses. Conversely, in conditions in which a permitted left turn status is conveyed by the signal (i.e., green globe), a compatible sign that conveys verbally the same status [e.g., "left turn yield on green (symbolic green globe)"] should allow better understanding than an incompatible sign that conveys a "protected left turn" message. The possible errors drivers can make interpreting those signals which imply a permitted left turn status are false go responses. For combinations with a red globe or arrow no predictions can be made with respect to the compatibility between signal and sign, since no sign used referred to a red arrow or globe. However, we would expect that a red light indicates a yield or stop response and thus should benefit from a sign that implies a yield response.

Method

Subjects. 32 drivers were tested; 16 of which were between 20 to 32 years of age (average 23) and had at least four years of driving experience. The other 16 drivers were between the age of 63 and 84 (average 71). Subjects were reimbursed with $10 for each session in which they participated.

Subjects were tested on the two cognitive tests of the Wechsler Adult Intelligence Scale (1955), the digit span test and the vocabulary test. On average, older adults had a vocabulary score of 38.25 and a digit span score of 11.31; younger adults had an average vocabulary score of 37.38 and a digit span score of 12.31. These tests were used to ensure that both age groups had equivalent educational backgrounds. Older and younger adults did not differ significantly in both test scores as established by a tow-tailed t-test at $\alpha = 0.05$ ($t = 1.069$ for the vocabulary test, and $t = 1.54$ for the digit span test).

Apparatus. The driving simulator consisted of a sedan (Saturn) positioned in front of a screen. A virtual driving scenario was projected onto the screen using a Sony Multiscan Projector VPH-1272Q/1272QM, 1993©. The car was equipped with the usual devices installed in a car with an automatic gear shift. Steering wheel, brake and accelerator pedals, as well as the gear shifting stick, allowed realistic driving maneuvers. The scenarios were designed using a real-time 3D modeling environment (Designer's Workbench 3.1) developed by Coryphaeus Software, Inc. 1995©. Driving within a built scenario and interaction with other cars were accomplished using another software package developed by Monterey Technologies, Inc. 1995©.

Visual Database. One scenario consisted of four 4-way signalized intersections which were built continuously, one intersection after the other. There were two through lanes and one separate left-turn lane for the driver with a white stop line at the end of this lane. The length of the left turn lane was about 33.5 meters. The intersections were built according to MUTCD (Manual on Uniform Traffic Control Devices, 1988, 4b-12/4b-13) recommendations. One intersection was 31 meters across and 31 meters wide. The traffic signal was visible within a 40 degree visual angle from the position of the driver at the white stop line at a distance of 14.5 meters to the traffic light. The height of the lower part of the casing of the traffic signal was 4.9 meters with the sign positioned to its right.

The relevant traffic signals consisted of either a 2x3 signal head- (Signals 4, 6, and 8) or a 1x5 signal head (Signals 1, 2, 3, 5, and 7) arrangement as depicted in Figure 1. The size of the signal and signs differed from MUTCD recommendations in that they were bigger than real signs to allow for better legibility. Signs were legible at a distance of about 25 meters. The signals 1 to 8 were combined with each of the signs A to D depicted in Figure 1 resulting in 32 relevant combinations. Not shown are eight additional signal/sign combinations that were chosen as "fillers" to induce variation in the scenarios and to convey the impression of an "realistic driving" task, resulting in a total of 40 signalized intersections. "Fillers" included two additional signs, i.e., "left on arrow only" or "left turn not protected". All signs are currently in use in the United States. Signals in combination with signs D and B allowed us to compare directly the effects of compatibility between the signals and the sign. Sign A (no sign) represents a control condition in which only the effects of the shown signal are tested, whereas sign C, "left lane must turn left", allows us to assess the distracting effects of signs that do not relate to driver actions with respect to the depicted signal.

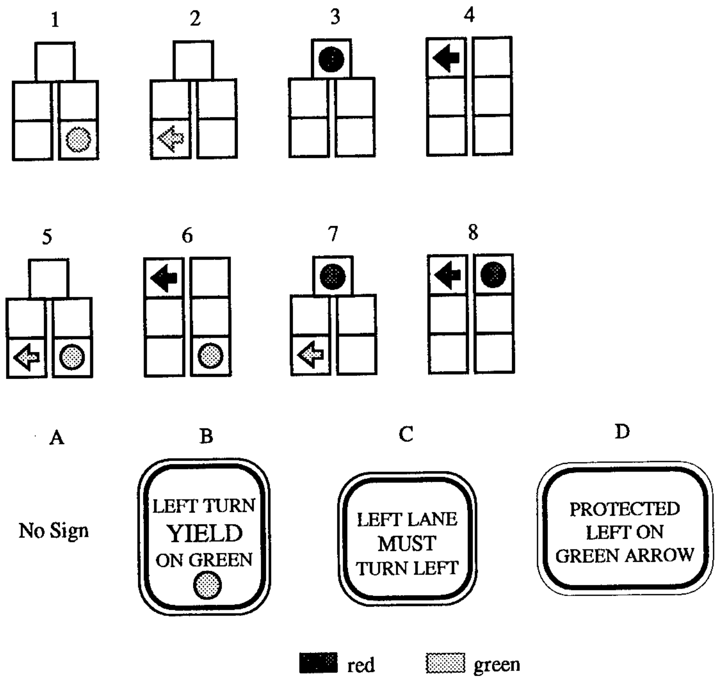

Figure 1: Signal (1-8) and signs (A, B, C, D). Each of the eight signals is combined with each of the signs. The dimensions are not drawn to scale.

Scenario Dynamics. Some of the signals included a red light (red globe and/or red arrow) which induced the driver to stop at the intersection. If the driver slowed down and continued to slowly approach the intersection the red light would change to a green light, i.e., a green arrow and/or a green globe. When the driver approached the intersection there was approaching traffic (2 to 4 cars) in the opposite lane for through traffic. The velocity of the approaching cars was set around 100% relative to that of the driver. Movement onset of the approaching cars was triggered at a distance of about 100 to 300 meters to the driver. At a certain distance (between 40 and 80 meters) from the intersection the approaching cars drove independently of the velocity of the driver and continued through the intersection or stopped at the traffic light depending on the traffic signal shown to the driver. If the driver was shown a protected left turn status (signal-sign combinations 2A-D, 5A-D, 7A-D) the approaching cars stopped at the intersection. If the driver saw a permitted left-turn status displayed by the traffic signal and sign (combinations 1A-D) the approaching cars proceeded to drive through the intersection. If the driver had to come to a stop because of a red light (red globe and/or red arrow) the approaching traffic stopped also. After the signal changed and the driver could continue, the approaching cars proceeded accordingly, i.e., dependent on the traffic signal status shown to the driver.

Design. Within a scenario the four intersections were arranged such that no signal or sign occurred twice in a row. Since there were 40 traffic signal and sign combinations, 10 scenarios were constructed. The order of the 10 scenarios presented to each subject within an age group was different.

Procedure. Before the experiment drivers were given instructions and familiarized with the driving simulator in two practice sessions. In the first practice session the driver sat on the passenger seat and the experimenter drove through one scenario to show the driver the dynamics of the car and to demonstrate steering and braking behavior. After that, the driver drove through one scenario in a second practice session. The practice scenarios consisted of four signalized intersections, however, no signals or signs were visible. The practice scenarios were otherwise identical to the experimental scenarios. Drivers were instructed to drive between 10 and 15 miles per hour (16 to 24 km/h) and to make no abrupt steering or braking movements to avoid potential simulator discomfort (e.g., dizziness, nausea). Controlled driving was emphasized.

Subsequent to the practice sessions the experiment began. The driver was informed that he/she would see a signalized intersection. There would be approaching traffic in the opposite lane of the intersection. Drivers were supposed to approach the intersection and turn into the left-turn lane. Their task was to turn left at the intersection if they thought it was safe to do so given the depicted traffic signal. To ensure that drivers read the sign they were informed at the beginning of the experiment that they would be given a sign comprehension test at the end of the study. If drivers decided it was safe to turn left they should turn across the intersection. If they decided it was not safe they should stop at the white stop line or yield at the intersection, and then continue the left turn when permitted either by changes in the traffic or by changes in the status of the traffic signal, finally driving to the next intersection. Drivers were further instructed to indicate verbally their decision by saying, for instance, "I have to yield" or "I can go". Drivers were informed that the other cars would drive according to traffic regulations. After four intersections, the driver stopped and took a break for about 2 minutes during which time the next scenario was loaded. After completing a pair of scenarios the driver could take a break of 5 minutes if he/she wished to do so. If drivers drove 15 miles per hour (24 km/h) they needed about 2 minutes to drive through the entire scenario. The entire experiment lasted about one hour.

Dependent Variables. A driver error was recorded if the driver falsely stopped (yielded) or falsely went through the intersection. Driver behavior (yield or stop vs. go) and errors were recorded manually. The velocity of the driver's car (meters/second) and the x, y, and z coordinates of the car were recorded at a frequency of 33 Hertz. The velocity data were analyzed over data points within a 2-second window before and after subjects passed the white stop line at the intersection to establish the validity of the manual coding procedure.

Results

Three older subjects canceled the experiment due to experienced nausea and were replaced. All drivers were able to give a correct definition of the used signs. A repeated measures ANOVA was computed over the velocity data with driver behavior (yield or stop vs. go) and age group (young vs. older adults) as factors. The velocity data are shown in Table 1. Depicted are the average velocities (in km/h) for correct responses. Subjects drove significantly slower when they correctly yielded than when they correctly drove through the intersection, $F(1,30)= 91.28$, $p < 0.001$, and older drivers, in general, drove slower than younger drivers, $F(1,30) = 65.32$, $p < 0.001$. The interaction between age and driver behavior was also significant, $F(1,30) = 37.29$, $p < 0.001$, indicating that the difference between yield and go responses was more pronounced for younger adults.

Table 1: Average velocity in km/h for correct go and correct yield responses. Velocity data are averaged over data points within a 2-second window before and after drivers passed the white stop line.

	Correct Yield	Correct Go	Total
Young	10.65	18.66	14.66
Old	9.46	11.22	10.34
All	10.05	14.94	

Pair-wise comparisons were made between the error percentages of selected signal and sign combinations. The selected test statistic was $z^* = (p_1-p_2)/[p(1-p)(1/m+1/n)]^{1/2}$, where p_1 and p_2 are the respective proportions and m and n the selected sample sizes. Parameter p is the pooled proportion value, $p = [(m/(m+n))p_1+(n/(m+n))p_2]$. The proportion differences were tested at $\alpha = 0.01$. Summary data are depicted in Table 2. The overall error rate was 3.9%. There were significantly more false yield than false go responses, $z^* = 6.99$. There was no age effect reflected by the error data, $z^* = 0.64$. The error data collected for the different traffic signal and sign combinations are depicted in Figure 2 for the "false yield" responses, and Figure 3 for "false go" responses. In Figures 2 and 3, the signal/sign combinations are depicted in a matrix-like arrangement. The number of the signal and the letter of the sign, as well as error percentages are depicted in the "cells". For signals displaying a protected left turn status Sign B (16.7%) produced significantly more "false yield" responses than sign D (4.2%), $z^* = 2.83$. Sign C (13.5%) produced significantly more false yield responses than no sign (sign A, 3.2%), $z^* = 2.61$ (see last row of Figure 2). No significant differences between the signs were obtained for "false go" responses (see last row of Figure 3).

Table 2: Error Percentages for false yield and false go responses for the different age groups.

	False Yield	False Go	Total
Young	9.89%	0.94%	4.3%
Old	8.85%	0.31%	3.5%
All	9.37%	0.62%	

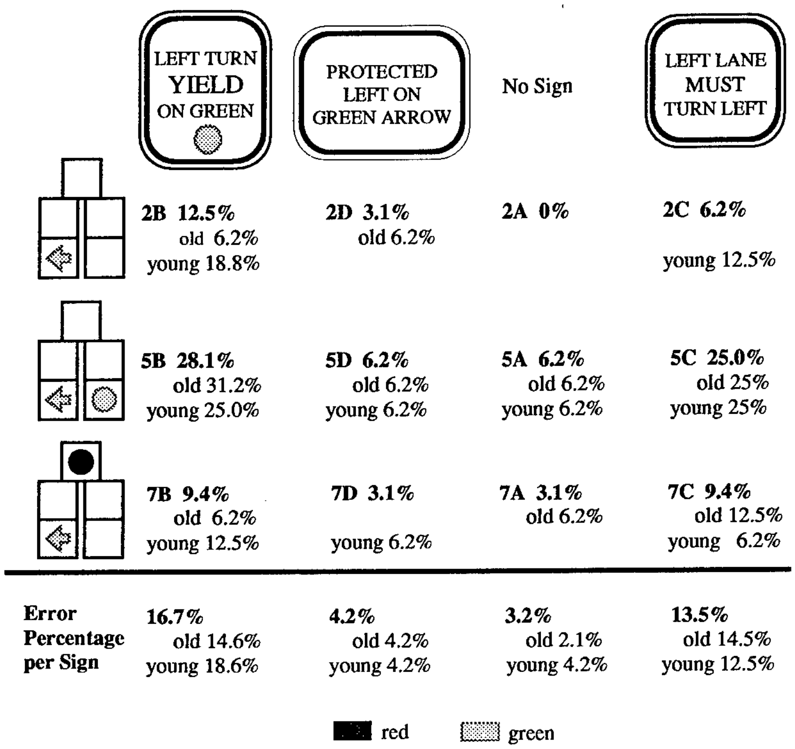

Figure 2: Percentage of false yield responses for signal and sign combinations for younger and older drivers. Each of the signals shown in the left column is paired with each of the signs in the first row. The respective signal/sign combinations and the percentage of errors are depicted in the "cells".

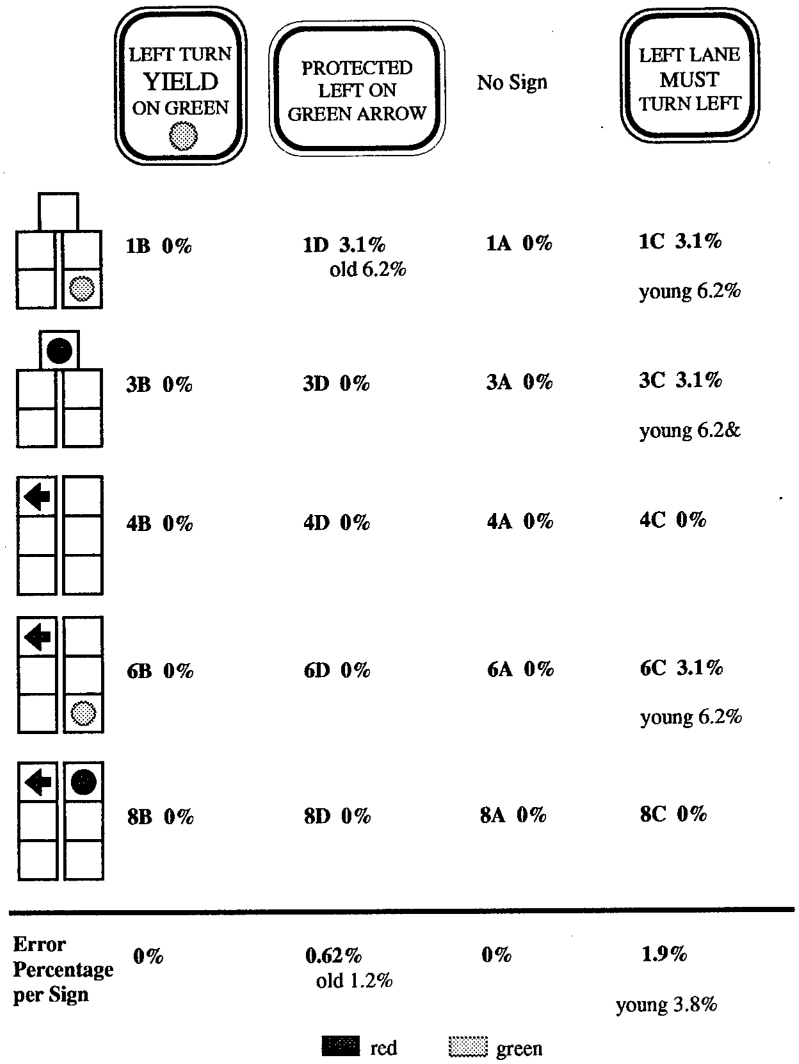

Figure 3: Percentage of false go responses for signal and sign combinations for younger and older adults. Each of the signals shown in the left column is paired with each of the signs in the first row. The respective signal/sign combinations and the percentage of errors are depicted in the "cells".

Discussion

The velocity data support the results of the manual coding procedure: Participants drove slower when they had to yield than when they drove through the intersection. The low overall error rate (3.9%) indicates that subjects understood the task well. Interestingly, no difference in errors between the age groups over false yield and false go responses (Table 2) was found. The low error rate indicates that subjects can make efficient use of the presence of and interaction with approaching traffic to respond to traffic signals. For a comparison, Staplin and Fisk (1991) obtained 22% and 23% false yield responses for younger and older adults, respectively, whereas the corresponding percentages were 9.89% and 8.85% in our study. Their percentage for false go responses was 24% and 46% for younger and older adults, whereas we obtained 0.94% and 0.31%, respectively. Although Staplin and Fisk's subjects saw approaching cars on the still frames of the upcoming intersection one might speculate that subjects might benefit from an even more realistic, that is dynamic, environment as in the current study.

Regarding a particular signal and sign combination, a closer look at the error rates for signal combinations with sign B and D over all drivers reveals that the error rates are consistent with the compatibility hypothesis described earlier in the introduction. As expected, for signals implying a protected left turn status (Figure 2) significantly more errors were produced when the sign implied a permitted left turn - all combinations in which both signal and sign imply a protected left turn status (2D, 5D, 7D) are related to lower error rates than combinations in which the sign implies a "yield" or permitted left turn status (2B, 5B, and 7B). For combinations implying a permitted left turn (Figure 3), errors occurred only in condition 1D (green globe combined with "protected left on green arrow"), and in combinations 1C, 3C and 6C. Note that no errors occurred with Sign A and B combinations. Since Sign B is compatible with a yield or stop response whereas sign D implies a go response, the result is consistent with the compatibility hypothesis, however, overall error rates are too low to allow reasonable conclusions.

The lowest error rate overall was found when no sign accompanied the signal (see last rows of Figures 2 and 3). This is also in agreement with the results by Bonneson and McCoy (1994) and Hummer et al. (1988). The data clearly indicate that in almost all cases participants benefited from the absence of a sign. An unexpected result was that significantly more errors were committed if sign C was presented with a signal than when no sign was presented with the protected left turn signals (Figure 2). Sign C did not relate to the status of the traffic signal, however, almost as many errors were produced for combination 5C as for 5B which produced the highest error rates for a particular signal/sign combination. It appears that if the meaning of the sign does not directly correspond to the meaning of the signal, its presence is harmful for interpreting the signal.

Conclusions

The following conclusions can be drawn from the above study:

- False go responses are potentially much more serious than false yield errors. Since no false go responses were made when the sign was "left turn yield on green (symbolic green globe)" it can be concluded that this sign is beneficial if used with a green globe by itself.
- If a protected left turn status is conveyed by the signal, the sign should state so explicitly, too. Thus, a green arrow by itself can be accompanied by the sign "protected left on green arrow".
- In the case that both signals occur alternately, the use of variable message sign technology seems obvious: If the signal is a green arrow the sign should convey a "protected" left turn status; if the signal is a green globe it could convey a "yield" status.

- If a protected left turn is conveyed by the signal in combination with a permitted left turn (green arrow and green globe), the sign should not emphasize a "yield" message, i.e., the sign should not be "left turn yield on green (symbolic green globe)". A great many false yield errors were obtained if this combination was used (Figure 2, combination 5B). False yield responses might lead to an increased risk of rear-end collisions; and
- Since all signals were best interpreted when no sign was present it can be concluded that the absence of a sign helps driver understanding. This was also supported by the fact that sign C which did not relate to the status of the signal was associated with many errors.

Acknowledgments

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Validation of an Economical Fast Method to Evaluate Situation Specific Parameters of Traffic Safety

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The need for efficient simulators for training and investigating complex and especially risky tasks is obvious. Accordingly simulators for as diverse tasks as flying a plane, driving a car, flight control and operating nuclear reactors have been developed. While the benefits of simulator training are easy to see, for instance, dangerous situations can be trained without any risk for personnel of machinery, the question how valid a simulation is, that is, how similar is the behavior in the simulator to the behavior in real-life situations quite often is left open or only answered by appealing to the obvious simularity in the layout of instruments plus the physical characteristics of controls and the realism of the depictured visual scene. Especially, the lacking degree of realism in computer generated visual scenes has been criticized: the lack of non-geometric perspective cues as haze or blue-shift, the unnatural regularity of buildings, the crispness of contures, and, in general, the lack of realistic clutter starting from pedestrians on seemingly random courses to debris and discolorations of the surfaces. This situation has led to the development of video-simulators (2D and 3D) at the Experimental Applied Psychology Unit at the University of Regensburg, among others (for an overview, especially for research in the US, see MacAdam, 1993); in this simulation methodology videos from real traffic scenes are used.

The simulator developed in the Experimental Applied Psychology Unit at the University in Regensburg consists of a BMW limousine, where all the controls and displays are linked to a computer, and a video projector producing for the driver a visual scene with a visual angle of about 45°. It is obvious, that such a kind of simulation is sensitive only to the skills on the basic level of Janssen´s (1979) hierarchy of the driving task (van der Molen & Bötticher, 1988): Subjects can accelerate and decelerate the speed of the video, and steering control can be simulated by keeping a target in the middle of the lane. Even on this level the task is not as interactive as in full fledged computer simulations because deceleration and acceleration influence not only the simulated car in relation to the stable environment but also influences all other moving objects in the video. Despite these draw-backs, the advantage of video simulation lies in the realism of the depicted scenes. In our experiments we were especially interested in drivers´ speeding behavior, for the adjusted speed is the main cause of traffic car accidents.

In order to determine the validity of this simulation technique the correspondences with real-life driving have been determined on three different levels corresponding to three separable research questions:

(i) Do individually different driving styles induce a corresponding regulation of velocity in the simulation and in the real-life driving?

(ii) Do different driving tasks (velocity maintenance vs. self paced driving) lead to the same effects in those situations? and

(iii) Do corresponding situations in the video and in the real world give rise to the same pattern of acceleration or deceleration?

Additionally, subjective evaluations of both tasks have been elicited with questionnaires in order to check if they are rated in such a different way that the experiences cannot be compared.

Method

The general experimental plan is shown in Table 1.

Table 1:

TASK	SEX	FIRST CONDITION
speed maintenance	female	real life driving style
		simulatordriving style
	male	real life driving style
		simulator driving style
free driving	female	real life driving style
		simulator driving style
	male	real life driving style
		simulator driving style

Additionally, in a questionnaire data about the subjects´ driving style were obtained. As in Assmann (1985) nearly all variance could be attributed to three factors, namely,

Factor 1: following the traffic flow,

Factor 2: attitudes towards car driving, and

Factor 3: judging once own driving ability.

Using factor scores to classify subjects it was possible to determine the influence of the driving style in the two experimental situations.

Table 2 gives an overview over the route used in the experiments; numbers indicate the corresponding situations. In order to determine if accidental influences in the real-life driving influence the choice of velocity any of the following observations were timecoded: oncoming traffic, following traffic, slow traffic ahead, passing or being passed, cyclists on the lane, pedestrians on the lane or immediately beside the lane, and children close to the road. The real-life driving was done in a BMW 730i with an automatic transmission. During the field experiment all the relevant driving parameters were entered into an on-board computer.

Table 2:

#	Traffic situation or road section respectively	Speed limit	Description
1	Segment of a county road	60 km/h	straight, flat
2	Entering a village with a reduced speed zone (Oberisling)	60 km/h 30 km/h	slightly curved, incline
3	Passage through a reduced speed zone (Oberisling)	30 km/h	slight decline, straight ahead
4	Leaving the reduced speed zone (Oberisling)	30 km/h 60 km/h	right turn, approximately 60°
5	Entering the reduced speed zone (Leoprechting)	60 km/h 30 km/h	straight ahead, flat
6	Leaving the reduced speed zone (Leoprechting)	30 km/h 60 km/h	straight ahead, flat
7	Entering the reduced speed zone (Graß)	60 km/h 30 km/h	straight ahead, priority of the turning road
8	First T-intersection in Graß (without traffic signs)	30 km/h	90°-turn to the right, with right of the way
9	Second T-intersection in Graß (Sign:"yield")	30 km/h	90°-turn to the right, while respecting the „yield" sign
10	Free lane road	60 km/h 50 km/h	straight ahead, slight decline
11	„Sleeping policemen" with following cross-walk for pedestrians	30 km/h	straight ahead, slight decline
12	„Sleeping policemen"	30 km/h	straight ahead, slight decline
13	Connecting road	30 km/h	straight ahead, slight decline

52 subjects participated in the experiment, 26 female and 26 male, in the age range from 19 to 26 years (mean 24,1 years). Subjects had their driving licences between 1.8 and 11.8 years (mean 6 years). 26 of the subjects were driving more than 10 000 km/year, 26 less. Half of the subjects have had experience with an automatic transmission. Subjects got a fee of 15 DM. Two subjects missed either the simulator or the real-life driving situation, therefore their data could not be used in the comparison of the corresponding behavior.

The simulator consists of a BMW 325i, where by means of the above-described projection technique driving can be simulated. Figure 1 shows what has been simulated for the speed regulation and what variables have been skipped.

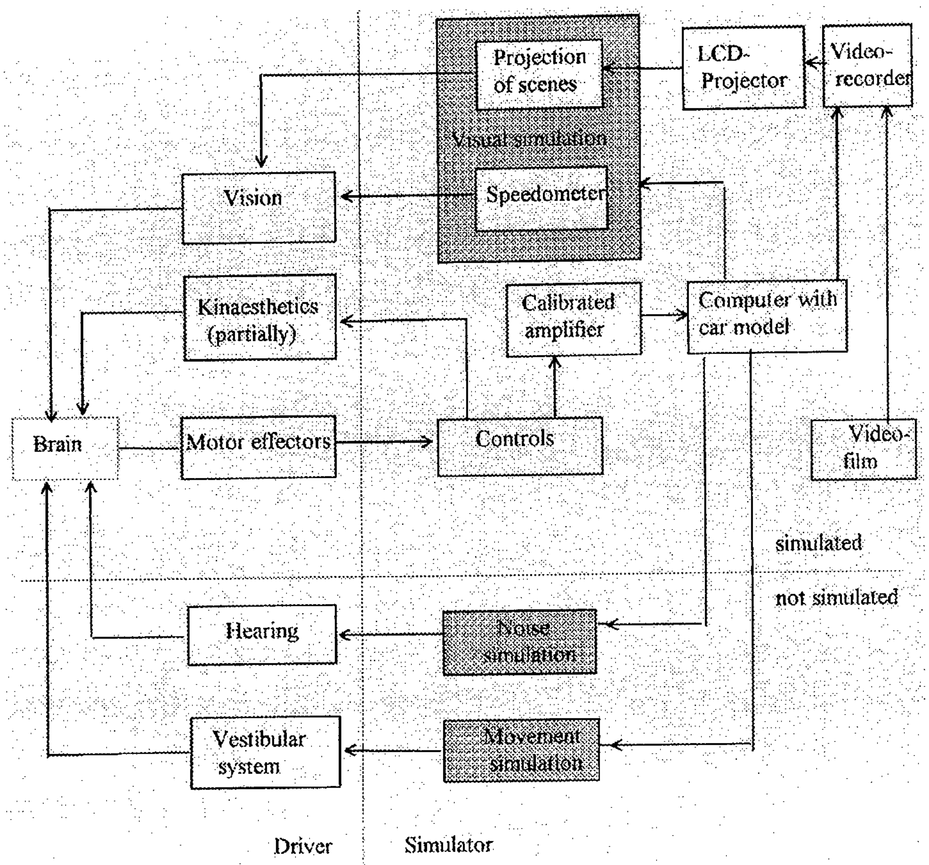

Figure 1: Influence diagram of the driver-simulator system

During simulation a virtual velocity is shown on the speedometer in the car. In order to influence the speed of the video realistically, the pressure on the effectors in the car (brakes and accelerator) are fed into a computer where by means of a formal car model the virtual speed is determined according to the following formula:

$$v_{psd} = \int_{t_0}^{t_f} (u^2*(g - b/u) - u*v_{psd}*y)dt$$

u	$= 1 - (v_{psd} / v_{max})$	acceleration depending on the given velocity
g	$= g_0 * 1{,}5$	pressure on the accelerator
b	$= b_0 * 4{,}0$	pressure on the brake
y	$= y_0 * 0{,}15 = 0{,}0\ 03$	rolling and air resistance

Due to the fact that the available videorecorder (Panasonic AG 7330) can not increase and decrease continually the following relation between the virtual velocity as shown on the speedometer and the projection velocity is as in Figure 2.

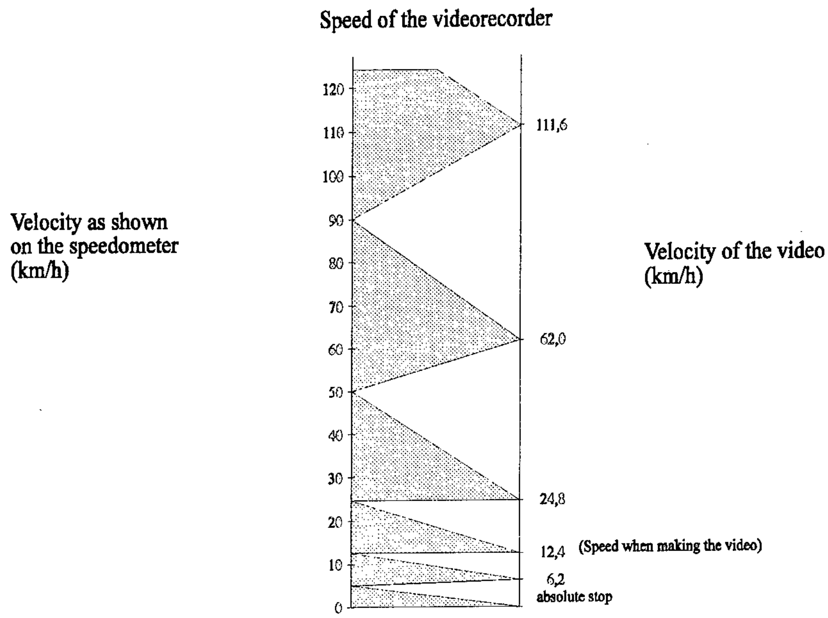

Figure 2: Relation between pseudospeed and recorder speed

Results

In general, subjects regard driving in real-life situations as easier (median answer: „easy“) than in the simulator (median answer: „rather diffucult“). Furthermore, the simulator driving is regarded as needing more attention. Despite these differences, subjects when asked if the simulator influences their driving behavior, describe this influence as negligable (modal answer: „slightly if at all“). For this reason it can be assumed that the driving experience is comparable for both the field and the simulator.

Three analyses of variance regarding driving styles with the factor scores of the questionnaire on driving styles as the dependent variable, reveal no significant differences between real-life driving and simulator-driving with one exception: There is an interaction between the values of the factor 1 („going with the traffic flow“) and the driving situation. The Scheffé-Test reveals that subjects who „go with the flow“ increase the speed in the simulator in contrast to the subjects with negative factor scores who drive faster in the real-life situation.

An analysis of variance of the task („speed maintenance“ vs. self-paced driving) shows significant main effects for the speed maxima and the average speed. The task „speed maintenance" induces slower driving (53,5 km/h) with less variance (1,62) than self-paced driving (67,8 km/h and 2,71 respectively) but no significant interaction with the driving situation (real-life vs. simulator). Furthermore, there is no significant influence of sex on the velocity regulation.

Figure 3 shows the variability of velocity during one test drive.

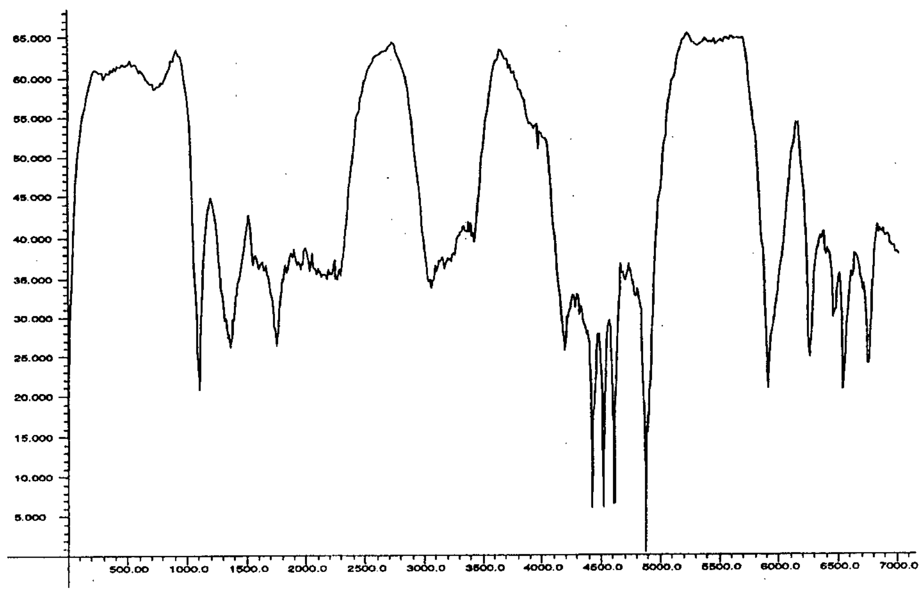

Figure 3: Curve of the driven speed in real-life driving (subject female, 21 years old with the task „speed maintenance") in relation to the position on the driving course.

Figure 4 shows the corresponding curve for the simulator condition.

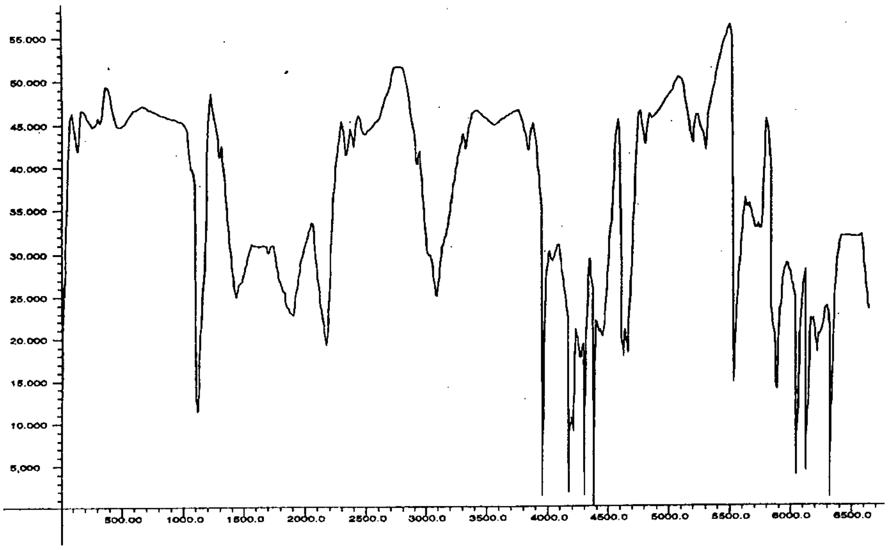

Figure 4: Curve of driven speed in the simulator in relation to the driven course.

If one determines the average maximal velocity for the 13 situations (see Table 2) the following curves for real-life driving (upper curve) and simulator driving (lower curve) result (see Figure 5)

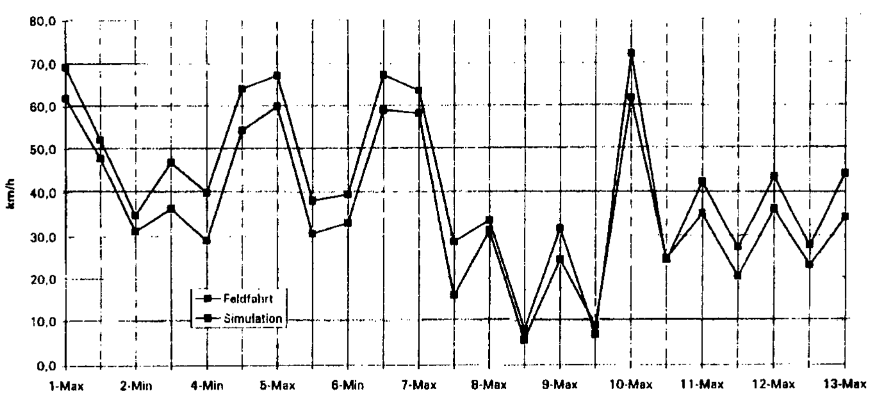

Figure 5: Mean values of the maximal velocities for the 13 situations

For all 13 situations (see Table 2) and all subjects the data for the real-life driving and for the simulator driving results of the scattergram in Figure 6.

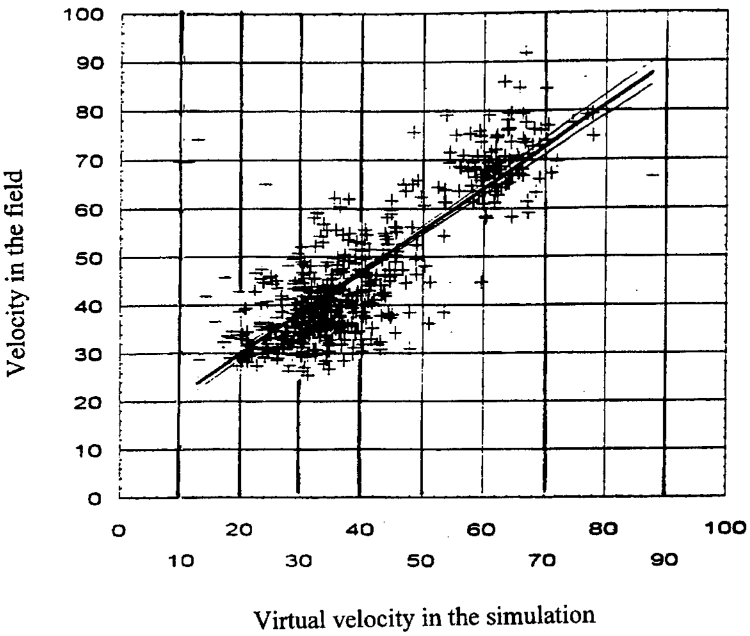

*Figure 6: Scattergram of driven velocities per situation in real-life driving and in simulator driving for all subjects (r = .7158; Regression (real-life) speed = 12.983 + .852 * simulatorspeed*

If one reduces the noise and uses only the mean velocities for the 13 situations the scattergram of Figure 7 results.

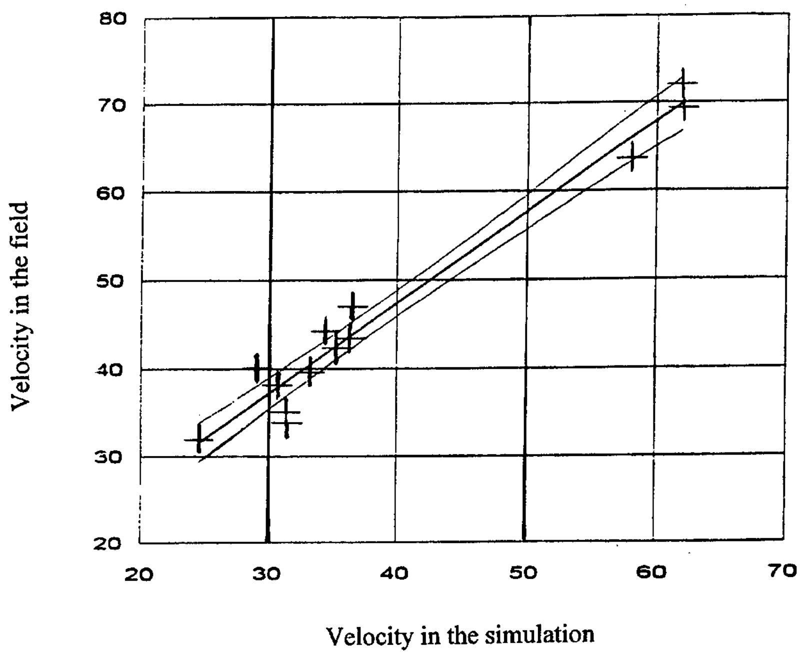

*Figure 7: Real-life driving velocities vs. simulator driving velocities (r = .982; Regression: (real-life) speed = 6.48 + 1.02 * simulatorspeed)*

Discussion

The data from the questionnaire where the subjects describe their experiences in the real-life driving situation and the simulator situation reveal that both situations are regarded as equally interesting and not influencing ones´ driving behavior. However, driving in the simulator is regarded as more difficult and requiring more attention. The reason for this might be that the simulator situation is novel and that the velocities in the simulator are not changed continuously but in steps. The fact that driving in the simulator is experienced as difficult and requiring special attention indicates that the motivation of the subjects is high even in the simulator situation. That is, when driving in the simulator subjects tried to exhibit „normal" driving behavior. This can be seen not only from the subjective reports but also from the fact that the observed driving style does not influence the driving in the two situations differently except for the interaction between „going with the flow" and average speed regulation, but also this influence is very slight. The conclusion can be drawn that in the two situations there is no differentiating influence of driving attituedes on the real-live vs. simulator driving.

Most important for the validation of the simulator are the situation dependent correlations of situation specific velocities in the simulator and in the real-life situation. Accelerating and decelerating behavior in real-life and simulator driving correspond nearly perfectly. The main influence on the driving behavior are the situational characteristics independently from the fact whether subjects experience real-life driving or simulator driving.

If one analyzes the individual correlations between the simulator data and the real-life data for the 13 situations, it turns out that only 4 subjects show correlations less than .5 but more than 75 % of the subjects show correlations above .85. The effect that the regression coefficient does not differ significantly from 1 shows that there is nearly a one-to-one correspondence between the driving behavior in real-life and in the simulator, only the additive constant of about 6 km/h shows the influence of a „tunnel effect" in the simulator.

Conclusion

Standard approaches for estimating the validity of measures start from the theoretical assumption that the „true validity" only depends on the correlation between the „true values" in the measure and the „true values" in the criterion. These „true values" cannot be measured directly and are practically always confounded with the covariation of systematic errors. For these reasons the selection of situations, measures etc. has to be planned exactly: For instance, in the case of the evaluation of our video simulator it was not important that *individual* characteristics of drivers („speeding" vs. „dawdling" etc.) show in both situations but that the same *situational* factors elicit corresponding kinds of behavior, that is, for validating a simulator aimed at the improvement of traffic conditions the decisive carrier of information is not the *individual driver* but the *specific situation*. Generalizability of results therefore depends on the representativity of the situations. Insofar the video simulator can be regarded as a valid system for determinating situational characteristics of traffic safety.

Since finishing this field and simulator study the video simulator has been further improved, (i) it is now possible to increase and decrease the projection velocity continually, (ii) steering control can be simulated additionally by shifting the video picture to the left or right in accordance with a computerbased model of steering.

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New Multimedia Components Inside a Car-Cockpit

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Abstract

Modern cars will be equipped with an increasing number of complex technical systems. Many of these systems require the driver to interact. Such an interaction is a process of controlling the subsystems and taking its response into account reading a display. The more subsystems will be integrated into a car, the more control devices and displays have to be placed in a car-cockpit. In the paper a variety of multifunction controls are described, that can be used together with screen displays for multipurpose input/output for automotive communication. Experiences are included. A resume is given for known as well as novel control concepts

Introduction

The development of modern automobiles leads to more and more complex technical systems. Vehicles are equipped with more sophisticated systems onboard. Traditional modules in a car will be electrically controlled (windows, sunroofs, convertible roofs etc.). All these systems require controls to operate them and in many cases displays to inform the driver about their state of operation (door locking state, radio frequency, accessibility of a cellular telephone channel etc.). CAN Bus and other digital busses are used in the electrical automotive system. They are capable of reducing the increasing number of discrete controls as well as the increasing cost and effort of wiring. Ultimately the vehicle will be a "drive-by-wire" system with less mechanical parts with even steering wheels, switches to operate the headlights or direction indicators replaced by computers and integrated controls.

The operation of traditional and more recent onboard systems using discrete mechanical controls may no longer be feasible because spatial restrictions and operational shortcomings as well as marginal designs with respect to Human Factors aspects are concerned. Considerations to use these controls not only in the vehicle standing still but also during operation do even increase difficulties designing a control concept for a modern automobile.

Future Car-Cockpits

Flat screens are increasingly installed as multifunction displays in cars. Presently they are mainly used as front ends for dedicated components, mostly for automobile navigation systems. The potential for flat screens as a modern user interface for automobiles can only be fully explored when the screen will be used as a universal front end for a larger number of electronically operated automotive subsystems (car radio, air conditioning, on board computer, telephone and functions to comfort the driver and the passengers). One or more flat screen displays in connection with a carefully designed concept of control devices will be capable to replace dedicated traditional controls by a multifunctional, flexible, and powerful Human Engineered automotive cockpit.

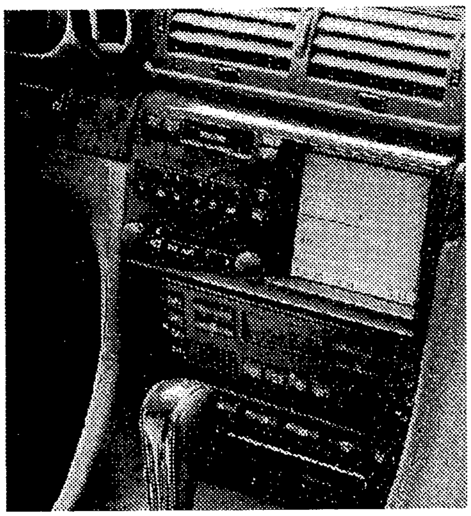

Figure 1: The BMW navigation system

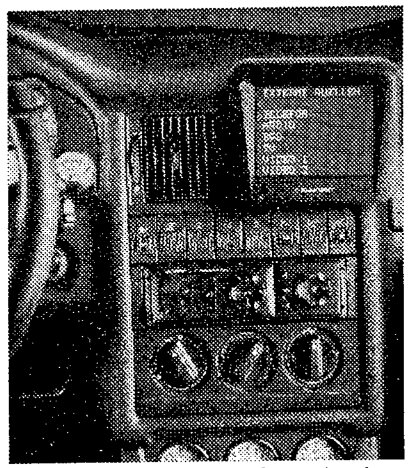

Figure 2: The Blaupunkt navigation system

New displays and controls require space in the automotive cockpit. Especially smaller modern cars offer even less cockpit space than more traditional designs. Especially scarce is the space for displays in the so called secondary field of vision. This field is located in the central dashboard area behind the steering wheel. It will be called secondary field of vision because the driver mainly monitors traffic conditions outside the vehicle through the front window, the true primary field of vision. The secondary filed of vision refers to the cockpit area that the driver can monitor safely while the vehicle is in motion. This area of the cockpit accommodates speedometer and other important displays crucial to the function of the automobile. Tertiary space is available in the center console, mostly next to the dashboard controls and displays. The ever increasing number and complexity of automotive systems require more display space, especially in the secondary field of viewing area. The adjacent controls must be installed in those areas of the cockpit as closely related to the displays as possible. The position called primary control space is in the steering wheel (or in the future position of the main steering device, which may be a displacement side stick mounted in an arm rest to be reached at ease by the driver). The secondary display area is practically unreachable for the driver because it is obscured by the steering wheel. Even in a future automobile this space will not be part of the secondary control and reach area because restraining harness systems will hinder the operator to access that area easily. The tertiary visual range is really the secondary control area, that is the space in the middle console. It is quite obvious that major automotive systems will be operated using controls in the primary reach area and correspond to displays in the primary or secondary display space.

The described space restrictions make it evident that it is not feasible to increase the number of discrete controls and displays in a car. Integration of controls and displays is a vital interest for both the manufacturers and the users of modern automobiles. Yet the integration has implications from the technical side (aspects of production, installation, maintenance, and safety of operation), operability (function and ease of operation, adequate night design, gerontotechnical aspects), and acceptance by the customer (Human Factors concept, self explaining user interface, little instruction effort required).

Thus an integrated concept for an advanced control and display system is required. Such a concept will have to include multisensory aspects for such an Input/Output system. Human senses such as the visual channel, the auditory system, speech, and the haptic/proprioceptive capabilities should be included. The visual and the auditory senses lend themselves for display purposes, the speech and haptic as well as proprioceptive channels can both be used controlling automotive components and systems. An integrated concept is far beyond the scope of this paper.

Multipurpose Input/Output for Automotive Communication

In the experimental study on which this paper is based a number of control devices were selected and tested to control an automotive subsystem similar to a car navigation system but not restricted to the functions of such a system.

Speech input and acoustic output alone were not considered because of the complexity of the task. Yet, such an approach is very appealing to operate a cellular phone in a car or other dedicated subsystems of comparable complexity. In this application there is a need to input single commands. Phone operation requires only 15 different commands for comfortable operation. For a navigation system, the acoustic system for information input is not flexible enough. Moreover, the acoustic systems may not always work properly if it is very noisy during speech input. Acoustic output alone with no visual display involved may also unacceptably restrict communication.

Existing navigation systems in automobiles use different approaches for the Human Machine Interface. Mercedes Benz (Figure 4), for example, uses function keys next to the screen. The BMW systems uses a twist button (Figure 1), and the Blaupunkt navigation systems (Figure 2) are controlled with a so called four way module. Some products can be mounted as add ons, not being integrated in the dashboard thus facilitating later installation in older cars. All designs require hand and arm movements towards the screen, use cockpit space in the secondary control area respectively in the tertiary display space.

Control Devices for Use in a Car

In the following chapter, control devices for mechanical information input using haptic/proprioceptive senses will be described and compared. They are always referred to as input devices in combination with a flat screen display that requires interaction such as moving a cursor around or selecting from a screen menu.

There are four main groups of such devices: first there are touch-screens and touch-pads with or without function-keys next to the screen. The next group are rotating knobs or switches, also called twist systems. The third group are the so called pressure systems generating inputs by pressing on a control device surface. The fourth group are four-way-switches, a device called EN-Joy device and trackball systems.

A touch-screen (Figure 3) is basically an overlay mounted in front of the screen. The user touches the screen on the desired location. There are three different kinds of touch-screens: The capacitance screen is based on a glass plat with a layer of conductive transparent material. Because of the capacity of the human hand touching the screen, the capacity between the sensors on the layer will change. The infrared touch-screen works with IR- photoelectric barriers witch are arranged in a horizontal and vertical position on the edges of the screen. A hand touching the screen interrupts at least one x- and one y-ray of light. A controller locates the position. The resistive touch-panel is also based on two transparent layers. In contrast to the capacitance technology, resistance between the layers changes under pressure.

A touch-pad does not work in front of a display like the touch-screen. The Versa touch-pad, for example, detects the touch position using two semiconductor layers. One layer records the x-position, the other one the y-position. Touching the surface changes the resistance between the two layers. It is also possible to register the intensity of the touch. This allows data input in a "third dimension". There is also a capacitance touch-panel that works like a capacitance touch-screen, yet it is not transparent.

Function keys, used for example with the Mercedes-Benz navigation system, are mechanical switches mounted next to the screen. They are used as multifunction keys. Their present functions will be displayed on screen. They cannot be used for analog control.

Twist systems or rotating knobs can be distinguished by three different physical effects. The paddle-system (Figure 5) transfers it's position to the computer changing the resistance between two conductors. It has been used as controller for the first video games. Paddles are analogous devices. Their resistance tends to change with time. For this reason they cannot be used for precision input. An additional problem is the missing operator feedback.

Mechanical Incremental Resolvers (Figure 6) produce two digital impulses when being rotated. The direction of the spin can be determined through the chronological order of both output signals. The advantage of the mechanical devices is that they do not need much space. Yet, they tend to wear out when used frequently.

Optical Incremental Systems (Figure 7) produce the same output as the mechanical devices. They need a small tension and a little more space. The big advantage is, that they have nearly no attrition. The output is produced by a light barrier.

Pressure systems (Figure 8) are based on two different physical effects: the Hall effect and the Force Sensing Resistor (FSR). Combining four such sensors, a position sensing system can be realized.

Four-way-switches belong to the group to multidimensional sensors. They are applied to adjust outside mirrors in a car. Blaupunkt uses them in their navigation systems as well. The technical principle is based on a button, that actuates four or more switches.

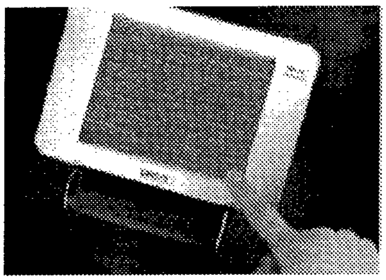

Figure 3: The touch-screen

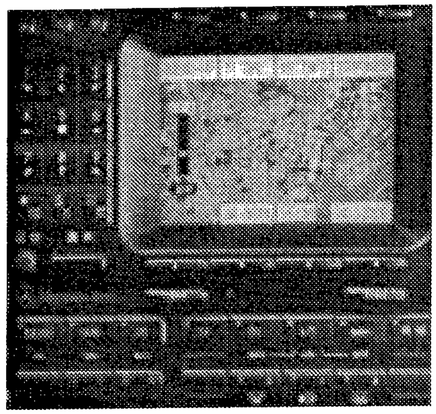

Figure 4: Function keys

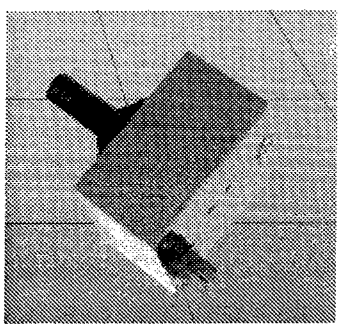

Figure 5: paddle system

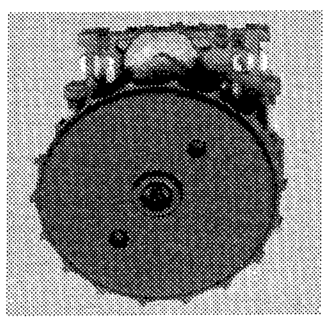

Figure 6: mechanical incremental system

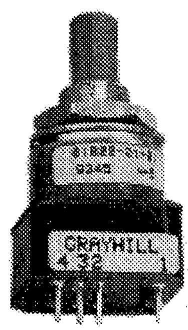

Figure 7: optical incremental systems

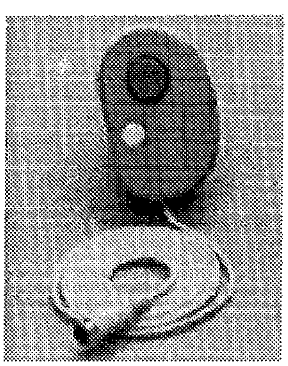

Figure 8: hall sensor

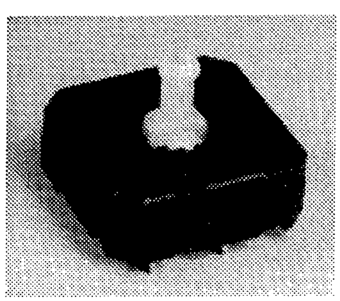

Figure 9:four-way-switch

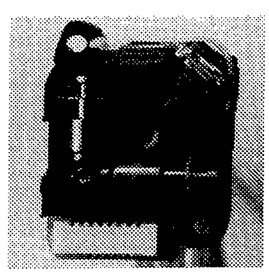

Figure 10: Trackball

The EN-Joy element, also known as the Stick Switch from Matsushita (Figure 9), is a device that accommodates different elements in one system. It consists of a mechanical incremental system, a confirmation button and a four-way-switch.

A trackball (Figure 10) uses a sphere rotating in all directions. The sphere drives two rollers, one to measure the motion of the sphere in one direction, the x-position, one to take the y-position. Photoelectric barriers measure the spin-information and turn them, with the help from a controller, into orientation signals.

The Joy-Three-Dim device is a small joystick accommodating x-, y- inputs plus a z- coordinate when moved up and down as well as an angular information when rotated. It is available as a prototype and can be moved with thumb and forefinger when installed in a steering wheel.

Based on the construction size and the function range, elements like the Interlink Pointing device, the FID from Fujitsu and the GHImouse enable efficient input strategies. These devices also include mirror operation in cars. If equipped with noticeable switching points these device have a wide range of automotive applications.

Experiences

The before mentioned control devices where all installed in an experimental setup similar to a car cockpit. The experimental task was to operate a subsystem similar to a car navigation system which was simulated on a computer controlled screen. A cursor had to be precisely positioned on the screen and menu items had to be selected. The experiments were not conducted and evaluated following a strict experimental design. The task chosen could not be standardized at this early point in the development in integrated control in a vehicle. The primary aim was no direct ranking of the different products but a clearer understanding of their pros and cons with respect to a task similar to the task chosen. A quantitative ranking of the different control setups did not seem to make sense

Some input elements, like switches, have a mechanical feedback (switching point). This allows the user to make inputs without a direct optical control. So he can devote his visual attention to the traffic. Most of the analog elements do not produce noticeable control response. It was difficult to realize whether an appropriate input action was taken. This effect makes it particularly difficult to use such control devices while the car is moving. This disadvantage could be in part compensated by allowing to use the full range of the functions only when the car was not in motion. With the car moving the available input functions should be reduced. User friendly control devices, such as touch screens could lose their importance in the future. The reason is that screen displays could be installed in the secondary vision range replacing the speedometer.

Certainly those multidimensional sensors will be in demand, which can be integrated in the steering wheel. A device with many functions as the joy-three-dim lead to problems during operation. Most car owners may not be prepared to work with such a complicated device. A four dimensional device will require precise instruction before use to avoid wrong input. Pointing devices could do more than just mirror adjustments. They are user friendly and easy to apply.

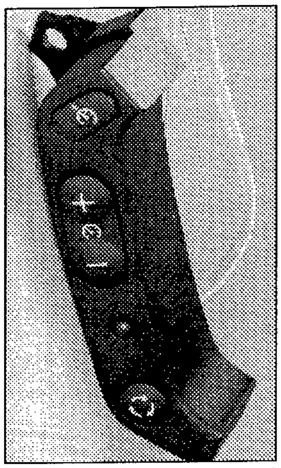

Figure 11: push trackball

The push trackball is a patented trackball system (Ohler, 1997). The push trackball was installed in the control section a normal steering wheel (Figure 11). In the figure the push trackball is installed as the small sphere in the second location from the bottom. It works much like a normal trackball when operated by the driver's thumb. The system works as a zero-order or position system. That means, that the screen cursor will move when the track ball is rotated and stand still as soon as the trackball is halted. The only difference is a switching function built into the device. Pressing the ball down is like pressing a confirmation button. The push trackball will then send a signal to the controller. Though a bigger push trackball could be installed in the middle console, the miniaturized push trackball in the steering wheel was accepted and worked very well. The prototype showed little haptic feedback to the driver. A later version should be built that has a noticeable stepping effect when rotated. Another version of the trackball was tried out. This trackball only works in two directions, up-down and left-right. Such a system gives less flexibility but may sometimes prevent wrong inputs.

Conclusions

Dependent on different applications, users found numerous the pros and cons using different input devices in an experimental setup similar to operating a car navigation system. Systems installed in the steering wheel, that is in the primary control range, may have advantages over devices installed elsewhere. Screen displays for multifunctional use in a car will probably be mounted in the dashboard, in the secondary visual range. Input systems with many degrees of freedom can induce input errors due to complicated mode of operation and lack of instruction or experience on the driver's side. A two dimensional device such as the push trackball is easy to learn and use, the push function is acceptable and effective to be used as confirmation. Devices with no proprioceptive feedback seem to be less acceptable. Controls with no clear haptic characteristics such as a missing feedback during operation are less favored. Combining more than one input technology can be a great help but was not tested. One possible solution is a combination of speech-input and the push-trackball. In this case the trackball will be used to interact on the map which is displayed on the screen, while the speech-input can be used for commands.

Complex interaction should be conducted while the vehicle stands still. Yet, there is a chance of safe interaction while the vehicle is in motion if a control device is installed in the primary control range being operable with a finger while the hand is securely rested. A multifunctional control strategy can be established to control a wide variety of on-board systems if connected properly to a multifunctional screen display and an efficient optimized Human-Machine-Interface.

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Bedienelemente zur Menüorientierung und –steuerung auf einem Bildschirm im Kraftfahrzeug

Diplomarbeit, Fachhochschule Bochum, University of Applied Sciences, Bochum, Germany

Changing Attitudes of Speed-Limit Offenders Using a Multimedia Programme

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Abstract

The Traffic Research Centre developed, in co-operation with digiTAAL inc., an interactive multi-media computerprogramme to change speed-limit offenders' attitudes with respect to speeding. The computer programme is meant to be used during speed controls; the offender may be remitted a part of the fine by completing the programme. Objective of the programme is to make speeders aware of the negative implications of their behaviour and to change their attitude negatively towards offending speed limits. To attain this goal, offenders are confronted with possible negative consequences of their behaviour while their arguments for speeding are refuted, using small video-clips, demonstrations of counter-arguments and short verbal stories. The effects of this multi-media programme were studied in a laboratory evaluation, in terms of knowledge and attitudes, compared with two information conditions, a general leaflet about traffic, and a specific leaflet about speeding. One week after participation in the study subjects were sent a questionnaire again, to measure whether changes in knowledge and attitudes were retained afterwards. It appeared that the general attitude towards speeding was changed most in the multi-media programme condition, subjects became more negative towards offending speed limits and various related aspects. The specific speeding leaflet appeared to influence the attitude towards driving fun positively and obeying traffic rules negatively, which are unwanted directions. With regard to knowledge of speeding and its consequences the computer programme did not do better than the other conditions. However, the subjects considered the programme more impressive than the leaflet conditions and indicated that they would consent to participate when being stopped in real speeding conditions.

Introduction

In assignment of the Regional Traffic Safety Council Groningen (ROG) and the Ministerial department of Waterworks and Road Maintenance (RWS) the Centre for Environmental and Traffic Psychology developed together with digiTAAL inc. a multi-media computer programme for driving speed enforcement by police and justice. Drivers who violate the speed limit are halted and can choose between the normal fine or participating in the programme and a reduced fine. Firstly this paper will summarise the social-psychological models that are the basis for the programme. Secondly, an experiment will be described that evaluated the programme in terms of its ability to change an attitude towards speeding in a laboratory set-up, compared with more traditional leaflets. The paper will be finished with some conclusions and recommendations.

Behavioural change with multi-media - a social-psychological perspective

A literature review was done to find out to what extent multi-media applications may teach a different driving speed choice (De Rooij, Wierda, Rooijers & Steyvers, 1994). It appeared that nothing was found, and this did not change since then. There are, howerver, other ways to change traffic behaviour, and there are other behavioural goals that were subject to change by multi-media applications. Concerning traffic behaviour it appeared that driver improvement courses do not (immediately) change the behaviour of problem drivers, because 1) it is difficult to identify these drivers (Veling, 1986), and 2) the driver improvement programmes evaluated had serious flaws (Kaestner, 1981). These flaws are: the programmes are far and foremost verbal, whereas the goal behaviour is sensory-motoric, only attitude was the most important goal, thus underestimating external factors, accident involvement is not a personality trait, there were no controls for experimenter effects of placebo effects, and although a large attitude change was established, there was no change in behaviour. In spite of this, attempting to influence behaviour by influencing attitude is the only way to try to establish a "change from within", since other and proven more effective methods are politically, technically and/or financially unviable. Heavy enforcement and fining campaigns may also bring about a behavioural change , but this is not "from within", and will end as soon as the campaigns come to an end (see e.g. Rooijers, De Waard & Söder, 1992).

The theoretical basis for a multi-media application to change (attitudes towards) speeding behaviour comes from the "Theory of reasoned action" (Fishbein & Ajzen, 1975). Behaviour is thought to originate from a behavioural intention, which stems from attitudes and subjective norms. Attitudes are modulated by beliefs about the consequences of the behaviour in question, and evaluations about these consequences, in this case of speed in terms of driving fun, risks, travel time etc. The subjective norm is the expected judgement of the social environment and is modulated by normative believes about speed and by a personality factor that may be called tendency to comply. Some remarks are in place here. This model implies that drivers constantly have conscious control over their behaviour, which is not so. Furthermore, the model implies that behaviour is always the consequence of an intention, which is not so. And attitudes are, in this view, rational and objective, only to be changed by rational activities, which is too narrow-minded.

To counteract these objections the model had to be extended: Ronis, Yates & Kirscht (1989) expanded the ways behaviour is created. There are two ways: reasoned and unreasoned influences. Intentions are part of the reasoned influences, whereas habits are part of the unreasoned. Both these influences are subject to modulation by internal and external stimuli (such as infrastructure, weather, time of day, reason for vehicle use etc.), and behaviour that originated from them may be influenced by facilitating factors (such as the availability of a car, driving skill and knowledge, etc). Hence this model incorporates the possibility for other than rational-conscious factors to influence behaviour. Driving habits are very strong behavioural modulators. Furthermore one may argue that before a trip is taken various social factors may influence behavioural intentions, but once in the "wheeled cage" the possibilities for influencing drivers by social factors diminish strongly (ways to communicate with drivers by other drivers are minimal), and hence within a certain task and environmental context habits take over.

Ronis et al. however maintain that habit change only will take place when repeatedly conscious information processing takes place. The driver, however, will resist reasons for other behaviour. Petty & Cacioppo (1986) incorporate this resistance to change in their "Elaboration likelihood model". This model has two routes by which behaviour may change. When the driver is willing and able to do conscious and rational information processing, persuasion of the driver towards the wanted behaviour is possible by a direct or central route of rational information. When the driver is not willing and/or able to consciously process rational information a kind of detour, a peripheral route has to be taken. In stead of a rational an emotional and associative approach has to be taken.

In case of speeding behaviour all attempts to change behaviour can be expected to meet certain resistance. Speeders, halted in an enforcement campaign, are expecting beforehand attempts of influence and arm themselves mentally with arguments in favour of their (unwanted) behaviour. Influencing them by taking the peripheral route may be more successful, using associations, and emotionally loaded arguments. Using a computerised multi-media programme it may be an advantage that the speeder may be actively involved in handling the application (interactive approach), that more or less individual courses through the programme are possible, an that the emotional impact may be augmented by using various media (sound bites, short films, pictures of the actual situation of the offence etc.).

The basis of the actual programme is formed by eleven reasons speed offenders may think of for their behaviour: I was in a hurry, speeding is fun, I was behind a snail, this speed is best for my car, I was not aware of my speeding, I did not know you the actual limit, the speedometer was broken, I don't accept the local limit, I decide my driving speed myself, all drivers driver more than the limit here, and there is never a speed control. Each of these is counteracted by both rational and emotional arguments, by short and hefty pictures, films or sounds. Furthermore the offender is confronted with the negative outcome of speeding behaviour by him/herself, by engaging him/her in various tasks, such as a reaction time task, brake distance estimation task and the like.

A laboratory evaluation

To find out whether the programme is better in changing attitude than traditional leaflets an evaluation was performed. A situation was invented, a 50-km/h road running through a suburban village. The situational specific frames in the programme were equipped with pictures and accident information of the location. There were three conditions for the between-subject study: the programme, a specific speed-related leaflet, and a general traffic-safety leaflet. In each condition 20 subjects were scheduled: experienced drivers that once or even more often were confronted with a fine for speeding. 57 subjects actually participated in the study (33 male, 24 female): 18 in the programme condition, 19 in the specific leaflet condition, and 20 in the general leaflet condition. After an oral introduction subjects had to finish a questionnaire for assessing their attitude. Then they were confronted with their condition (doing the programme or reading the leaflets). Then they had to finish a questionnaire again. One week after participation in the lab a questionnaire was mailed to them, for assessing their attitude again.

The attitude questionnaire consisted of three bi-polar five-point scales (from -2 to +2) anchoring with good - bad, fun - no fun, attractive - unattractive. The composite (summated) score is interpreted as the attitude towards speeding. Table 1 shows these summated scores, separately for each condition and the pre- and post-treatment assessment. As can be seen the attitude in the programme group towards speeding is significantly decreased (speeding became worse, less fun and less attractive), whereas for the two other groups there was no (significant) change. Furthermore, the difference between the programme group and the specific leaflet group was significant in the post-treatment assessment: the programme group became more negative about speeding, whereas the specific leaflet group did not.

Table 1: Summative attitude scores for each of three treatment groups, separately for pre-treatment and post-treatment assessment. Scores range from -2 to +2. * = significant difference between pre- and post-treatment assessment.

Treatment group	pre-treatment assessment	post-treatment assessment
I Multimedia Programme	0.0	-1.1 (*)
II Specific Leaflet	0.4	0.3
III General Leaflet	-0.6	-0.2

There were also questions about motives. The following aspects were assessed: agreeable driving speed for the vehicle, driving fun, having self-control of the speed, the vehicle remains "speedy", endangering other drivers, traffic rule compliance, lacking time to react on other drivers' behaviour, probability of a speeding fine, incorrect estimation by other drivers of the subject's speed, gaining time, being quickly at the destination. Each of these aspects was expressed as a short statement. Subjects had to indicate their measure of agreement with these statements (from -2 to +2) and their measure of considering this important (also from -2 to +2). The product of these scores provides a score for behavioural motive. Table 2 shows these scores, for each of the treatment groups, separately for pre- and post-treatment assessments.

Table 2: Mean scores for the behavioural motives of the three treatment groups, separately for pre- and post-treatment assessment. Scores range is from -4 to +4. A high score means an advantage for speeding.

Subjects in the various treatment groups appeared to differ significantly in their opinion about various aspects. Since this was an indicative study the significance level was placed at 0.10 in stead of the usual 0.05. The specific-treatment group in the pre-treatment assessment considered driving fun more negative than the programme group ($t=1.70$, $df=35$, $p < 0.10$). The general-leaflet group was more negative about probability of a speeding fine ($t = 2.39$, $df = 37$, $p < 0.05$) and about the vehicle remaining more "speedy" ($t = 1.70$, $df = 37$, $p < 0.10$). Subjects of the programme group considered the aspect being quickly at the destination more positive than subjects from the general leaflet group ($t = 2.05$, $df = 36$, $p < 0.05$). In the post-treatment assessment subjects of the specific leaflet group considered the vehicle remaining more "speedy" a more positive aspect of speeding than the subjects of the general leaflet group ($t = 1.80$, $df = 36$, $p < 0.10$).

Treatment group	post-treatment assessment I	II	III	Pre-treatment assessment I	II	III
Motive						
Best speed for the car	0.7	0.7	1.1	0.8	0.8	1.2
Having driving fun	0.4	-0.6	-1.6	-0.5	-0.4	-0.3
Self determination of speed	1.1	0.5	0.2	0.6	0.3	0.5
Car remains more 'speedy'	1.2	1.4	0.3	1.4	1.9	0.9
Endangering other drivers	-0.7	-0.5	-1.1	-0.4	-0.7	-0.8
Compliance of traffic rules	-1.4	-1.9	-0.9	-0.4	-0.8	-0.8
Lacking time to react to others' behaviour	-0.2	-0.2	-0.6	-1.3	-1.9	-0.9
Probability of speeding fine	-2.1	-2.6	-1.9	-3.3	-1.9	-1.8
Incorrect speed estimation by others	-0.8	0.2	-0.9	-1.2	-1.1	-0.7
Gaining time	0.6	0.8	0.3	0.2	0.1	0.5
Being at destination more quickly	1.6	0.6	0.5	1.0	0.8	0.7

Then the change between pre- and post-treatment assessments were compared. Subjects in the programme group became less positive about the aspect of gaining time ($t = 1.80$, $df = 17$, $p < 0.10$). Subjects of the specific leaflet group considered the aspect diving fun in speeding more positive ($t = 2.09$, $df = 18$, $p < 0.10$) and traffic rule compliance more negative ($t = 2.52$, $df = 18$, $p < 0.05$)!. They became more negative about the time to react to other drivers' behaviour ($t = 2.51$, $df = 18$, $p < 0.05$), and about the incorrect estimation by other drivers of the subject's speed ($t = 2.05$, $df = 18$, $p < 0.10$). Subjects of the general leaflet group considered driving fun more positive ($t = 2.01$, $df = 19$, $p < 0.10$), as well as probability of a speeding fine ($t = 3.01$, $df = 19$, $p < 0.01$) and gaining time by speeding ($t = 1.76$, $df = 19$, $p < 0.10$).

There were questions concerning the specific situation that was well known to all subjects. They considered the speed limit of 50 km/h quite sensible, and they thought that traffic safety would increase when all drivers would comply to that limit. The statement "I comply to a limit earlier when accompanied in the vehicle than when alone" gave varied levels of agreement. In the post-treatment assessment subjects of the specific leaflet group more often were totally opposed the statement (chi-square=13.85, df=8, $p < 0.10$), compared to the other groups. Subjects from the general leaflet group and the programme group considered police speeding control more sensible than subjects from the specific leaflet group. This was found both in the pre- and in the post-treatment assessment (respectively chi-square 15.11, df 6, $p < 0.05$ and chi-square 11.44, df = 6, $p < 0.10$). In the post-treatment assessment the difference became smaller. All subjects estimated the probability of a speeding fine on the specific location rather small. Unnoticed one tends to drive faster than allowed. A speeding fine was considered very unpleasant. Subjects reacted variously when asked wether on would driver faster if speed controls were certainly not to be held.

In pre- and post-treatment assessments also knowledge was tested by asking questions about the following aspects: proportion of drivers that complied to the speed limit at the specific (fake) location, liability in case of an accident with a bicyclist, insurance policies in this case (loss of no-claim reductions), braking distance at 50 km/h, braking distance at 80 km/h, physical impact of a collision with 50 km/h in terms of a free-fall jump, meaning of traffic sign "end of built-up area" for speed limit, estimation of time gained by a speed of 20 km above the limit at a stretch of 10 km, magnitude of the fine in case of a speed of 15 km above the limit, speed over the limit that may cause the drivers licence to be withdrawn. In the pre-treatment assessment there were no differences in knowledge between the three treatment groups. In the post-treatment assessment there were two differences. The subjects of the specific leaflet group and (less pronounced) of the programme group responded more often that the drivers licence might be withdrawn at speed limit violations between 31 and 60 km/h (chi-square 13.24, df = 6, $p < 0.05$). Forty-five percent of the respondents in the general leaflet group thought (correctly) that a non-guilty collision with a bicycle would cause the loss of the no-claim insurance reduction, whereas in the programme group and the specific-leaflet group this was seventeen and thirty three percent respectively (chi-square 8.23, df = 4, $p < 0.10$). All respondents underestimated in both pre- and post-treatment assessments the proportion of drivers complying to the speed limit. Most drivers were aware of the liability in case of a non-guilty collision with a bicycle, but that this would mean the loss of the no-claim reduction of the insurance was not common knowledge. The meaning of the sign "end of built-up area" in terms of a speed limit of 80 km/h unless otherwise stated was common knowledge. And subjects estimated the time gained by speeding, and the fine in case of a speed limit violation of 15 km/h quite accurately Furthermore there was a systematic underestimation of braking distances for speeds of 50 and 80 km/h. Finally subjects underestimated the speed limit violation at which police officers may withdraw the drivers licence.

To gain information about the medium, especially the multi-media programme, immediately after the treatment a questionnaire was filled in. Subjects had to rate on a five-point scale (good-bad) the following aspects of the topics treated: educational-not educational, understandable-not understandable, clear-unclear, making sense-not making sense, good-bad, boring-exiting, realistic-unrealistic, fun-no fun. And they had to rate the way the topics were presented with: fun-no fun, understandable-not understandable, making sense - not making sense, good-bad, real-artificial. Subjects were more positive about the programme than about the leaflets (chi-square 12.30, df = 6, $p < 0.10$). Furthermore subjects of the programme group tended towards a more positive judgement about the contents of the programme. They considered it more understandable, exiting, and realistic. On other aspects the programme scores as good as the leaflets, with the one exception that the general leaflet was more "making sense" than the other treatments. This positive rating of the programme was also found for the aspects of treatment of the topics. The specific leaflet however, was found more understandable than the other two treatments. In general, the multi-media programme was appealing to the subjects. About the length subjects were diverted. Two considered it too long, nine neither too long nor too short, and seven too short, one remarking "a punishment in terms of time is horrible for speeders". Executing the computer was no problem. Given the choice between the programme and the full fine most (16 of 18) subjects would take the programme. Finally details of the programme were given ratings and subjects gave open-end remarks about anything they would like to comment on.

Discussion and conclusions

The results of this evaluation study may be summarised as follows. The multi-media computer programme for educational enforcement of speed limit offenders did bring about a change in attitude towards driving too fast. It became significantly more negative, whereas subjects treated with a more traditional medium - specific or general leaflets - did not show such an attitude change. Subject in the general leaflet group even showed a slightly more positive attitude towards speeding, and subjects in the specific leaflet condition remained more or less positive. Furthermore opinions about various aspects of speeding were assessed. The programme caused subjects to be less positive about the gain of time by speeding. Subjects are now aware that speeding does not automatically result in gain of time. The specific leaflet brought about that subjects became less negative about driving fun by speeding, and less positive about complying to traffic rules. This is in contrast with what one would want to achieve in such treatments.

The programme group did not gain more knowledge about the consequences of speeding, compared to the other two treatment groups. It appears that subjects already possess quite some knowledge in this respect. However the way the various topics are treated was judged more positive for the programme than for the other treatments. This was the case in this laboratory experiment. In a real-life setting the advantage of the programme over leaflets may become even larger. In this experiment subjects were actually reading the leaflets, whereas in real life people take the leaflet, put it away in order to drive on, and forget its existence.

Therefore, on may conclude that the programme may contribute to a change in attitude towards driving speed violations in general, and about the "myth" of time gained by speeding in particular. The question whether this treatment not only will cause a change in attitude but also in driving behaviour is the next step in the evaluation of the programme. Field trials are planned on both 50 and 80 km/h roads.

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Driving Simulation Systems as fast Tools to evaluate different Types of Head-Up Displays in a Vehicle

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Abstract

A Head-Up Display (HUD) is an optical control which is mirrored in the windscreen of a car. The apparent distance of this kind of display can be varied with the help of the optical system used. HUDs can be used to offer information to the driver without forcing him to accommodate to the instrument panel. This reduces the time the driver needs to perceive the presented information. Experiments with Head-Up speedometers show that subjects prefer using the HUD. After a short period of habituation the still available normal speedometer is used very seldom.

HUDs can also be used to display additional information: For example the distance a vehicle moves during the reaction period of the driver.

Actual experiments examine the use of HUDs for new navigation assistance systems. In this case the information, normally presented on a small screen in the car or as acoustical information, is presented directly in the environment and is perceived similar to road signs or traffic-line markings.

Because of reproducible traffic situations, short implementation time for new display types (they must simply be added to the simulation scene) and the possibility of examination of even dangerous situations with normal subjects, statements based on statistics can be made faster than in not simulated experiments.

In this presentation the actual research and results will be presented with an additional short video demonstration.

Introduction

Looking at the control panel to read the actual speed or other information about the car is something the driver of a car does very often. Normally the driver has to look away from the outside traffic situation in order to perceive the indicated information. To reduce the time a driver is turning away his attention from the outside some car manufacturers made studies whith HUDs – which were used in air planes for a long time - in their vehicles. Although the first prototypes for car HUD systems were realized more than ten years ago, only a few companies integrated simple HUDs in their cars on the market (e.g. Buick ParkAvenue, Nissan Bluebird and Pontiac Bonneville). Many of the other companies regard the HUD technique as a topic of basic research for future developments. They don't believe that the HUD offers a security enhancement even if there are a lot of studies which show the advantages of the HUD technique. Some of these mentioned by Schneider et. al. (1992) are:

- The driver perceives the indicated information in a smaller viewing angle to the traffic situation.
- There is less or in some cases even nearly none accommodation between near and far distances needed to read the indicated information.
- Adaptation to different lightning conditions on the board instruments and the outside of the car are no longer necessary.

All these items lead to shorter periods of time in which the driver is turning his attention from the traffic situation. For example Bartolomäi (1990) found that the time to read the speedometer in different conditions can be reduced from a range of 100 to 2000 ms to a range between 100 and 800 ms by using a HUD speedometer. As an interesting detail about HUDs Bubb (1992) mentioned the fact that air planes with this technique have to pay less insurance fee, because of the improved security level.

How an HUD works

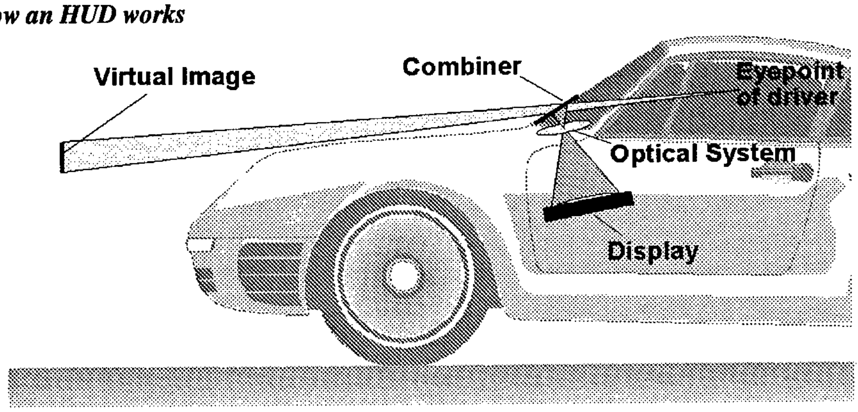

Figure 1: The basic implementation of a HUD

The basic implementation of a HUD as shown in figure 1 is always the same: An ordinary display consisting of any source of light (e.g. an arrangement of LEDs or an TFT display) is mirrored in the windscreen of a car by an optical system. The optical system must be adjustable to the viewpoint of the driver, so that the user perceives the HUD at the right position behind the windscreen. The distance of the virtual image of the HUD depends on the optical system used. For simple HUDs often a distance between 2.5 and 3.5 meters is used. This distance is easy to realize and works for all standard information such as speed, rounds per minute, remaining fuel and motor temperature warnings. An disadvantage of these simple HUD systems is that the HUD seems to move in relation to the outside traffic situation whenever the driver moves his head. Therefor this simple system has to be replaced by another with a variable or a larger apparent distance of the HUD to indicate information that should be combined with the outside traffic situation by the driver. A HUD that offers such information is called a contact analogue HUD. Some applications of such HUD systems will be described later.

Our own experiences using HUDs

In our institute there where a lot of studies related to HUDs. Most of them where done with HUDs in real vehicles. These studies concerned with HUDs which had a fixed apparent distance to the driver. Most of the studies like those of Assmann (1985) and Stürzer (1983) were about a new HUD concept that allows to indicate the distance a car moves during the reaction period of the driver. This HUD with an apparent distance of eight meters consisted of a rectangle that could be varied in size and height to simulate a green bar lying on the road in the desired distance. The apparent distance of eight meters was enough to achieve a sufficient realistic impression. As a base of these studies Bierbrauer already did studies in an other simulator with this concept in 1980.

Other studies at our institute dealt with the habituation of subjects to a HUD speedometer similar to the one shown in figure 2. In these studies our line of sight detection system JANUS was used to get information about how often and how long a subject looks at the HUD and the still available ordinary speedometer. Gengenbach (1997) showed that all subjects in this study preferred using the HUD speedometer. He also confirmed the shorter time that is needed to read a HUD with his evaluation.

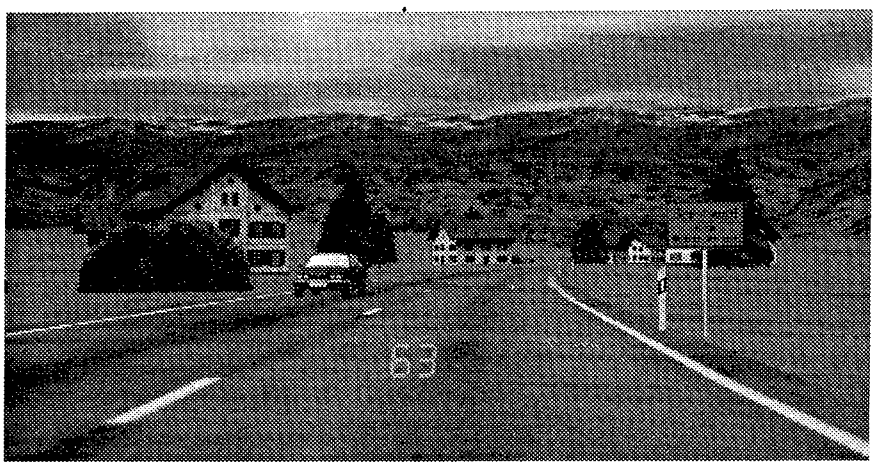

Figure 2: Current implementation of a HUD speedometer in our simulator.

The simulator as a tool to evaluate new HUD concepts

A lot of our studies about HUD systems tried to show the advantages of contact analogue HUDs. To obtain the best possible quality for this kind of display there were many experiments with adjustable optical systems. Gengenbach (1993) even made studies with a holographic HUD. A result of all these studies was, that there is a lot of engineering necessary to realize a HUD system that is able to indicate an contact analogue HUD for a special purpose. In addition an optical system that worked good with one HUD concept often couldn't be used with others. The free programmable TFT display used by many vehicle manufacturers, which is very flexible to examine new standard HUD concepts are also not suitable for these kind of studies. One way to generate a tool that makes it possible to examine the man-machine-interface of new contact analogue HUDs without having to develop a complicated optical system that is able to indicate this HUDs in the desired way was to use virtual HUDs in a simulator.

By using a virtual HUD it is also much easier to examine concepts that normally would cause a lot of expense. For example a HUD prototype for a navigation assistance system that normally should be linked to an on board GPS (Global Positioning System) or for a driver assistance system that indicates warnings if the vehicle gets to near to the roadside or if it gets to close to the car ahead can be implemented by using the already available information about the positions of all objects in the simulated scene (including other cars) and an additional database that includes the rights of way at road junctions or road crossings, the speed restrictions, information about traffic signs and the suggested courses for a navigation assistance system. It is also much easier to realize completely new ideas like an assistance system for parking between two other cars where a HUD could be used to visualize the distances to other cars, traffic-line markings and other obstacles in all directions of a car without having to integrate a lot of measurement instruments in a prototype vehicle.

The simulator offers a wide palette of possibilities to implement HUD systems. The virtual HUDs can be moved in relation to the car by using DCSs (Dynamic Coordinate Systems), the indicated HUD can be modified in size, color, transparency and brightness by using morph nodes and last not least it is possible to implement HUDs with different states such as the digits of a speedometer by using switch nodes. For more information about the graphical abilities of a simulation system it's recommendable to have a look at a handbook for a simulation software like the IRIS Performer library by SGI.

Examples of contact analogue HUDs implemented in a simulator

The first contact analogue HUD that was integrated in our new simulator was the already mentioned security distance indicator. To be able to compare the virtual HUD with the one we examined in a real car we did two different implementations. The first was a green rectangle with an fixed distance of eight meters that could be varied in height and size to get nearly the same impression as with the display that was implemented in the real car. The second implementation was a simple rectangle (shown in figure 3) which wasn't modified in height and size, but was lying on the road and moved to the point of the road where the car would be after the reaction period of the driver.

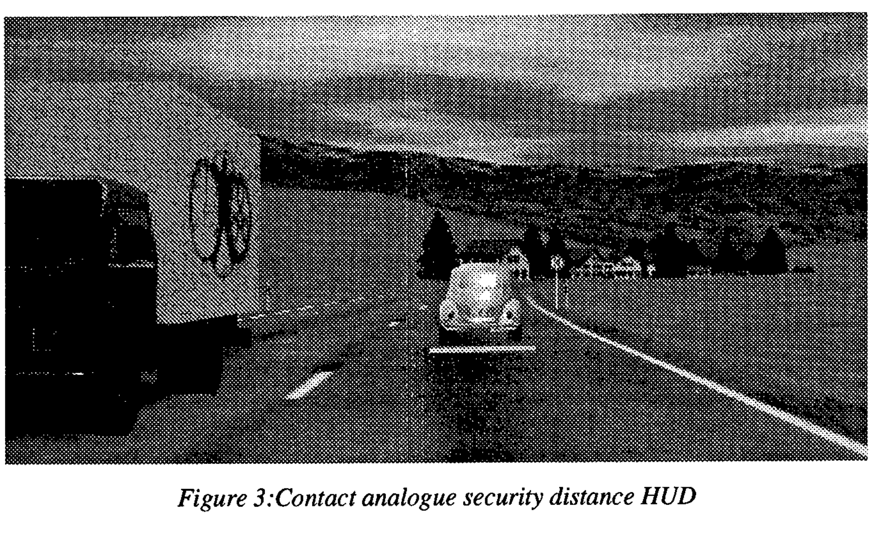

Figure 3:Contact analogue security distance HUD

The main advantages of the second implementation were that head movements of the driver didn't result in apparent movements of the indicated HUD in relation to the road surface and that the HUD didn't had to be adjusted to the viewpoint of the driver.

Another HUD project in our simulator is about navigation assistance systems. These systems are expected to show the driver where he should turn left or right in order to get to a spotted point of the scenery. A simple and quite good possibility for such a system would be another car which leads you to the selected location. As it is not possible to indicate a leading vehicle in a HUD, because this display would hide to much of the surrounding and would take to much of the attention of the driver, an more simple HUD had to be implemented which offered nearly the same comfort. A first implementation as shown in figure 4 was a simple HUD which indicated the navigation systems advises in an symbolic way.

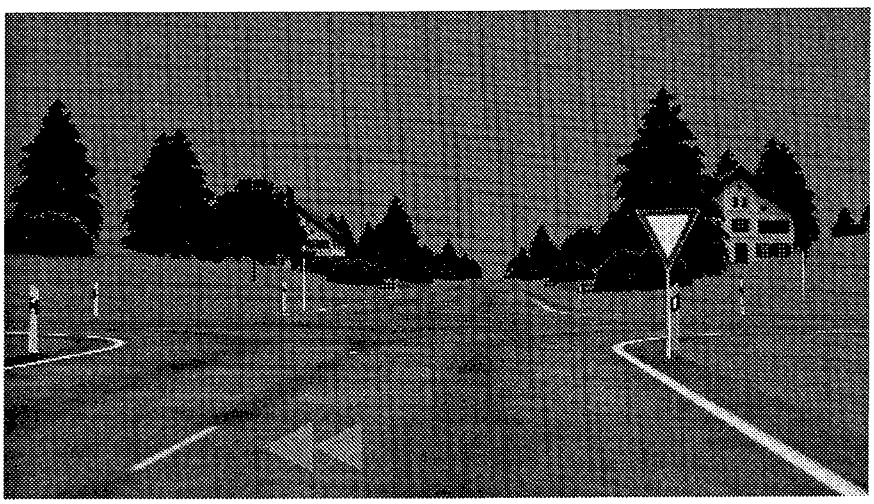

Figure 4: Simple HUD for navigation control information

This HUD system was sufficient in most traffic situations. Only if there is a short succession of road junctions the indicated information might not be clear. To improve this HUD a contact analogue HUD was realized which consisted of a set of arrows which had a similar appearance like traffic-line markings and which were virtually laid down on the road surface just a few meters in front of the road crossing, where the driver had to turn left or right. This HUD which is shown on figure 5 was easy to interpret by the driver but couldn't be read from a distance from the crossing. As a result of these studies both of the two displays were combined. The simple HUD was used to indicate that the driver has to turn left or right in the next seconds and the contact analogue HUD was used to indicate the exact position where he had to leave his present road.

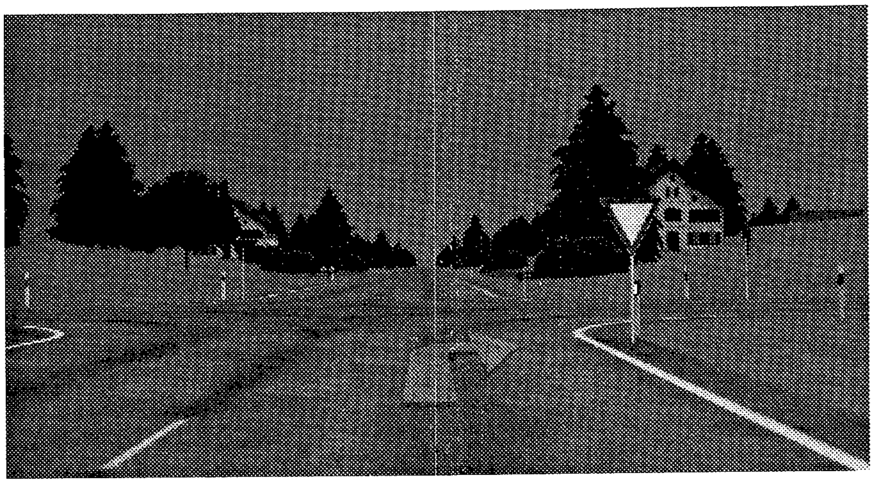

Figure 5: Contact analogue HUD for a navigation control system.

Conclusions

Driving simulators are not in the first place a tool to adjust existing HUD concepts to a special vehicle, but a good tool to examine the man-machine-interface of new kinds of HUDs without the limitations of actual technical practicabilities. By doing some studies with a new HUD concept in a simulator the expense to integrate a prototype in a vehicle can be reduced, because it is possible to limit the indicated information to those parts of the concept that were accepted by subjects.

As an additional field for simulator studies it is possible to examine if the HUD technique improves the security in different traffic situations. For example it would be possible to evoke a special event sometimes the driver reads the speedometer. This event – for example a ball that suddenly rolls on the road – should cause the driver to reduce his speed immediately. By comparison of the periods of times needed to reduce the speed by 5 km/h for example, or by comparison of the part of events where an accident could be avoided an objective security judgement of the HUD technique in vehicles would be possible. In order to measure the influence of the HUD technique and not just typical simulator effects a kinesthetic feedback to the driver is absolutely necessary to avoid the loss of control while having no optical feedback about the actual driving situation. To be able to do these kind of studies in our simulator, too, we're actually examine different possible kinesthetic feedback systems for our simulator.

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Analysis of Hand Position in Unstructured Environments

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Abstract

We are developing a system for the marker-free analysis of hand position in real-time, which performs in undefined, non-stationary environments. The system is based on a frame-to-frame SSD correlation of greyscale video images, and currently provides the two-dimensional coordinates of thumb, index fingertip and hand at a frame-rate of 14 Hz. This system can be applied as a man-machine interface(e.g. replacing the mouse), and for the recording of human motor performance in complex, uncontrolled scenarios (e.g. clinics, military, aerospace).

Introduction

Several systems for the determination of 3-dimensional limb positions are available on the commercial market. They all require that „markers" are affixed to various locations on the limb, and track the marker positions through space. Some systems employ active markers such as light sources (e.g. Selspot®, Optotrack®) or induction coils (Fastrak®), while others use passive markers such as fluorescent balls (Macreflex®). Unfortunately, however, all markers obstruct the free movement of the limb, due to their physical size, weight, and in case of active markers the leads to operate them. Thus, markers modify what they are supposed to measure.

As a second problem, marker-based systems require special environments for error-free operation, such as rooms free of metal or glossy surfaces. This excludes their application in many real-life scenarios, where environment is not controlled.

As a consequence, we decided to develop a marker-free systems which can operate in undefined, nonstationary and nonhomogenious environments. To be of practical use, the system should have a spatial accuracy of about 1 mm and a temporal resolution of 100 Hz. Such a system could be deployed in scenarios such as virtual reality, man-machine interaction, testing of human performance in clinical, military, and aerospace settings, or quality control. The long-term objective is to achieve 3 dimensional measurements by means of 2 cameras.

Methods

In the following we describe the actual state of the development and the methods used.

Test setup

The test setup of this system is shown in figure 1.

Simple graphical objects varying in shape and position are displayed on a computer monitor. The subjects task is to point onto the targets with his index finger or to grasp them with his index finger and thumb Fig 1. These movements are recorded by a camera, the signal of which is digitised, is sent to the CPU of a PC, and evaluated to yield 2D hand position coordinates in real-time.

The working range for the hand is 50 by 50 cm with a distance of 90 cm between camera and screen.

Hardware

The actual hardware used is one camera DALSA CAD1-256 with 8 bit greyscale and 256*256 pixel resolution, a lens COSMICAR 8mm, one framegrabber CORECO OCULUS F64 (with signal processor TMS 320C40 and special image processing functions) and one standard Pentium MMX 200 MHz PC.

Possible ways of image analysis

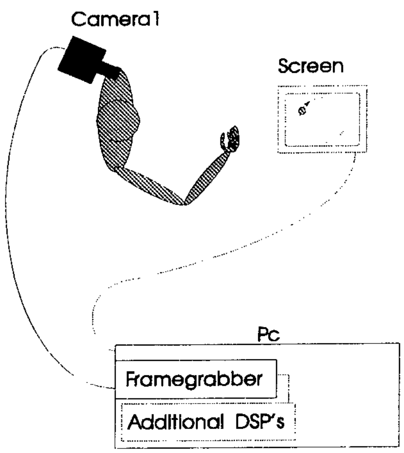


Fig. 1 Test setup.

To determine hand positions from the recorded frames, we could use several techniques:

1. Edge detection with fixed or adaptive threshold level.
2. Filtering with different kind of operators (Laplace, Sobel, Prewitt ...) and subsequent edge detection with fixed or adaptive threshold level.[1,3]
3. Knowledge based methods which fit descriptive models direct in the greyscale or filtered image. [1,2,6,7,8,9,10]
4. Transformational methods, e.g., Gabor filter, FFT, Hough transformation to change from the spatial space into a transformation space.[1,2]
5. Neural networks which work on greyscale, filtered images, or following an transformation method.[11]
6. Direct pattern searching in the greyscale image with pattern matching algorithms.[1,2,4]

Methods 1 and 2 are highly dependent on in the quality of the image background and the structure of illumination and their result is not an distinct position. Their benefit lies in the field of image pre processing, and augmented by simple knowledge based rules.

Methods 3,4 and 5 are cumbersome and time consuming, and may therefore be unsuitable for high speed real-time applications.

We therefore decided to use method 6, based on a fast pattern matching algorithm similar to the SSD algorithms[4].

The pattern matching method

The presented method is based on a combination of pattern matching and knowledge based evaluation of the image. A modified SSD algorithm is used with dynamically updated search pattern and greyscale discrimination to determine the required positions. The knowledge based component is used to determine the search areas, and the greyscale discrimination parameters to refine the determined finger positions.

To start the analysis, the subject has to bring his hand in a pre specified starting position in front of the camera. The software then determines the pixel pattern of the known locations of thumb, index finger and the area where thumb and index finger meet (which we will call "hand" in future) as shown in Fig.2. these patterns serve as templates for the subsequent search algorithm. The size of these templates is 14*14 pixel for the index finger and thumb, and 22*40Pixel for the hand. The system determines the mean grey-value from a 6x6 window of the centre of the hand template.

As a next step, the pattern matching algorithm searches in the second frame for a pixel pattern that is maximally similar to that of the hand template from the first frame. This search is limited to a search area of 39x57 pixels and the template is displaced within this area in horizontal and vertical steps of 3 pixels. Once a best position is found, the search is refined locally displacing the template in steps of 1 pixel.

As a further step, the algorithm searches in the second frame for a pixel pattern that resembles the thumb and index finger templates, respectively, within a search area of 23x23 pixels. The templates are displaced in this search in steps of one pixel. To prevent that the found pattern "runs " towards the hand pattern [5], the algorithm searches not for the maximum similarity, but rather for a location as far as possible to the left of the maximum (for right handed subjects) which still yields at least 90% of the maximum value.

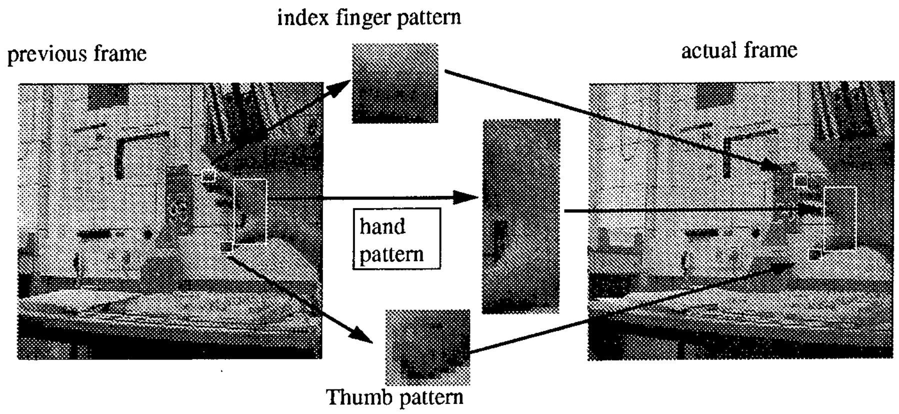
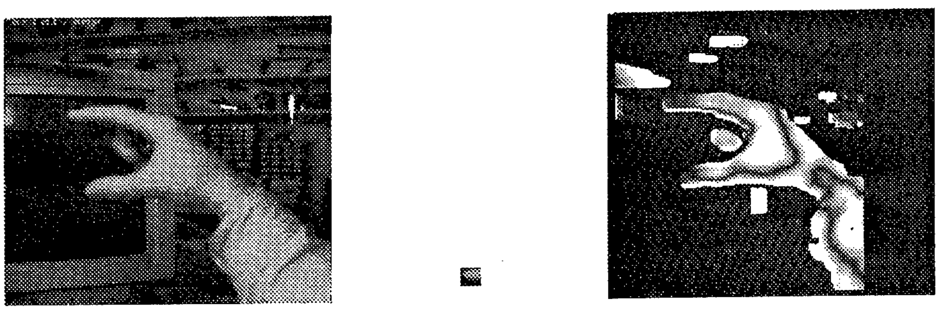


Fig. 2 Search templates.

Once the hand and the finger pattern are found in the second frame, they are used as templates in the third frame, etc. in an iterative procedure.

To determine the grade of similarity between a template and a pixel pattern in a image, we use the modified SSD algorithm[4] shown in function (1). This function gives a value MR(sx,sy) that becomes 0 at the location sx,sy in the image with best coincidence between template and the pixel pattern. The factor k provides the greyscale discrimination. If the grey value of one pixel at x,y in the template or the corresponding position x+sx,y+sy in the image lies not within ± 25 % of the mean grey value, k becomes 0, else k is set to 1. Nx and Ny represent the size of the template N = Nx*Ny is the normalisation faktor, with each k = 1 N becomes decreased by 1 to ensure a proper normalisation, I_{xy} and P_{xy} are the grey values of the template and image respectively. The result of the search Function (1) is shown in Fig. 3 for a large search area and an index fingertip as search template.

$$MR(sx,sy) = \frac{\sum_{x=0}^{Nx} \sum_{y=0}^{Ny} \left| k * \left(P_{x,y} - I_{x+sx,y+sy} \right) \right|}{N} \qquad (1)$$



Greyscale image Search pattern Mr(sx,sy) for a large search area

Fig. 3 Grey value image index finger as search template result of search function.

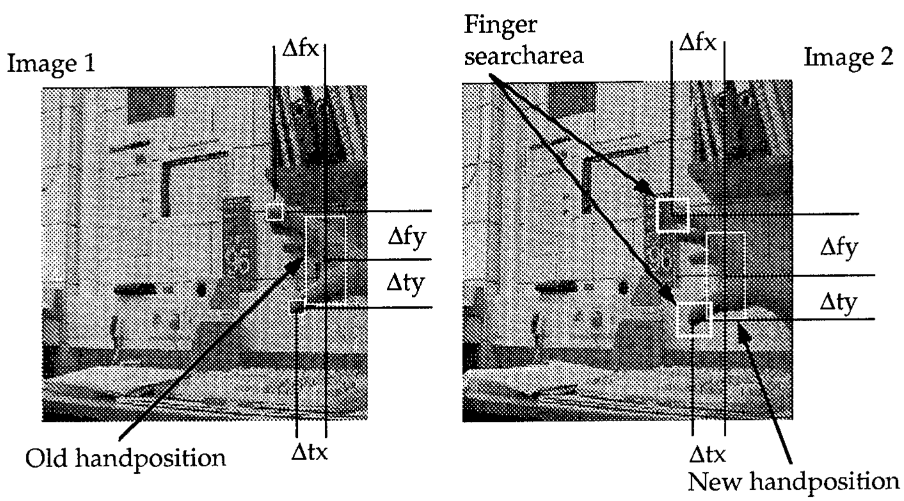


Fig 4 Determination of finger search areas.

Further features of the algorithm

In order to increase the speed of the search algorithm, we displace the finger search areas in each frame along with the displacement of the handposition. To achieve this we use the relative distances of the finger positions to the hand position (Δfx,Δfy) and (Δtx,Δty) in the previous frame and use these with the hand position in the actual frame to determine the search area for the finger positions Fig 4. So we could reduce the finger search area shift to 23 pixels in x and y direction. Due to the fact that the template and the search area are now overlapping with about 50% of template size, the algorithm becomes more robust against locations in the image background with a high grade of coincidence to the searched template..

Results

With the system presented in this paper, we achieve an recognition rate of 15 frames per second, or 67 ms per frame, yielding 3 coordinates per frame. The frame time consists of 20 ms for image analysis, and 47 ms for transferring the images from the frame grabber to the PC.

Hand and finger positions are tracked successfully and independent from image background, while the hand executes transitional or rotational movements, or changes its shape.

The accuracy of tracking the finger positions is ± 3 mm from frame to frame, and ± 6 mm across 30 frames.

The maximal trackable actual velocity is ± 25 cm per sec for the hand, and ± 12 cm per sec for the finger.

With an increase of the recognition rate to 100 frames per second the maximal trackable velocities should increase to ± 166 cm per sec for the hand and ± 80cm per sec for the finger. These values correspond to very fast real life hand movements.

Next steps

Our future work will address the following issues.

- Improvement of accuracy for the finger positions by improvement of the search technique which actually determines the leftmost finger position (for right handed subjects).
- Resolving problems with overlapping fingers by adding shape-orientated components into the matching algorithm
- Increase of processing speed by migrating and parallelisation of the algorithm from the PC to the signal processor and the coprocessing system, and by reducing the search areas by means of a prediction algorithm for the next finger and hand position.
- Introduction of three dimensional processing with 2 cameras to achieve three dimensional coordinates. The extension of the system to two cameras will provide real 3 dimensional coordinates and the possibility to dynamically adapt the size of search templates and search areas. While the algorithm gives only 2-D coordinates it is a relative simple task to transform the two camera outputs. This task can be simplified by a dextrous camera arrangement.
- Automatic determination of the positions in the very first frame by means of neural networks which recognise the hand shape irrespective of their position. This approach which has recently started in our lab, will eliminate the need pre-specified starting position.

Conclusion

The presented preliminary system provides a encouragingly fast and accurate, marker-free algorithm to determine the position of 3 interconnected objects with almost no constraints on image background or light conditions. Greyscale cameras are sufficient for our system and faster in processing than colour cameras would be. The algorithm is applicable to objects with a narrow banded histogram. The field of application is not limited to physiological applications and rather could include, e.g., the localisation of any moving objects in an unstructured environment. The system can be used as a interface in virtual environment generators.

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An Experimental Multimedia Process Control Room

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Abstract

The centralised control rooms of large industrial plants have separated people from the processes they should control. Perception is restricted mainly to the visual sense. Only telephone or radio links provide narrow-band voice communication with maintenance personnel down in the plant. Multimedia equipment can *perceptionally* bring back the operator into the plant while *bodily* keeping him the comfortable and safe control room. This involves video and audio transmission from process components as well as sights and sounds artificially generated from measurements. Groupware systems support interaction between operators, engineers, and managers in different plants. With support from the German government, the state of Hessen, and industrial companies the Laboratory for Systems Engineering and Human-Machine Systems at the University of Kassel establishes an Experimental Multimedia Process Control Room. Core of this set-up are two high-performance graphics workstations linked to one of several process or vehicle simulators. Multimedia periphery includes video and teleconferencing equipment and a vibration and sound generation system.

Introduction

Today, operators in few or even only one central control room are separated from the process control large industrial plants. Increasingly sophisticated control systems shift the role of the human operator from manual to supervisory control, and research for autonomous operation of large plants is in progress. However, the presence of the operator in the control room of a plant is still necessary. Thus, the interface to the process and its control system remains an important component. Process operators, seeing only selected physical measurements of large systems on their small displays, and physically separated from the equipment loose contact to the process.

Before introduction of CRT technology, process control had walls showing mimic diagrams, electro-mechanical instruments, and mechanical switches. Still today, mimic diagrams and instrument walls influence the design of CRT displays. While the number of process variables increased, the task of deriving the necessary information about the process state out of all these variables is still mainly left to the operator. The operator has to perceive a vast amount of information. Except for acoustical alarms, the visual channel has to convey the majority of this information while conventional interfaces do not yet take advantage of other human senses and new, multimedia-based technologies.

Experience in nuclear power industry shows, that plant operators do not need support systems during 95% to 98% of operation. In the remaining cases, support systems do not always provide the support necessary and the operators depend on their own knowledge. Although highly trained and motivated, operators are unable to cope with situations when they cannot access the necessary information about system state and performance. In the 2% of operational cases, that are unusual, complex, and mostly new, the operator needs all available information to solve the problems. This information may comprise phenomena not transferred by usual measurements and unsuited to conventional displays. Additional media, integrated in the control room, may be able to convey the information.

Extensive task and knowledge analyses performed by our laboratory in a variety of industrial processes showed that an experienced operator uses more information from a plant than just the measurements displayed in the control room. The noise spectrum, sounds, vibration, temperatures, direct vision, even odour adds information to form the overall picture. It may be helpful to bring this information back, specially to the operator who is more and more separated (physically as well as conceptually) from the process. Opposed to hardware and software used in process control rooms today, equipment and procedures used in computer graphics show immense improvements. This offers the generation of virtual images based on physical measurements, abstract data, and process structure. Multimedia technology can bring the process closer to the operator in a distant control room by adding some of the lost sensory channels. Instead of showing the icon of a tank besides a level measurement, the computer-generated image can show the tank itself, along with the correct liquid level inside and a sound depicting liquid flow. Using computer graphics and virtual reality algorithms, other measurements can enhance the image, for example component colour for temperature, surface structure for efficiency. Using an image of a process component instead of physical measurements, showing live videos along with stereo sound from the process can again establish the close contact to the process. Simulating a reality sufficiently close to the operator's view of the process will enable the operator to identify problems quickly. A live video image can show process failures not captured by measurements. In parallel, video conferencing enhances contact between process control operators and maintenance personnel in the plant. Beyond this, groupware and co-operative interfaces for multi-user interaction in plant-wide control and communication can support problem solving on all levels, such as the operational, the maintenance, or the management level.

We know from own experience, how much the background sound in a control room next to the turbine room and boiler changes with slight variations in the plant state. Experienced operators will benefit from good reproduction of these phenomena. Besides giving back information to the operators they had in conventional systems it is also possible to use these additional media to transmit new information and to support collaborative work.

The Future Control Room: Co-Operative Work and Multimedia Support

Because of the growing complexity of systems, more operators, even in different locations in the plant need to co-operate. Telephone or radio communication provides only poor means to exchange process measurements and drawings from operation manuals along with views and ideas for co-operative problem solving. The co-operation between different human user classes (e.g., operators, engineers and managers) can be facilitated by the combination of several multimedia representations on different abstraction levels. The different information needs of these user classes are considered in the multi-human interface design by providing them with dedicated windows or screens and audio information. Engineers and managers may more often want to use goals-means hierarchies and multilevel flow model presentations whereas operators can use the less abstract presentations of ecological and topological displays. However, free navigational access to all display options must be allowed for all user classes, based on the different focuses of their individual preferences. The concepts of visual momentum and cognitive layouts should be implemented in such a way that they support the integrated view among team members of multi-user groups across all different forms of graphical representations. Related video and audio information further support this.

A large number of pictures in a complex display network is characteristic for many industrial applications. In such cases, only some of these pictures may be individualised for different user classes. Tani *et al.* (1994) suggested to use a large screen as a shared display for all group members, together with detailed personal displays on individual workstation screens for each of the group members. Multimedia presentations of live video can be combined with computer graphics presentations. The visual momentum is implemented by means of highlighting manipulated objects as well as by corresponding movements of individual cursors for each group member in the shared and detailed screens.

Relatively new communication technologies for human-machine interaction have been developed with the field of multimedia. The main idea of multimedia communication is to combine and integrate different visual and auditory media for the display and visualisation of information about tasks to be performed with a machine or a computer. In particular, the following media are combined with each other: computer-generated visual displays, video recordings, and auditory information such as recordings of noises and synthetic speech (Steinmetz and Herrtwich, 1991). In addition, three-dimensional stereoscopic video scenes and stereoscopic computer graphics can be superimposed upon one another (Milgram, *et al.,* 1990). Even music and haptic information as well as smell may be used for multimedia communication.

A connection of multimedia objects with an information network can be used interactively, for example, in travel agencies and libraries (Jerke, *et al.* 1990). In this pure human-computer interaction, the querying technique is combined with the method of browsing in a hypertext environment. A hypertext system is a network of information nodes that are connected by links, in a non-sequential way, to arbitrary non-linear information structures (Bogaschewsky, 1992). A hypertext network has been combined with an automatic fault-diagnosis module in order to support the problem-solving activities during trouble-shooting (particularly, motor diagnosis) tasks of human technicians in car-repair shops (Hollender, 1995).

In general, the human user can navigate through a hypertext network by analysing the connections between the nodes. Conceptual connections between alternative interaction procedures lead to a hypermedia information network. The separate nodes of this network are related to the separate types of information, such as text, graphics, video or audio, which are different forms of multimedia. Thus, hypermedia represent an information concept connecting several media (Begoray, 1990), whereas multimedia encompass a combination of different presentation media. The terms hypermedia and multimedia are, thus, distinguishable from each other in a similar way as the dialogue and the presentation layers are, in a user interface management system.

Multimedia communication systems will be introduced in the future in several application domains. We mentioned libraries and travel agencies already above. In addition, the entertainment industry is highly interested in this new technology. Particular applications will be possible in medicine, for co-operative conferencing between physicians (Kleinholz and Ohly, 1994) and for surgery. Industrial applications may be possible in glass production, the paper and pulp industries, the chemical industries (Heuer, *et al.*, 1994), the power industry (Zinser, 1993), and the maintenance of networks such as those for distribution of electricity (Akiyoshi et al., 1995). Tanaka et al. (1988) suggested a tutoring system for the latter case.

Alty and Bergan (1992) emphasise that many questions still exist with respect to the application of multimedia communication in dynamic industrial process-control tasks. The general problem of the interface design remains: Which information is needed by the human user, when, in which form and why? This problem becomes more severe with a larger number of technological options, which increase further with the multimedia domain. Therefore, the information needs of the later human users have to be investigated by means of task analyses. This requirement becomes even more important in the cases of co-operation among several human users in co-operative work situations.

Expert analyses (performed in a cement plant, as a kind of unstructured task analysis) indicated some aspects of the co-operative work situations in that particular application domain. The face-to-face communication is absolutely mandatory. In addition, the audio channel, e.g., telephone communication, is very important. Multimedia technologies can be used for integrating the video information from some of the equipment, which is now available in the control room on separate video screens. Otherwise, video observations are rejected as a spy system in this application domain. Consequently, the important aspects of multimedia communication for cement plants comprise: (1) computer graphics and related video presentations with interaction facilities for human-machine and human-human communication, as well as (2) teleconferencing with highly improved face-to-face video presentations and screen-based audio communication. Both aspects need to be related to one another and integrated in a task-oriented manner. Overlapping windows need to be avoided as much as possible, as usual in process control applications.

The important aspects for travel agencies do not include the teleconferencing part. However, a much more substantial search for related multimedia objects in an information network is required (Jerke, *et al.,* 1990). The human user classes are travel agents and customers, who are possibly also co-operating with one another for more efficient customer support. Special computer skills cannot be expected from the average customer. This leads to the necessity of easy-to-use multimedia interfaces with related text, picture, graphics, video and audio information.

The same general tendency exists with the important aspects of multimedia communication in the entertainment sector. Everybody wants to participate and enjoy in an easy, direct and interactive way, comparable to strolling through a garden or singing a song, e.g., in a Karaoke environment (Tamura, 1995). This most intuitive computer use required in the entertainment domain will probably contribute strongly to new powerful and highly user-friendly multimedia systems. Although they will appear more as game instruments rather than as conventional computers, they may become the next generation of multimedia computers also in industrial and service applications.

The research into computer supported co-operative work (CSCW, 1994) and groupware deals with theories, design concepts, architectures, prototype systems, and empirical results for co-operative work situations in application domains such as offices, classrooms and factories. Electronic mail systems, computer and videoconference systems, office information systems, organisational knowledge bases, shared window systems and other communication and co-operation systems are being investigated. Some of these systems do not allow the human users to interact or co-operate with each other directly in space and time. New approaches for the integration of action space and time have been suggested, e.g., by Ishii, *et al.* (1992). Such support for co-operative work seems to be particularly required in industrial human-machine systems.

As the results from the expert analyses in the cement plant indicate, co-operative work should be organised as far as possible using face-to-face communication. Large projection screens are not welcome, because they are very soon too overloaded, and are not adaptable enough. However, they have already been implemented in some other application domains, but the concept of overlapping information for different human user classes has not been taken into account in the information content of these projection screens. Thus, their use for co-operative work needs to be rethought. Display screens for group meetings in different offices and the control room are welcomed as multi-human machine interfaces in the cement plant. They will also be accepted as dedicated human-machine interfaces in a network, and for discussions of smaller problems over the telephone.

The display screens for the group meetings may consist of one screen with four to five windows. They allow access to all pictures in the control room, rather than having just printouts, as presently available. Different, most favoured pictures may be selected by different user-group representatives. All the selected pictures need to be seriously considered by all members of the meeting, because co-operation rather than ego-centred views are required, where each user-group representative contributes. Modifications of control-room pictures are foreseeable for the display screens in group meetings. Quick-change and easy-to-use editing facilities may allow the selection of important lines or variables from a table, qualitative zooming-in and selection of subareas of component flow diagrams, and manoeuvring or selection by sliders or text menus through different levels of abstraction. The latter range from physical forms, such as scanned-in photos, e.g., taken from databases or just of broken components (inside a pump, etc.), to goal hierarchies via multilevel flow-modelling representations.

The consistency and coherence across selected and edited multimedia has to be guaranteed. This will support the visual momentum, which is now already available, when a trend curve is selected by the cursor for a particular variable in the component flow diagram. The consistency will be increased when the computer completes the other selected pictures shown in parallel, e.g., consistent with the information reduction in the just-edited picture. The information filtering, reduction and qualitative modifications may be supported by the computer, or can be done solely by the group members. Further, computer-supported drawing facilities, e.g., for straight lines or for rapid prototyping (sketching) of new pictures and ideas or for modifying existing ones, are possible. However, they may be more suitable for exploratory purposes rather than for normal group meetings, because the latter might become too long with too much computer interaction.

The overlapping information for the different user classes has already been considered in the logbook, now available on a PC in the cement plant. This information has still to be implemented further in the presentation, the dialogue and the explanation facilities of the human-machine interfaces, particularly of the display screen for group meetings. Thereby, the visual momentum between different windows, which relate primarily to different user-group representatives, has to be supported.

All the suggested designs of human-machine interfaces for co-operative work also have to consider face-to-face communication. Otherwise, the social contacts would not be improved if this face-to-face contact were to disappear. Tele-co-operation is often not feasible because the contact with the production will be lost, e.g., the feeling for clinker quality will disappear. In addition, the work climate will deteriorate and, thus, there will eventually be no co-operation.

Design work is often accomplished in teams where human users interact and co-operate with each other directly in space and time. New approaches for the integration of action space and time have been suggested, e.g., by Ishii et al. (1994), as mentioned above. Two people work on the same drawing for design and, at the same time, see the co-operative design partner through the transparent digitiser sheet. The two designers can physically work in remote places from each other. The basic metaphor of this concept is "Talking through and drawing on a big transparent glass board." Thus, it is believed to be very important to have face-to-face communication as well as audio communication with each other in a team.

Similar design principles were used for a co-operative work support system, which allows the supervisory control as well as the maintenance of a power plant (Muraoka, Ohi, 1995). Not only image data but also audio and drawing data are combined with each other. Several windows on the display screen allow to visualise in parallel topological component-oriented presentations and video scenes from the plant or, alternatively, from the face of the communication partner, e.g., of the maintenance person in the field work. Additionally, a communication board can be shown in a further window. The communication board can be used as a white board or a pin board on which selected information, cut out from any other window, can be pasted. This white board is shown to both communication partners in the remote sites. They can circle and mark or write anything they wish on top or besides the pasted information, again visible also for the remote site. Thus, a direct telecommunication can be used for co-operative problem solving.

The already mentioned multimedia means of video conferencing with audio and face-to-face communication are even more important on the management and the marketing levels. As the facial communication is regarded as very important in many cultures, it seems to be worthwhile trying to reduce the huge amounts of data to be transferred in telecommunication. It is feasible to simulate computer images of a person in the remote partner's place. Then, only minimal parameter sets, which characterise the perceived impressions of a human face, e.g., fierceness or gentleness of a face, have to be transferred. An example of such investigations of facial features was presented by Kato et al. (1995).

Advances in virtual reality technology allow to explore freely the virtual environment, e.g., of a maintenance situation by manipulating 3D graphical objects. Liquid-crystal glasses and data gloves have to be used for viewing and manipulating the stereoscopic display. Currently, the possibilities for exploiting such virtual reality and multimedia technologies for learning and training environment and for marketing are investigated (Akiyoshi et al., 1995).

Integrating the above approaches across all levels in an appropriate human user- and task-oriented manner will be a major challenge of the next coming years. It will be important to think about desired work organisations, first, and to pursue corresponding cognitive task analyses in order, then, to build plant-wide control and communication systems which will be welcomed with high user acceptance. It is also very likely that remarkable cultural and socio-political differences with respect to optimal or, at least, satisfying solutions may exist even within individual countries between different companies.

Even in the next future, process control rooms will need the presence of human operators. Those cases, when pre-programmed automatic systems would fail to control the process specially demand for skill and knowledge of the operators. In these rare cases, all available information on the process and the combined skills and knowledge of operators, technicians, engineers, and managers is needed for co-operative problem solving. The integration of new media for information presentation and co-operative work to support humans in these situations is a main research topic of the new Multimedia Process Control Room established in the Laboratory for Human-Machine Systems of the University of Kassel. The next sections describe the desirable capabilities of such an experimental instrument and the current implementation.

Essential Capabilities of a Multimedia Process Control Room

For technical (and financial) reasons, the multimedia process control room in its current configuration addresses the auditory and the visual sense with some support for perception of vibrations. Visual and acoustic information is presented supporting perception of directions and depth. Artificial, fully computer-generated information, play-back of prerecorded information, as well as life presentation is foreseen. In detail, a multimedia control room should provide

- Computer-generated and animated visual displays, showing process information and incorporating textual, pictorial, and graphical objects, combined with live or prerecorded video;
- life video image display for plant supervision as well as visual inspection of equipment or products and video presentations for operator and maintenance support;
- life, reproduced, or computer-generated audio, vibration, and speech for supporting visual perception, alerting, and informing operators;
- 3D stereoscopic and holographic presentation of the generated visual scene and spatial presentation of audio information;
- face-to-face video communication and conferencing, incorporating document exchange, drawing and annotation facilities; screen-operated telephone and radio communication; and,
- maybe in the future haptic information, motion, music, odour, and more.

For research and experimentation in this area, an experimental set-up needs in addition facilities for development of software, scenes and environments. Some additional preparations necessary are

- recording equipment to take audio and video samples in existing plants, import filters for CAD data from existing environments;
- modelling software to generate 3D objects and assembling those to scenes together with audio and video objects;
- various means for manual interaction like mouse, joystick, keyboard, together with related analogue and digital input channels;
- software to generate realistic behaviour of the interface, like plant, process, and communication simulators; and
- support for supervision and control of experiments, data collection, and evaluation.

The following section describes some functions of a multimedia process control room with examples assuming a live process environment.

Computer Graphics and Video Support

Today, computer graphics in process control rooms are still too much copying the traditional means of walls with control instruments to the computer screen, while separate monitors provide video information. Current research shows the value of displays developed into two directions. One is creating more abstract views that are appropriate to the operators' task, behaviour, and knowledge (Ali, 1997; Ali and Heuer, 1995; Johannsen et. al., 1997). The other direction supports the objective to bring back the operator into the plant by generating views close to reality (Wittenberg, 1997). In both cases, integrating video information can support the view.

The demand for further enhancement of a computer generated view leads to stereoscopic and holographic displays. *Stereoscopic* displays extend the view from the flat screen into the third dimension without taking account of the observer's position. The common technology generates separate images for each eye of the observer, displayed alternately on one screen or in parallel on two screens. Head-mounted devices providing one screen for each eye support the second solution while the observer needs to wear special glasses for the first version.

Stereoscopic views look abnormal to the observer when moving around the scene, as a 3D stereo view presents the image seen from one specific position only. The advantage is that the image is the same for every viewer from every position. The disadvantage is that the viewer cannot just walk closer or around the image. Even shifting the head from side to side or forward-backward does not change the view as expected from natural scenes and creates an annoying effect.

Holographic views take into account the observer's eye-point by tracking the position of the 3D-glasses. A holographic projection adapts to shifts in all directions (left-right, up-down, to-from) within the range of the tracking device. The observer can see the scene from different directions as long as he looks towards the screen surface. This feature easily adds to stereoscopic views with additional tracking hardware and software components. The display generation, however, supports only the view of one person; other persons need separate sets of display, glasses and tracker. Using head-mounted screens and sensing position and orientation provides means for full virtual reality that also shows views from the reverse side. The drawback is the weight of the helmet to carry and the isolation from the real world. The latter also acoustically, as common headsets moreover provide headphones. With this set is possible to walk around the display in the virtual world but difficult to avoid at the same time falling over the objects in the real world.

Besides video integration to enhance personal communication and conferencing, we see the necessity of two different video applications in process control: Live video for equipment or product observation, and video sequences for operator support. Live images from the plant, integrated into computer generated diagrams enable operators to inspect critical equipment visually. Cameras either placed in strategic position down the plant or hand-held (or even helmet-mounted) by maintenance personnel may provide these signals. In case of failures, video clips can instruct operators as well as maintenance personnel on correct procedures.

Audio Support

In a conventional control room, the audio channel provides the operator mainly with alarms. A multimedia environment adds acoustic information from the process as sounds and noises that provide the operator with relevant information on process state. These need to cover the full range of audible frequencies and include vibrations. Acoustic information from the process can be collected live in the plant or generated from process measurements. Process sounds can give a static acoustical picture of the process or focus on specific sections of the plant according to operator needs or current operator focus and actions. Individual microphones, placed at strategic points in the plant area can collect a live acoustic picture. The individual signals need appropriate mixing taking care of different sound intensities, thresholds and masking effects. In contrast, it is also possible to generate a synthetic acoustic picture artificially from plant data using stored sound samples or from noise and sound generators. In all cases, the spatial arrangement of sound sources must meet the layout of the control room.

As an example, the control room of a fossil-fired power plant shows a spatial separation between furnace and steam generation and turbine and power generation. Instruments and controls for steam generation cover the left, those for power generation the right side of the control room. Important parameters are the continuity of the combustion process, the balance of heat and water on the left side and the turbine revolution rate and vibration on the other. In the past, operators were able to feel harmful vibrations of the turbine in the control room as long as it was sufficiently close to the turbine. The current load as well as the revolution rate provides a continuos background sound in the turbine building. Microphones can pick up the sound down in the plant and speakers on the right side of the control room play it to the operators. Special transducers or low frequency speakers provide vibration information. As operators have to keep turbine speed very close to the nominal rate, an artificial generated signal, providing more contrast in deviations from set points, may be of more use. In this example, acoustic information provided on the left side of the control room relates to the steam generation system. As an example, sounds of flowing water with different intensity can provide state information. Besides spatial arrangement, such sounds show good contrast to the noise from the turbine in frequency and complexity.

Acoustic information from the process control system includes alarms and attention getters. These can be generated or pre-recorded tones, sounds, or voice messages. The system should provide means to spatially separate attention-getting audio on and arrange it according the general control room layout.

System Components

Following a market evaluation in 1996, we selected the equipment and implementation begins in late summer 1997. The Hardware selected includes high performance graphics workstations as well as high-end consumer electronics. The main software component is a set of programs for generating, animating, and displaying virtual worlds.

Hardware

Central components of the hardware are two graphics workstations, a SGI Octane/MXI with two 195 MHz R10000 processors, 256 MB memory, 4 MB texture memory, and a SGI O2 with 180 MHz R5000PC processor, 96 MB memory, Video I/O and camera. Both workstations are equipped with identical 20" monitors capable of displaying stereo and holographic images.

Hardware for holographic presentation of images consists of active stereo glasses with liquid crystal shutters, an infrared emitter synchronising the shutters with the monitors frame rate, and a tracking system to determine the actual eye point. The system from CrystalEYES will be used in combination with the 3rd EYE software.

As an input device, the Space Mouse will be used. This device, developed by the German aerospace research establishment DLR, is basically a force stick. However, along with the x- and y-axis, it senses translation force in the third dimension (z) and rotational forces in three dimensions (pitch, roll, and yaw). A 3D audio system will be added in the future. A possible candidate is the *Acoustreon.* This system, hosted on a separate workstation, applies signal processing to given audio data. Given the distance and direction from the observer to the sound source the system filters the audio data such that the observer has the impression of a distant sound source in this position.

The conventional audio periphery centres on a 6-channel amplifier and equaliser.

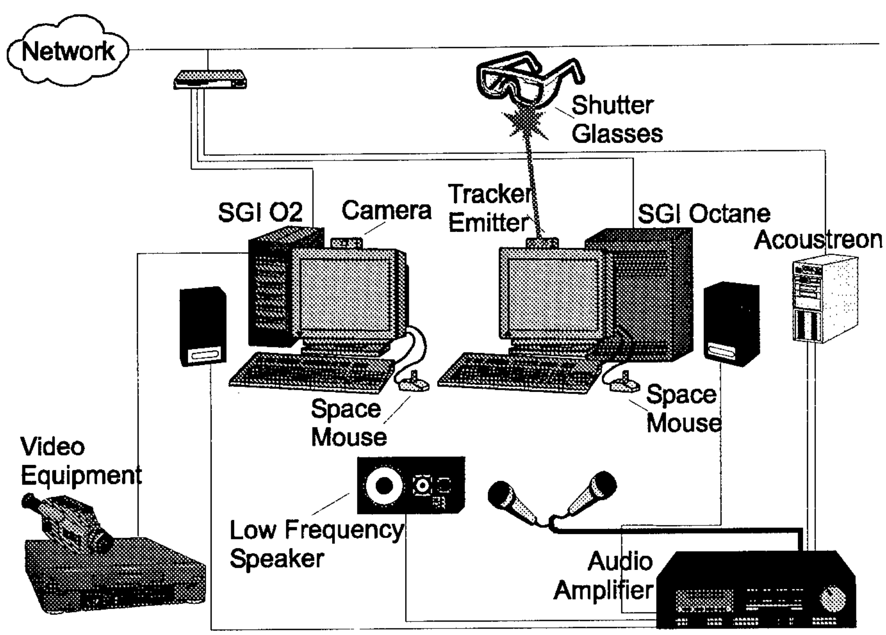

Figure 1: System Components

The two graphics workstations, a DAT recorder, and microphones provide audio inputs signals in stereo. For output, four speakers are placed around the workstations as well as headphones for privacy. The DAT recorder will be used to take high-quality samples of process noise and sounds during field studies. Integration of a special low-frequency amplifier and speaker (subwoofer) or a vibration device is under consideration. Such a vibration device, the *T.A.N. Vibrofloor System* is a disk with 20-cm diameter, coupled to the floor or the operator's chair. It can provide vibrations with a power of 100-Watt RMS with frequencies down to five Hz.

The video option of the O2 workstation provides Essential equipment for videoconferencing. This includes two input-, one output-channel and the monitor-mounted digital camera. A camcorder will be used for recordings in plants. We also imagine the use of portable, helmet-mounted cameras (for, e.g., maintenance personnel) coupled to the control room by radio links. Systems with a range suitable for in-house use are available at a price below 1.000 DEM. Besides this local video equipment, support exists by the universities Media Centre providing professional video cutting and editing facilities.

Both workstations will have access to the laboratories local area network, the universities future ATM network, and the local ISDN telephone exchange. The laboratory's network provides access to several simulators, among those are a high fidelity simulator of a distillation column, cement plant and power plant simulators, a small business jet and a simplified helicopter.

Software Tools

The major software are five components from the virtual reality package of the German company REALAX. The modeller enables to create 3D volumes or to import shapes from conventional CAD data. Objects are than grouped and combined to scenes in the editor, which also provides material properties (colour, reflection, transmission) and surface textures. The scene generated this way is displayed using the real-time component. Additional software in combination with the stereo glasses described above generates the holographic view. Features of this software important in our applications are *level of detail switching, morphing*, and *callback functions*.

Level of Detail switching saves limited computer capacity. Instances of an object are created with different complexity. The close-up view shows the object with all its details. When the distance between object and observer increases, displaying the less complex version keeps the number of polygons in the scene smaller.

With morphing, it is possible to use several (slightly) different shapes of an object and display a weighted average of these shapes. This feature is impressively demonstrated in animated sequence of car crashes. However, we can imagine giving an operator hints on pressure and stress by displaying deformations in boilers, pipes, and joints.

Inevitable in research, when own software extends existing tools or when simulation data will be integrated is a means to access and manipulate of the visual scene. Callback functions hand control to user programmes periodically or on defined events. They also pass pointers to scene data. When control is transferred and data is accessible, the scene can manipulated or information extracted for other applications. Thus, measurements provided from an external simulator can change dials in the scene and information on eye point position can be used for correctly generating 3D audio.

Intended Research Topics

Some of the features wanted for a multimedia control room are already build into or delivered with the computer equipment, such as the *InPerson* teleconferencing tool. This provides a shared whiteboard, on which the local and different remote users simultaneously view and manipulate images and video windows displaying the conference participants. However, the multimedia process control room is a research vehicle. Existing software provide only tools and existing solutions from other areas provide only pointers to own developments. Microphones, speakers, and the camera are standard equipment of modern workstations as they become to be for home computers. Now it will be our task to evaluate existing capabilities of hardware and software as well as known solutions from, for example, the entertainment industry for their use in process control.

Examples for possible use of multimedia in control rooms have been given already above. In all research performed in our laboratory we include the final user in the early phases. Considering the growing awareness of multimedia in present-day life we expect useful proposals from future users. Intended research topics include multimedia-supported co-operation between plant operation, maintenance, and management, management of information, user-support for large multimedia data bases.

Conclusion

The experimental Multimedia Process Control Room is a new vehicle to support future research projects of the Laboratory for Human-Machine Systems in cooperation with industrial partners. It will also enhance lectures and support diploma- and PhD theses.

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A Multimedia Decision Support System for Work Groups in Flexible Manufacturing

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Abstract

In flexible manufacturing, the shop-floor staff is increasingly organized in semi-autonomous work groups with an enriched task spectrum. This suggests to provide assistance in the form of decision support systems. However, there are few decision support systems specifically designed for work groups, which moreover do not yet have received a widespread acceptance. Therefore, a new support concept, focusing on the universal problem solving strategy of case-based reasoning, has been developed. This concept was realized as an application program for Personal Computers, in close cooperation with the shop-floor staff of a CIM pilot plant. The program allows to record cases in a format similar to a news report, including multimedia illustrations, to ensure a vivid representation. The resulting case database can be searched for records that are similar to the current task, which then serve as models. In addition, the system provides functions to integrate the case data, to support the work group in its strategic decisions.

Introduction

The increasing complexity of flexible manufacturing systems requires an integration of the human resources, which takes into account the interactions between previously separated task domains. Correspondingly, there is a growing number of manufacturers who integrate duties formerly performed by their specialized departments, like quality control and maintenance, into the task spectrum of the shop-floor staff. Such an enrichment of the task spectrum has considerable positive effects on the performance of the employees (Lovén, Helander, 1997). As a supplementation, the shop-floor staff is frequently organized in semi-autonomous work groups, coordinating the activities and pursuing a continuous improvement process. As an example, in the German machine building industry the proportion of companies practicing group work in their manufacturing departments increased from 29% to 43% between 1991 and 1993 (SFB 187, 1994, p. 3). That is, substantial expert decision competencies are transferred to the shop-floor.

Due to the complexity of flexible manufacturing systems, it seems to be advisable to provide the shop-floor staff with appropriate decision support tools, as an assistance in exercising its new competencies. However, most of the currently available decision support systems are primarily designed to fit the requirements of specialized departments. Presupposing a sophisticated educational background, these tools represent the work system in an abstract, generalized way. In addition, they are rather incompatible with an integrated task spectrum, because of their frequently narrow field of application.

Lately, a number of decision support systems specifically designed for a shop-floor environment have been introduced, to assist work groups in short-term scheduling

(Mertins, Carbon, 1996), quality management (Triebe, Falter, Krings, 1996; Wasserman, 1995), or failure diagnosis and repair (Engel, 1996; Timpe, Rothe, Gaßner, 1997). But there are indications that these systems meet the practical requirements on the shop-floor only to a certain extent. As a current example, in the research project RE-INST, concerned with 'Job Enrichment by Reintegration of Maintenance Tasks', the participating companies had to resort to internal developments, which were more or less ad-hoc solutions, because of the limited software development resources (IAW, 1997).

Therefore, in the following section weak points of the currently available decision support systems and potential alternative design concepts will be discussed. Subsequent to this discussion a prototypical realization of the proposed design alternatives is outlined. The final section addresses possible shortcomings of this prototype.

Current Systems and Alternative Design Concepts

Currently available decision support systems for work groups are frequently characterized by three weak points, a restricted scope of application, an insufficient flexibility, and a tutorial support concept. Generally, the systems are designed to assist a single task, for example maintenance, whereas the enriched task spectrum of the shop-floor staff requires a more comprehensive support. Moreover, they are frequently restricted to specific equipment, for example a certain manufacturing center, which seriously limits the set of potential users and provides difficulties for the integration of the system in the information infrastructure of the factory.

A solution to the problem of a restricted scope demonstrates SAP, for example in its latest product R/3. Here, the software is a rather general frame that the users tailor to their needs and requirements by entering the equipment and company data relevant for their purposes.

However, experts are necessary to adapt such an installation to modifications of the equipment or the organization. This limited flexibility carries a lot of weight in the present context, as work groups, in their continuous improvement process, are expected to identify weak points of their work system and to eliminate them rather autonomously, whenever possible. Therefore, it would be more coherent if the shop-floor staff could represent these improvements in the corresponding databases of their assistance system.

Finally, the support concept of currently available assistance software is generally based on the expert system approach. That is, the knowledge of external experts about the equipment and the task domains is implemented in databases, which the shop-floor staff uses as more or less intelligent computerized manuals. However, such a tutorial support concept is rather incompatible with the motivation to introduce group work, to tap the staff's practical knowledge and make this expertise available to the colleagues.

An alternative support concept can be derived from the finding that expert employees frequently accomplish a task in analogy to a previous, similar case (Rothe, Timpe, 1997). According to Riesbeck and Schank (1989) this principle is a ubiquitous problem solving strategy, or as they say, 'the essence how human reasoning works' (p. 7).

The concept of case-based reasoning is outlined in Figure 1. Supposing that an employee realizes that the fill-level of an oil gauge is only 75% (if-component of the current case).

Then the question arises how he or she should react to this finding (then-component of the current case). To clarify this point, one can refer to episodic memory, in which numerous previous cases are stored, each as an if-then-relation. First he or she tries to recall the case whose if-component approximates to the if-component of the current case (Best Match). Subsequently, the employee has to adapt the then-component of the recalled case to the one under consideration (Analogy Formation). In the scenario in Figure 1, for example, he or she would refill a smaller amount of oil, as the fill-level is now a little bit higher than that in the recalled case.

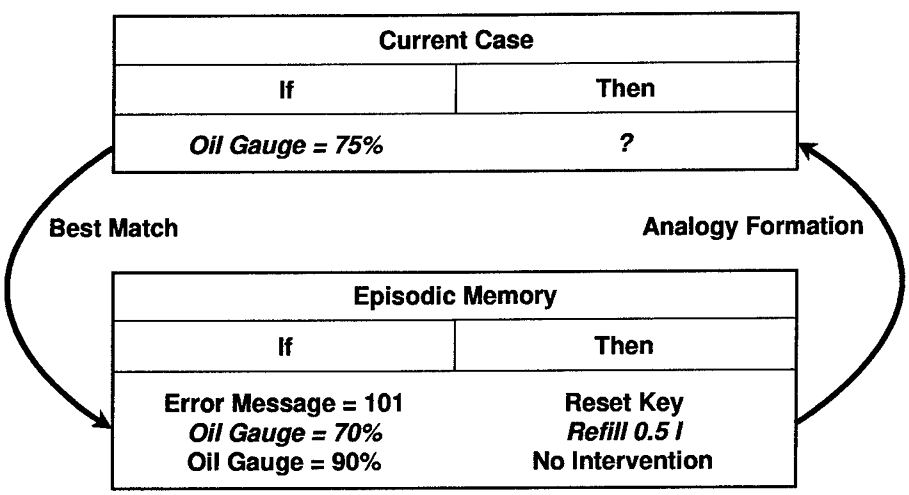


Figure 1: Conceptual outline of case-based reasoning

According to the outline in Figure 1 an assistance system supporting case-based reasoning should have at least three components. First, the shop-floor staff needs a database containing previous cases, as a reduction of the memory demands. Secondly, the system should provide a function allowing to retrieve a case whose if-component fits the current task, as a support of the best match. Thirdly, the system ought to assist in the adaptation of the then-component of the retrieved case to the current conditions, the analogy formation.

As the case database represents the practical knowledge of the shop-floor staff it cannot be provided by external experts. Rather, the shop-floor staff should record the cases they accomplished, which requires an equipment- and task-independent data recording interface. In addition, the cases are to be represented as illustrative as possible, to allow that they can be reconstructed by those colleagues who were not directly involved, as well (Proctor, Dutta, 1995). This requirement of a vivid representation leads to the application of multimedia (Hasebrook, 1995). That is, cases should be illustrated by graphic, sound, or digital video files, if necessary.

However, the work group needs not only support in the execution of specific tasks, but also in its strategic decisions concerning, for example, quality control procedures or preventive maintenance intervals. With regard to the requirements of such a support, Lockamy and Cox (1995) claim that 'at the plant level, performance on the strategic objectives must be evaluated with a minimal passage of time to provide an appropriate level of control' (p. 233). Thus, the decision support should also supply functions for the integration of the case data, allowing to perform weak point analyses.

Prototypical Realization

The alternative design concepts outlined above have been realized in a Windows application program for Personal Computers. The program, called Behavior-Outcome Feedback (BOF), has been developed in a CIM pilot plant, in close cooperation with the shop-floor staff, which in addition tested different versions in practice. BOF is installed directly at the equipment and thus is integrated in the activities on the shop-floor. The program provides a facility for the recording and administration of cases. These cases are merged by feedback functions, presenting the underlying behavior-outcome contingencies in a graphic way. In the following, the use of the program is illustrated by referring to data that were recorded at the flexible manufacturing center Hüller-Hille nb-h 90.

The desktop is designed as a Multiple Document Interface (MDI), the case administration and feedback charts are child windows within the main program window. Figure 2 shows the child window of the case administration. Its structure is based on text grammars for news reports (Dijk, 1983), to provide a format that is general enough to document cases from different task domains. The field *Condition* describes the state of the object under consideration before and after the event or activity. These values do not necessarily differ, in an inspection, for example, they are identical. Field *Cost* allows to record aspects relevant for the evaluation of the event or activity, which typically are economic variables. Beyond that, they may include features like the cognitive or physical strain, if one advocates a more general cost concept (Fry, 1995; Gelders, Manaerts, Maes, 1994).

The values for the fields *Status, Who, What, Where, Why, Condition,* and *Cost* are entered using dialogs in which the alternatives are organized in hierarchical selection lists, similar to the Explorer in Windows 95 and NT. These selection lists can be edited, permitting to adapt the case administration to arbitrary equipment, task spectra, to be controlled conditions, and cost aspects. For example, one might record not only maintenance activities, as shown in Figure 2, but also quality control measures, specifying the corresponding items.

The section *Illustration* allows to attach multimedia files depicting a specific aspect of the case in a more vivid way. The program processes a fairly wide spectrum of multimedia data, be it audio, bitmap, or digital video files. Such a file might be a scanned technical drawing showing the construction of a component or a tutorial video about how to perform a specific measure. Pushing a button in the *Illustration* section, the multimedia file is displayed in its original size in a separate child window, which provides some extra presentation functions.

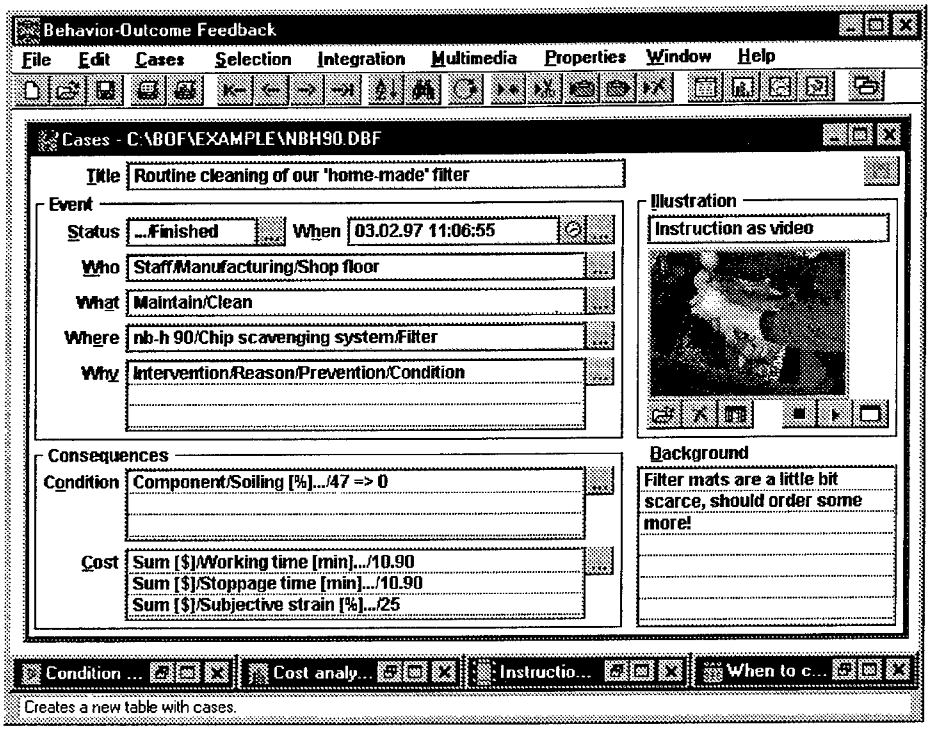
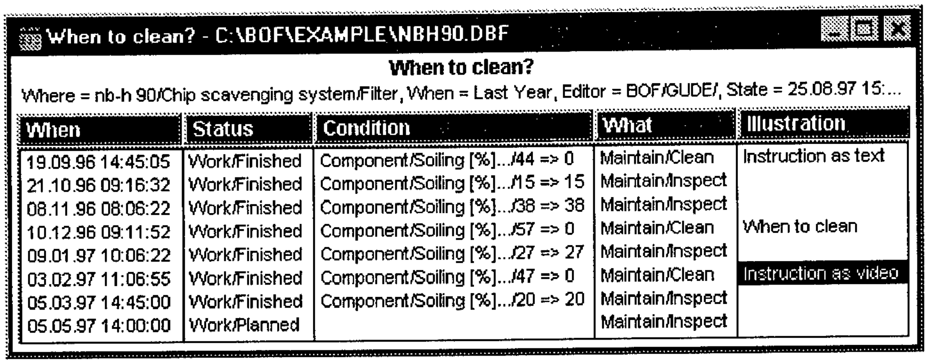


Figure 2: Main window of BOF with the child window for the administration of cases, presenting a maintenance activity

Case-based reasoning is supported particularly by a table function. In such a table the previous cases relevant for accomplishing the current task are listed. Figure 3 shows a table for the question with which soiling the filter of the chip scavenging system has been cleaned so far. In addition, one of these cases provides an Illustration 'When to clean', showing the cleaning criterion in a digital photo. For an easy access of the complete case data, tables provide a navigation facility – clicking on an item the corresponding record is presented in the child window of the case administration.

Other functions perform an integration of the cases, to support strategic decisions of the work group. One aspect is to aggregate the cost values, in order to determine weak points of the strategies. An example of a cost analysis is shown in Figure 4, presenting the working time expenditures for the maintenance of the coolant system components during a specified period of time. According to this bar chart, exceptional working time values were recorded for maintaining the tank, as compared to the other components of the machine unit.

Again, BOF is rather flexible, as it allows to analyze arbitrary subsets of the selection lists. Moreover, the case data can be analyzed with regard to different levels of the cost hierarchy. For example, the program permits to specify a weighted sum of costs, rather than a single item, as the outcome variable.



When to clean? - C:\BOF\EXAMPLE\NBH90.DBF

When to clean?

Where = nb-h 90/Chip scavenging system/Filter, When = Last Year, Editor = BOF/GUDE/, State = 25.08.97 15:...

When	Status	Condition	What	Illustration
19.09.96 14:45:05	Work/Finished	Component/Soiling [%].../44 => 0	Maintain/Clean	Instruction as text
21.10.96 09:16:32	Work/Finished	Component/Soiling [%].../15 => 15	Maintain/Inspect	
08.11.96 08:06:22	Work/Finished	Component/Soiling [%].../38 => 38	Maintain/Inspect	
10.12.96 09:11:52	Work/Finished	Component/Soiling [%].../57 => 0	Maintain/Clean	When to clean
09.01.97 10:06:22	Work/Finished	Component/Soiling [%].../27 => 27	Maintain/Inspect	
03.02.97 11:06:55	Work/Finished	Component/Soiling [%].../47 => 0	Maintain/Clean	Instruction as video
05.03.97 14:45:00	Work/Finished	Component/Soiling [%].../20 => 20	Maintain/Inspect	
05.05.97 14:00:00	Work/Planned		Maintain/Inspect	

Figure 3: Table of previous, similar cases for the problem when to clean the filter of the chip scavenging system; the case in the last row represents the corresponding current case

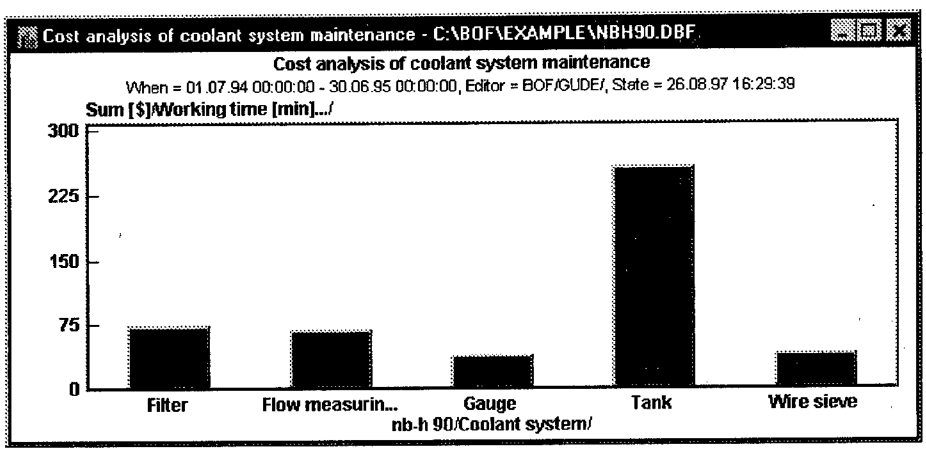


Figure 4: Cost analysis presenting working times for maintenance activities at the components of the coolant system during a specified period of time

If a weak point has been determined, the next step is to identify potential reasons. This is supported by providing time and condition analyses. A time analysis allows to determine whether an event or activity occurred periodically, after a constant time interval. For this purpose, the interval of successive cases is plotted as a function of time, expecting that they form a more or less parallel line to the time axis. Figure 5 shows the corresponding scatter plot for the events at the coolant system tank, which are obviously aperiodic. As in the tables, such a time analysis includes a navigation facility; pushing a circle one gets the corresponding complete record in the child window of the case administration. This would reveal that the events in Figure 5 were concerned with the inspection of the fill-level and the topping up of the tank. Therefore, a potential cause of the identified weak point is an inconsistently performed time-based strategy.

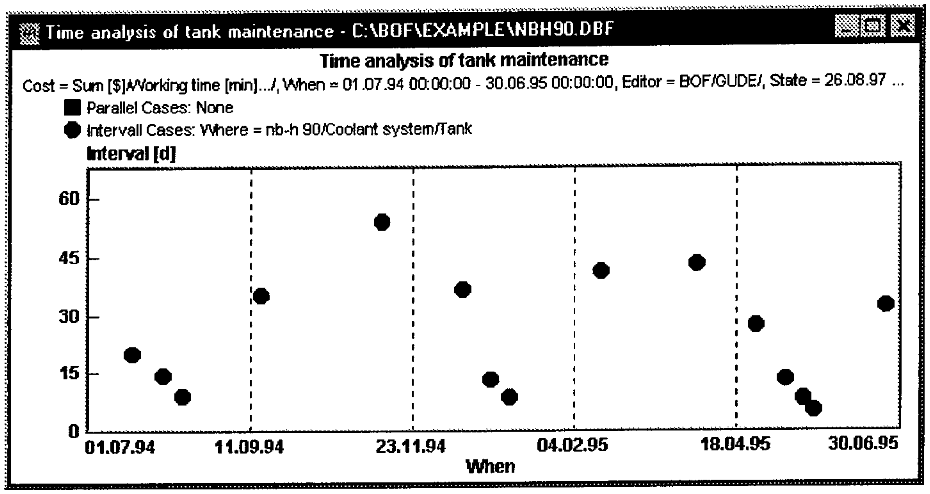


Figure 5: Time analysis for the maintenance of the coolant system tank during a specified period of time

However, an alternative explanation is that the maintenance of the tank was not performed as a routine task, but rather dependent on its condition. The shop-floor staff of the CIM pilot plant preferred such condition-based strategies, as can be seen from an analysis of their recorded maintenance activities. According to this, 52% of the cases were inspections. Moreover, condition-based service and condition-based preventive repair dominated over their time-based variants (26% vs. 6% and 2% vs. 1%, respectively). Finally, 11% of the records were corrective repairs. The preference of condition-based strategies seems to be rather general in nature, as the above finding is in accord with results from more controlled laboratory settings (Gude, Psaralidis, Stiegler, Seeber, 1996; Kerstholt, 1995).

Consequently, the assistance system permits to create so-called condition analyses. Such an analysis visualizes whether an event or activity occurred with specific values of the condition under consideration. Thus, for a consistently performed condition-based strategy one would expect that the cases line up on a parallel to the time axis.

Figure 6 shows the corresponding plot for the fill-level of the coolant system tank. A circle represents the condition before an activity, the top of the arrow depicts the resulting condition. According to the figure, during the first six months there was no well defined criterion when to top up the tank, occasionally this activity was performed rather late. During the last six months the behavior was much more consistent, with the criterion beyond a fill-level of 50%.

This pattern suggests that the identified weak point is based on an initial inconsistent condition-based maintenance. To test this hypothesis, the staff can create separate cost analyses for the first and last six months. These analyses reveal that during the first period of time the working time expenditure was 182 min, which then decreased to 87 min. That is, the strategy shift in 1995 had actually a beneficial effect on the outcome variable analyzed here.

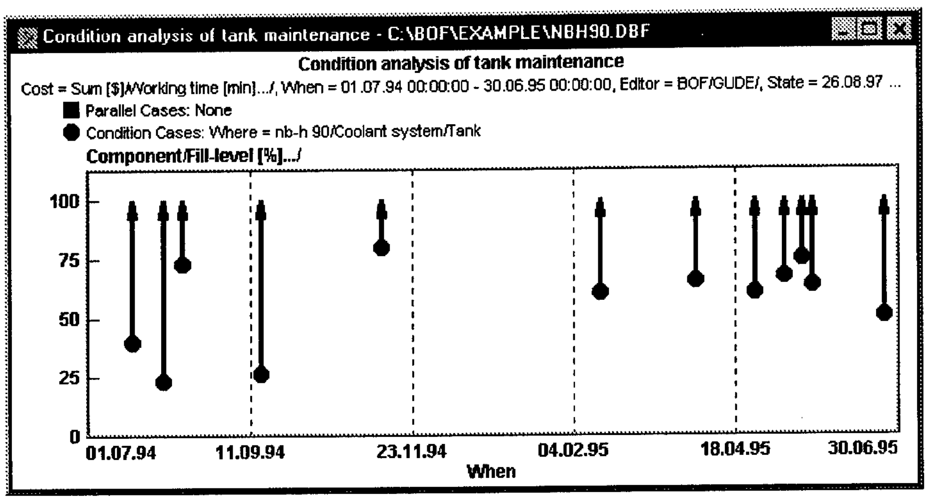


Figure 6: Condition analysis for the maintenance of the coolant system tank during a specified period of time; the three cases in Figure 5 for the period of time between 23.11.94 and 04.02.95 are not displayed here, as the required fill-level data are missing in these records

Condition analyses do not only assist in the evaluation of preventive maintenance strategies but can be applied in quality control as well. The corresponding plot is similar to a Shewhart control chart in Statistical Process Control (SPC), indicating required adjustments or replacements of tools. Moreover, examining the quality control procedures in cost analyses permits to optimize the sampling frequency as well as the sample size.

Conclusions

As a solution to the problems of a restricted scope of application and an insufficient flexibility, BOF provides a framework that the work groups can adapt to their specific requirements. As an alternative to the commonly realized tutorial support concept, the shop-floor staff is asked to record its practical knowledge in a case database, which supports the universal problem solving strategy of case-based reasoning. The database reduces, inter alia, the memory demands, which have been identified as a critical performance variable in manufacturing (Stanislaw, 1995). Moreover, less experienced employees can utilize their colleagues' practical knowledge, especially if the cases are illustrated by multimedia files. Finally, the program allows to integrate the case data for weak point analyses, which support the strategic decisions during the continuous improvement process.

The multimedia files are not provided by the development team, as the specific field of application is not known beforehand. Rather, the users have to get or produce those files that are relevant for their purposes. However, taking into account the current technical state-of-the-art, one should not expect that complex multimedia presentations can be produced by the work groups, because specific expert knowledge is still required. On the contrary, this is a task for specialized departments or the manufacturer of the equipment. Nevertheless, with the increasing application of multimedia in the office and at home, it is very likely that the required knowledge will be generally available in the near future.

In the current version of the assistance system the execution of the best match and the analogy formation is left to the shop-floor staff. The program allows to flexibly create a selection of previous cases. However, the user has to decide which of these cases optimally matches the present task and how to adapt it to the current conditions. For the moment, an automation of these processes has been deferred, as it presupposes considerable knowledge about the specific field of application (Reimann, 1997).

Although data recording was held at a minimum, it still requires some effort. Therefore, the users should try to achieve an additional return on investment. In particular, the exchange of case data ought not to be restricted to the members of a single work group but rather is to be extended across groups and companies, including the manufacturers of the equipment. Such an integration would be especially valuable for small and medium-size companies, which frequently have only restricted opportunities to obtain the practical knowledge required to develop optimized manufacturing strategies.

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Incorporating Ergonomic Considerations into Models of Manufacturing Systems

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Abstract

Today the consideration of worker, costs and environmental factors becomes more and more important in designing of technical systems. Diverse criteria, like qualification, work organisation, compensation of employees and work structuring, need to be more integrated into the planning process and for that reason also into the planning tools.

The qualification of workers is very important for reengineering manufacturing systems. Material flow simulators generate often only results concerning the utilization of workers. The developed evaluation module takes into consideration to what extent a worker is qualified for a given activity. It compares the qualification of the worker with the requirements of the working process. The interpretation of the results allows the determination of necessary training for the workers already in the planning stage.

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Introduction

In the last years many companies underwent a change from traditional structures, like productions in bulk, toward customers' order production. This requires new concepts of production organisation and flexible working structures. Planning and simulation tools must be able to describe these structures. In these kind of systems and their models, workers become more important.

Classic simulators are able to model technical processes in manufacturing and material handling systems with a variable degree of detail. They are used by factory planners to check and improve plans of technical systems. During the last years these tools were extended with components to support the modelling of flexible manufacturing systems, automated production lines and automated material flow processes.

One of the main application areas of factory simulation is the modelling of technical systems with their production processes and material flow. But today the consideration of worker, costs and environmental factors becomes more and more important in the design of technical systems. Diverse criteria, like qualification, work organisation, compensation of employees and work structuring, need to be more integrated into the planning process and for that reason also into the planning tools.

Background

Today's simulation tools are equipped with extensive components for the assessment of the behavior of manufacturing and material flow systems. The simulation results are delivered in a processed form as compressed result data. They include, for instance, information on the utilization rate of transport devices and manufacturing facilities, the utilisation of storage space, or the throughput time of items or orders. These data allow the materials flow planner an effective assessment of technical systems, their performance and their performance limits. Besides, most simulators offer primary result data. These are for instance trace protocols. The animation trace file is a special form of primary result data which allows a post-run animation. With the help of the animation components in today's simulation tools, the experienced user makes use of various possibilities in order to assess the modelled processes and/or to put the system states in a proper place due to their history.

Different levels of description and modelling for the workers are possible. In traditional simulation models workers are often only components required for the operation of the manufacturing system. This kind of description now is not sufficient to fulfil the extended requirements of simulation studies.

A team of the Association of German Engineers (German abbreviation: VDI) is developing a VDI Guideline dealing with the „Simulation of material flow and production systems". It is known as VDI 3633. Part 8 of this Guideline deals with the workers in simulation models. Two terms are introduced: worker-integrated and worker-oriented simulation. The main aim of this part is to define the minimum requirements for worker-integrated as well as worker-oriented simulation of manufacturing and material handling systems.

Worker-integrated simulation requires in addition to the modelling of the production and material handling system also the modelling of the workers.

For the modelling of the workers the following minimum requirements have been defined:

- description of each single worker or type of worker,
- description of teamwork,
- consideration of the qualification level of each worker or type of worker and
- separation between running time of technical system and working hours of the workers.

In addition to the classic simulation results, the planning team is provided with more information about the system for their decision making, e.g. they can estimate how many workers are necessary and what qualification they should have. This kind of modelling of workers only requires an appropriate detailed modelling of the technical system.

We use the term worker-oriented simulation in case that the simulation study primarily deals with worker related aims. Again, the basis is the model of the production and material handling system. Normally, the level of detail is higher than for worker-integrated simulation.

Aims of the simulation study are to get results about impacts of different working forms on workers. Therefore, the modelling of additional properties is necessary. These are, for example,

- physical and non-physical stress and strain factors for workers,
- changes in qualification due to learning and unlearning, or
- modelling of worker's reliability.

The modelling of these properties requires additional input data and evaluation algorithms. Additional input data and evaluation components are expensive and so only properties relevant for the aims of the simulation study are included.

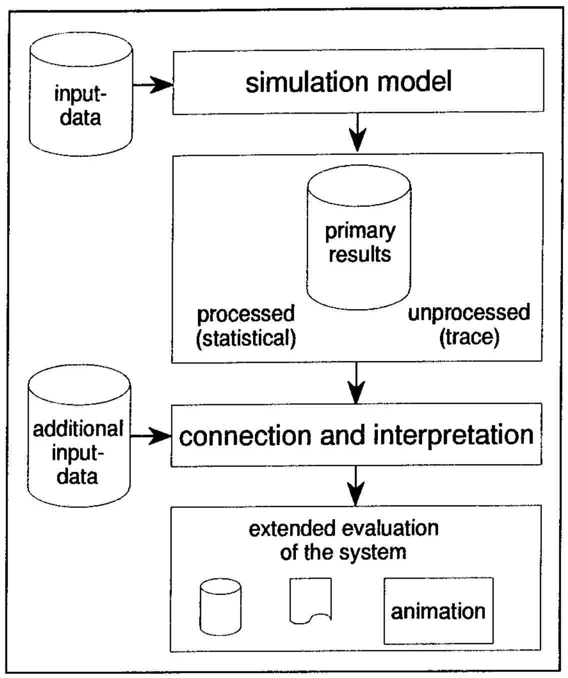


Figure 1: Data Flow in Advanced Simulation Models

In both cases, the worker-integrated and the worker-oriented simulation, the results about the workers have to be seen in combination with the results about the technical systems.

Extension of Simulation Tools

The Otto-von-Guericke University of Magdeburg and the Institute for Industrial Medicine, Safety and Ergonomics (ASER) of Wuppertal have been cooperating in the field of worker-oriented simulation for about 6 years now. Main aspects are the modelling of stress and strain as well as of qualification aspects. We prototypically develop and test modules to complement simulation tools with defined interfaces. As these modules are useful for a wide area of simulation languages and simulation packages, a high user acceptance can be achieved.

The precondition for getting additional information is a simulation model that describes the analysed system in a very detailed way. It must have a clear connection of all manufacturing sequences to machines, items and workers. The series of manufacturing sequences (processes) are to be recorded in trace protocols. Also the writing of trace protocols of changes in states of system components must be possible. Both forms of trace protocols constitute as primary result data the basis for the extended data evaluation.

In principle, two approaches are possible: Additional functions may be integrated in simulation tools, as is done, for example, in simulators with special economic evaluation components. Such an approach requires a special tool for each simulator.

A second approach is based on post-run data interpretation. The unprocessed trace data are connected with additional input data. Special modules allow the extended evaluation of the system (see Figure 1). Different views for different user groups are possible.

We used the second approach. As an environment for the simulator, the evaluation modules and the database we use a help and documentation system. The following basic functions are part of the system:

- collection and interpretation of input data
- evaluation of the results
- help and documentation
- database connection

The evaluation modules can be chosen according to the aims of the simulation study. Figure 2 shows the implemented modules and their interfaces.

Help and documentation system as an environment for simulation

Normally the users of simulation-models are engineers of planning divisions, e.g. material flow engineers. This group of users is often not so familiar either with the developing of a model or with the interpretation of ergonomic results. Therefore it is necessary to give assistance in all states of the simulation process.

The prototypically developed help and documentation system was designed in Toolbook™ as an environment for supporting a planning team during the process of changes in working structures. The aim is not to replace the planning team, but to give them advice in decision-making. Additional specific data and information can be integrated by the user.

The help and documentation system may be used in each phase of restructuring. In the first stage experiences from similar projects in other companies are demonstrated so that the planning team can put their aims in concrete terms. They are then asked for necessary input data to give a rough estimate of the planned system.

The system demonstrates to the users the possibilities and the limits of a simulation study for a special field of application. Based on this information, the planning team can decide whether a simulation study is necessary or not.

If more detailed information of the dynamic process is necessary, input data that have been introduced until this stage can be transferred into the simulation model. Examples for such data are the description of the working cycles and their characteristics, types of workers and their qualification as well as specifications of the expected order situation.

After the simulation runs, the help and documentation system supports the interpretation of the results. Another feature of the system is to document the restructuring process.

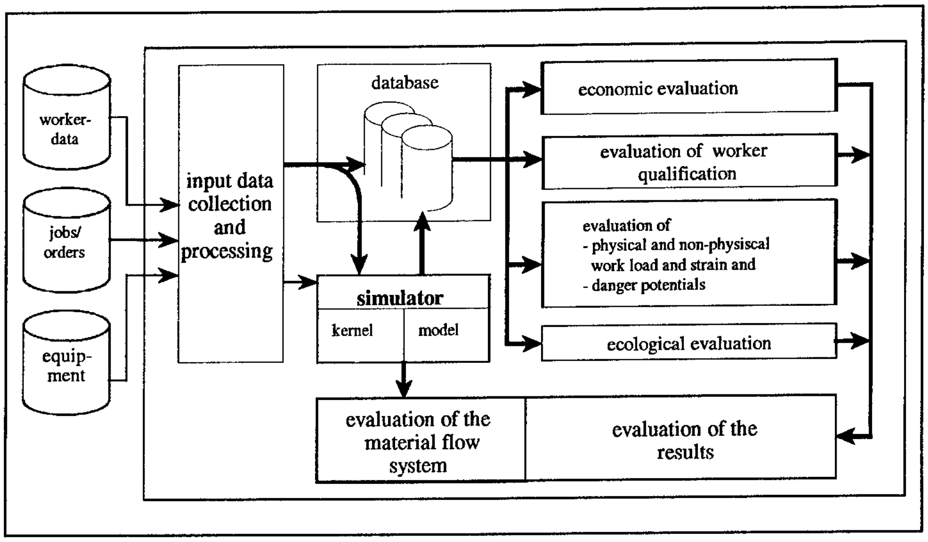


Figure 2: Components and Interfaces of the System

Collection, preparation and management of input data

In addition to the data collection supported by the help and documentation system, special modules can be used. Evaluated data for stress factors of working sequences can be directly imported from the stress documentation system (German abbreviation: BDS) which was developed for risk assessment in enterprises. Also special input data modules as a part of simulators can be used.

The data are transferred to a common database, in our case we use the PARADOX™-format. For the data exchange between database and simulator we use the ASCII-Format. This format is supported by nearly every database and simulation tool independent from the hardware and operation system.

For the extended evaluation of the simulation results, it is necessary to find a reference parameter the additional properties can be assigned to.

The application of this concept requires a trace file generated by the simulator with the contents starting and closing time, working location, working item and number of worker for each working sequence. The combination of working sequences and primary simulation results is realized by a connection file which is represented by a matrix.

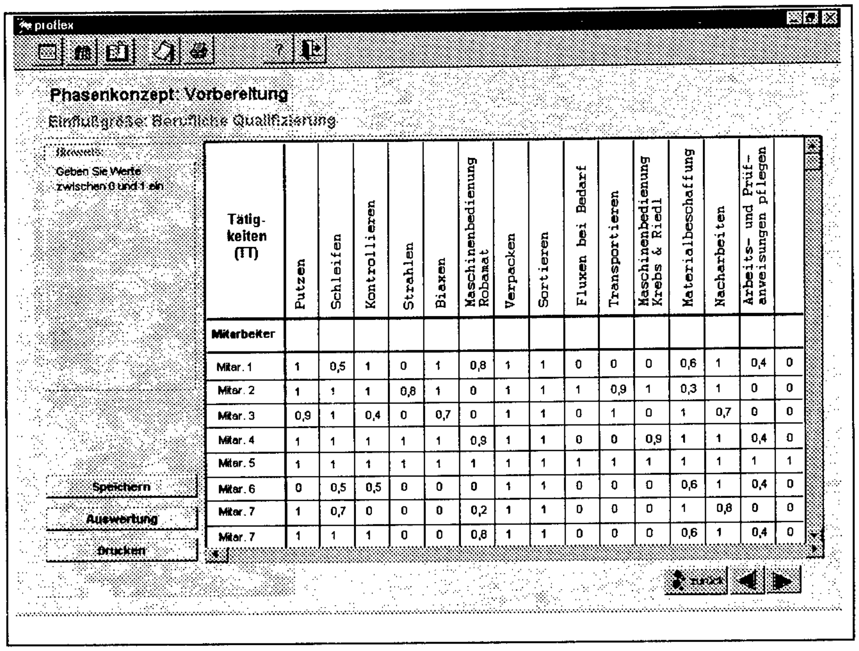
Another kind of data connection is the extension of state protocols generated by the simulator with additional data. These state protocols are necessary for the evaluation of data which cannot be collected from working sequences, e.g. environmental conditions.

One of the main aspects of our work is to get more information on the required qualification of the workers. Questions that arise often during the restructuring process are:

- Are the workers qualified for the new tasks ?

- Which tasks must a worker be qualified for?

It is difficult to generate results about the required qualification of the workers. Normally the simulator assigns a worker to a work task only if he has an adequate qualification. However, simulators do not consider the effects of qualification on task duration and product quality. If no worker with the required qualification is available, the process is suspended until such a worker is idle.



Tätig-keiten (TT)	Putzen	Schleifen	Kontrollieren	Strahlen	Biaxen	Maschinenbedienung Robamat	Verpacken	Sortieren	Fluxen bei Bedarf	Transportieren	Maschinenbedienung Krebs & Riedl	Materialbeschaffung	Nacharbeiten	Arbeits- und Prüf-anweisungen pflegen	
Miterbeiter															
Mitar. 1	1	0,5	1	0	1	0,8	1	1	0	0	0	0,6	1	0,4	0
Mitar. 2	1	1	1	0,8	1	0	1	1	1	0,9	1	0,3	1	0	0
Mitar. 3	0,9	1	0,4	0	0,7	0	1	1	0	1	0	1	0,7	0	0
Mitar. 4	1	1	1	1	1	0,9	1	1	0	0	0,9	1	1	0,4	0
Mitar. 5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mitar. 6	0	0,5	0,5	0	0	0	1	1	0	0	0	0,6	1	0,4	0
Mitar. 7	1	0,7	0	0	0	0,2	1	1	0	0	0	1	0,8	0	0
Mitar. 7	1	1	1	0	0	0,8	1	1	0	0	0	0,6	1	0,4	0

Figure 3: Input data collection using a help and documentation system here: Input of worker's qualification level

In our modules two approaches are realized: The first approach is to give each worker a very high qualification. During the post-run evaluation, we analyze to what extent each single qualification was used. Specialists interpret the results and determine the necessary qualification demands for the workers.

In the second approach, the model control of the simulator gets the qualification data by a number for each worker and each task in the range from „0" (not able to perform the task) to „1" (well qualified for this task) (see Figure 3). Different levels of qualification can be used for the assignment of workers. If the chosen worker is not so well qualified, this may influence the duration of performance in the model. The interpretation of the results allows the determination of necessary training for the workers already in the planing stage.

Integration of physiological aspects

In particular in case of heavy work load or aggravated environmental conditions physiological aspects should be incorporated into the simulation model to provide for the evaluation of the workers' stress and strain factors already in the planning phase and the prevention of overstrain.

Therefore different stress factors must be taken into consideration. They result from the task, on the one hand, and the environmental conditions, on the other. Stress factors caused by the task are, for example, dynamic and static muscular workload as well as the required body posture. Stress factors caused by environmental conditions are, for example, noise, vibrations, heat or cold. They may primarily depend on the working location, but also on the working item and the task itself.

The level of detail should allow the definite assignment of working sequences to any workers, together with the indication of duration and working location. A working sequence may be composed of several activities, but may not be interrupted in the simulation model. The required data may be derived from risk assessment studies, which has to be done due to European regulations. If no data are available, instruments for risk assessment studies (e.g. BDS) can be used in a prospective way.

As a result of a simulation study we get exposure times for each worker. By combining the stress intensity and the exposure times, we can evaluate the stress factors for a normal shift. Physiological models for the prediction of heart rate are available to take synergetic effects into account.

By incorporating such ergonomic considerations, the planning team gains information on potential risks in an early stage of planning. So it becomes able to improve both the technical system and the working conditions and is always informed about the expected stress and potential risks in combination with the economic data.

Conclusions

With the presented approach we intended to show new application fields for simulation models. Additional knowledge is integrated into the additional modules. Results are preprocessed for the user. Of course, the user has to draw his own conclusions and take his own decisions as ever. Simulation is not able to optimize the system, but is able to evaluate planning. The supporting level for the planning team is increasing.

The shown modular approach concerning the post-run data processing allows to use classical simulation tools under various conditions in the diverse fields of application.

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Concept of an Object-Oriented Multimedia System for Teleservice - Applications

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Abstract

Multimedia communication is a technology of growing importance for user interfaces in automation and process control. We are investigating and developing methods and utilities, that provide an object-oriented integration of multimedia aspects into modern distributed process control systems. A general approach of a multimedia-based teleservice-concept will be proposed. We introduce an object-oriented multimedia communication system based on our implementation of the CORBA standard, which will also be described briefly. A first prototype of the communication system allows a periodic exchange of still images between a supervising camera at one computer and a remote computer via a small-band ISDN telephone line.

Introduction

Multimedia communication is a technology of growing importance for user interfaces in automation and process control. Some actual keywords related to multimedia are teleworking, telelearning and teleservice, and these also influence concepts of process control engineering. Think of acoustic and visual data obtained from microphones or cameras applied to a certain automation system. Simply used and understood as a new brand of sensors or actors they can improve automation concepts significantly. Supervising and monitoring of certain process states is simplified, if the operator can "see" and "hear" the real process at the same control station, where the process is visualized. The user interface is much more intuitive, if the operator can interact on images of the real things (for example switch on/off a motor with a virtual button on a real image). A large impact and added value can be expected from the integration of multimedia concepts in teleservice applications. The mean time for service and diagnosis of complex machines, installed far away from the supplier, can be significantly reduced by an intelligent teleservice concept.

We are investigating and developing methods and utilities, that provide an object-oriented integration of multimedia aspects into modern distributed process control systems. The main fundament is a strong and efficient concept of object-oriented communication. Based on the CORBA-standard we have developed an object management system, the MiniORB, which promises for this. Another goal, which speaks for an implementation of multimedia concepts into automation systems, is cost efficiency, i.e. low-bandwidth communication lines, efficient data compression and low-cost equipment. We will describe our experiments with a simple object-oriented multimedia communication system based on our implementation of the CORBA standard. This prototype allows a periodic exchange of still images between a supervising camera at one computer and a remote computer via a small-band ISDN phone line with adequate quality and speed.

The object-oriented approach

In control engineering a hierarchical concept of four layers is generally used (*Tab. 1*).

Each different layer has its own responsibilities. It defines different types of interacting processes and the necessary communication between them, concerning human users and machines. All participants can be modeled as objects. This matches obviously for sensors and actors in the process field, as well as for any computing system. Even all the different processes can be seen as communicating objects. Especially the human-computer-interaction consists of interacting objects, but with different levels of detail, depending on the model layer, where they live.

Tab. 1 : Levels of control

Factory administration	Administrative functions, i.e. in managerial-economics and marketing (administrative management)
Production control	Logistics control, quality control, controlling, operations scheduling (economical, technical and disposing tasks)
Process control	Plant control and supervisory, machine control 0 supervision, starting and stopping of processes (operative tasks) 1 measurement, command, control, visualization (elementary functions of process control)
Field	Sensors, actors, wires (data acquisition and set point control)

The object-modeling-concept can be explained with the following example: *Figure 1* shows a part of a chemical process. We can derive three different classes of objects, container, valve and reactor. The reactor looks like a specialized container with a heater and a mixer. Valves are of types input control and output control. Obviously there are hierarchical relations. The whole technical process can be abstracted step by step until the object-model is complete.

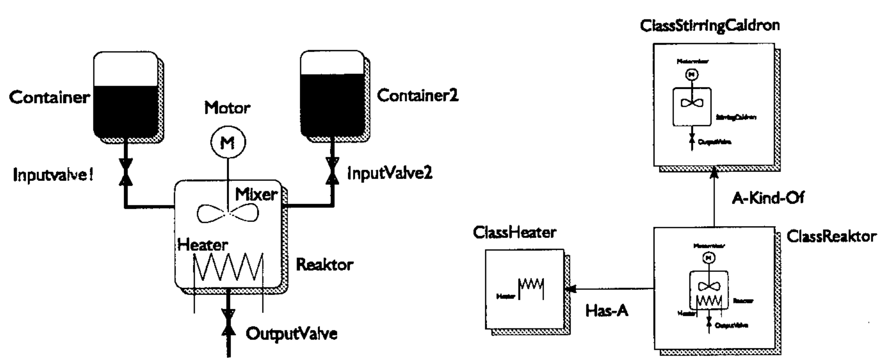

Figure 1 : A chemical process and its abstraction

Considering an object-model, which is universal and common for all layers we further deal with abstractions of all different real-world objects and communication. Therefor we mark several kinds of **communication-media** (i.e. speech, text, images), each of them instantiated as objects from different **classes** (i.e. reports, tables or process values). The communication-media are transmitted via special **communication-channels** like ETHERNET, field bus or telephone lines, according to special **communication-protocols**. A universal model must take this into account and provide the necessary mechanisms and concepts.

How does the object-model match a distributed automation system? A mechanism is necessary, which, based on a unique protocol, provides a network-transparent communication between principally heterogeneous computing platforms. An object should not need to have any knowledge about its computing environment, nor should it know, whether another object it communicates with, is local or remote. Also a fixed client-server relation is not possible, because the role of client and server can change in the context of an ongoing process. This demands a object- and communication manager - a **broker**.

Several broker concepts were introduced. OLE (object linking and embedding) and CORBA (common object request broker architecture) are the most important. OLE uses a fixed and binary compatible protocol, i.e. it demands equal operating systems and computing platforms. The implementation of a CORBA object broker is platform dependant, but the protocol is clear-text coded and independent of any hardware. This guarantees interoperability in any heterogeneous distributed computing system. Due to these evident advantages we chose CORBA as the basis for our developments.

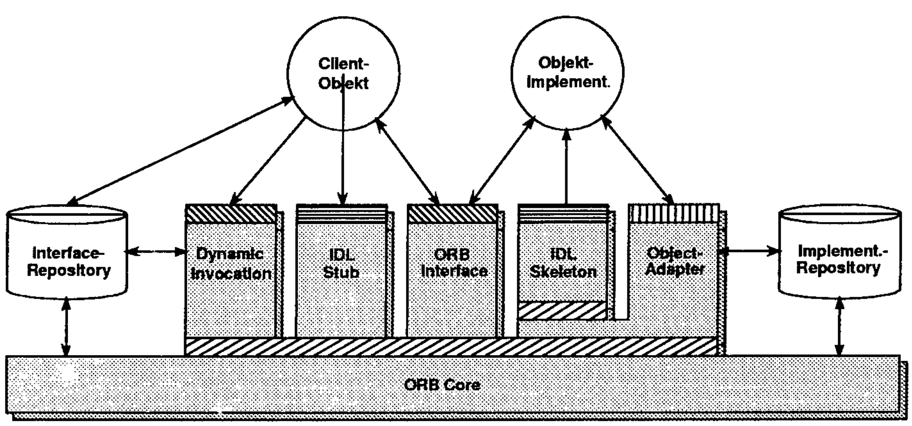

Figure 2: The architecture of an object request broker

A communication concept for distributed objects

The CORBA specification is part of the "Object Management Architecture" (OMA) developed by the OMG[1] and describes, how an "Object Request Broker" (ORB) has to be built. The ORB is the central component within an OMA environment. It supervises and

[1]OMG = Object Management Group

manages any messages between the distributed objects. The architecture of a CORBA ORB is shown in *Figure 2.*

A communication happens always between two members: a client object (CO), that needs a service and an object implementation (OI) that offers a service. It is neither platform-, nor implementation-dependent. The client object demands a certain service with a message called "request", that it sends to the ORB. The ORB knows, which object implementation is able to satisfy the client object's demands, locates the OI within the network and forwards the request message to it. The object implementation processes the request and produces some results, which it puts into a "reply"-message, that is then sent the way back to the client object.

The MiniORB

The MiniORB is our implementation of a CORBA-ORB (Heinz, 1996). Divergently from the original specification we have not yet implemented dynamic requests and a CORBA conformant exception handling, i.e. the dynamic invocation interface and the diverse repositories (*Figure 2*) are object of our ongoing work. The MiniORB is actually implemented in C++ under Unix, the interprocess communication between any hosts is based on Berkeley sockets.

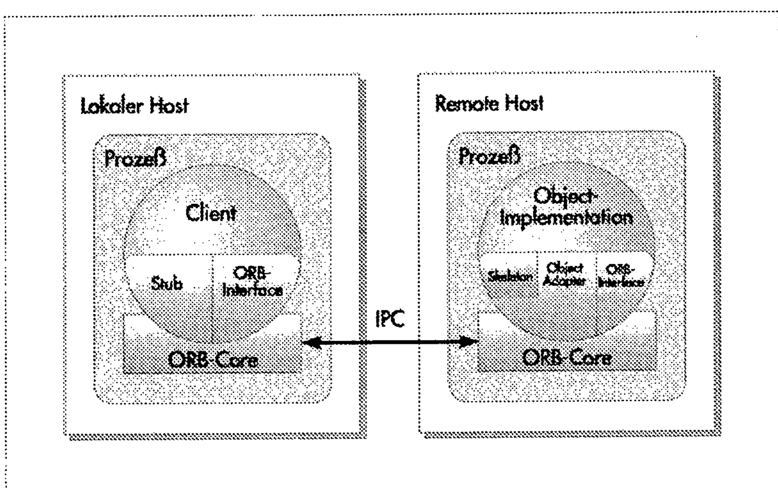

Figure 3 : Components of the MiniORB

Figure 3 shows the components of the MiniORB. It is a client- and object implementation- resident ORB, i.e. the ORB-functions are realized as library functions, which are linked to the respective code of the client object and the object implementation. These libraries contain

0 the ORB-core, that implements the inter-process communication (IPC) between the distributed computing systems, where the communicating objects reside on

1 the ORB-interface, that offers some general services to the client object and the object implementation

2 the object adapter, that coordinates the cooperation between the object implementation and the ORB.

The components "stub" and "skeleton" are generative components, which originate from the interface specification between a client object and the respective object implementation. They are generated as code-appendixes for any new object (see *Figure 4*). A client object is directly connected to a local "proxy object" (the stub), with which it exchanges any messages. The main task of a proxy object is to encode or decode the passing messages to or from the locally implemented ORB. A server-agent task (not shown here), residing on the remote system, resolves demanded object-to-object paths, initializes the correct object implementations and activates the inter-process ORB-to-ORB communication. The remote ORB then exchanges the message with the selected object implementation. The object implementation contains a special skeleton method, that decodes the received encoded data and calls the demanded service. The results are transmitted back to the client object by the opposite way.

The definition of interfaces

The interfaces between client objects and object implementations within a CORBA-environment are always well defined. The communication between any objects is transparent, i.e. an object can never determine, if its partner is a remote or local object. This is provided by a special interface definition language (IDL), which allows a neutral definition of all services a certain object implementation offers. The interface definition language is part of the CORBA specification.

The IDL description of an object implementation interface consists of the following components:

0 the name of the interface
1 the name of all services the object implementation offers
2 the data that are necessary for the execution of each service
3 the data that results from the execution of each service
4 the needed data types

IDL is a purely declarative language. The implementation of an IDL-defined interface requires the use of a conventional programming language. Therefore a mapping of the IDL constructs to the constructs of the implementation language is necessary. The CORBA-specification contains mapping rules for the languages C, C++ and Smalltalk. We have developed an IDL-compiler, which automatically generates a C++-implementation from IDL-defined interfaces (Sixtus, 1997).

The development of a distributed multimedia-application

With the MiniORB and our IDL compiler it is quite simple to develop distributed applications: For each certain object implementation an interface has to be declared in IDL. From each of these interfaces the IDL compiler automatically generates four sets of C++-files, each consisting of a header- and a implementation-file (*Figure 4*):

0 a *global file set*, that contains the implementation of code relevant for both the client object and the object implementation
1 a stub file set, that contains the implementation of the proxy object
2 a skeleton file set, that contains the implementation of the skeleton methods
3 the object implementation file set, that frames the real implementation of the services the object implementation provides

The several header files include each other.

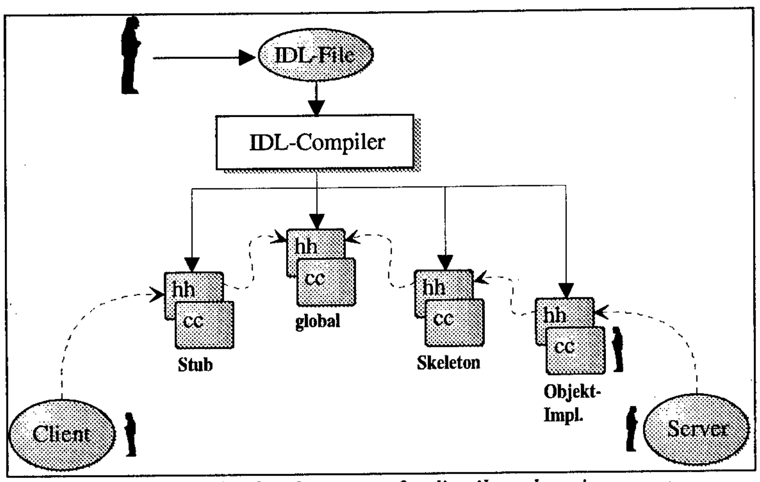

Figure 4 : The development of a distributed environment

The developer has to add the implementation code for any services the object implementation provides to the implementation file set. Furthermore he has to write a server program that activates the object implementation at runtime and a client program which calls the services of the object implementation via the proxy object. After all the source code is compiled and linked, the client object can transparently communicate to the object implementation, regardless where this resides in the distributed system.

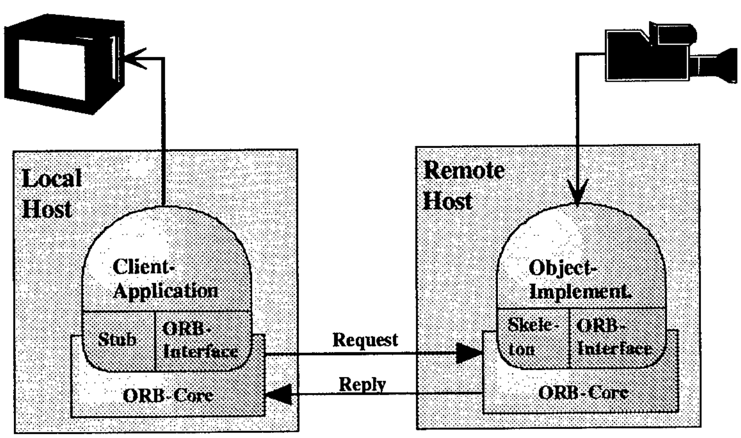

Figure 5 : First-step prototype of a teleservice system

The prototype

Our first prototype implementation of a distributed multimedia system for process control and teleservice applications is shown in *Figure 5.* It is a low cost communication system based on our MiniORB, that provides the ability to exchange image data from a camera between a local and a remote computer via a simple ISDN telephone line. We use a Connectix QuickCam™, which is wide spread in low-cost video applications because it works with any common Centronics parallel-port. Beside the CORBA standard we also use shared-memory and semaphore concepts for inter-process communication. The computing platform of our prototype are personal computers with a LINUX operating system.

We evaluated the three parts of transmission, i.e. image acquisition, data communication and image presentation, to find out the overall possible performance (Amshoff, 1997). Evaluation concerned processing speed, image resolution and size, image compression and refresh rates. We use JPEG compression/decompression and found a compression factor of 60 to be fully satisfying for diagnostic or monitoring tasks. The following tables show some results.

Tab. 2 shows, that with our environment an average image flow of 1/2 image/s is possible (including compression), with a maximum acquisition speed of 193 kBytes/s. This can be eventually advanced by using the ECP/EPP transmission mode of modern parallel ports, which promises a speedup-factor of 5..10.

*Tab. 2 : Image acquisition, Size 320*240 pixel (full color), JPEG quality-factor 60*

	486 DX 66 unidirectional parallel port	Pentium 133 unidirectional parallel port	Pentium 133 bi-directional parallel port
Compressed-image size	10100	8912	9082
Delay before first image	6.03 s	2.32 s	1.6 s
Time between two images	4.37 s	1.88 s	1.19 s

Tab. 3 shows, that an average communication speed of about 5900 Bytes/s is possible with our MiniORB. This is slightly below the approximate maximum of 6500 Bytes/s on a ISDN B-channel, due to the communication overhead caused by the object management.

Tab. 3 : Image transmission performance

File size (Byte)	Transmission time (s)	Performance (Bytes/s)
1992 Byte	0.345	5773
4009	0.676	5930
5998	1.007	5956
8006	1.340	5974

Tab. 4 represents the image presentation including decompression and local communication. It shows, that with our prototype a frame rate of 5 images/s is simply realizable.

*Tab. 4 : Image presentation, Size 320*240 pixel, JPEG quality-factor 60*

	486 DX 66 1MB/16 Bit Graphics Subsystem	Pentium 133 2MB/16 Graphics Subsystem
Resolution	1024 * 768 pixel	
Image size	12637 Byte	
Time between two images	918 ms	191 ms
Resolution	640 * 480 pixel	
Image size	12637 Byte	
Time between two images	860 ms	182 ms

Conclusions

The concept of an object-oriented multimedia communication system for teleservice applications was introduced. We presented the state of development of our object-oriented environment, the MiniORB and the IDL-compiler. It was shown, that the grade of integration of video (and audio) data into a process control system should depend on the real-time demands of the process. A regular ISDN-connection (one channel, 64 KBit) allows a periodical exchange of still images and packed audio data every few seconds. This is sufficient for many teleservice applications. Online process monitoring with audio- and video- components or teleconferencing requires higher bandwidths. But, for example, the online diagnosis of erroneous parts of a manufacturing machine works fine with low image rates or still images.

The next step of evaluation will be the transmission of audio data and process values between a technical process and its control system via the same communication channel at the same time, eventually by using a second ISDN B-channel. A main focus of interest will be on the synchronization of audio and video streams within our object management system.

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Architecture of the "Robotic Tele Lab"

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Abstract

With the growth of the Internet the ability to share remote laboratory resources and to monitor and control remote devices becomes more and more important. Since the Internet makes no guarantees of the communication link's bandwidth, tele-operation systems have to deal with possible lags in communication. This paper describes the architecture of the ''Robotic Tele Lab", a tele-operation system allowing multiple researchers in different locations to observe experiments on our task-level controlled mobile robot RHINO over the Internet. To cope with the poor communication properties of the Internet, our system uses a distributed virtual environment, predictive simulations and IP-Multicasting. This approach allows the monitoring of complex experiments even over low bandwidth connections with varying transmission delays. We further describe an experiment with our task-level controlled mobile robot RHINO. During this experiment RHINO operated for six days as a tourguide in a populated museum and was tele-operated over the Internet by more than 600 virtual visitors.

1 Introduction

A well known application area for robots, and especially tele-operated autonomous robots, is the exploration of dangerous environments or of environments whose direct observation is in some way difficult. The mars pathfinder mission [Sto96] is perhaps the most popular example of this type of application. However, we are concerned with a different research direction in autonomous robotics, namely the design of service robot systems. Such are robots capable of carrying out tasks like delivery jobs autonomously in ordinary environments like hospitals and offices. It is a common occurrence that these systems are being jointly developed by researchers working in different countries. Testing new robot control systems is a time consuming and expensive process under these circumstances because the developers have to meet in one location and have to assemble the whole system before they can test it.

This paper introduces the "Robotic Tele Lab" (RTL), a tele-operation system allowing researchers in different locations to test and demonstrate new control software on a robot over the Internet. We believe that this system will help to improve the utilisation of expensive robots and will lead to a more efficient development process. Software components can be tested frequently and new results can be demonstrated without the need to travel.

RTL is different in many respects from tele-operation interfaces used for exploration tasks. The operating environment is almost known but changes dynamically and since RTL is using the Internet as the communication link, it has to cope with low bandwidth and varying communication delays. Traditional methods of tele-operation, such as video transmissions and direct remote control of robots, are not feasible under these circumstances. We use the task-level control system of our mobile robot RHINO and a 3D computer graphics visualisation of the operating environment instead. A sophisticated scheme of synchronised simulations, adopted from the field of distributed interactive simulation [MBZ95+], bridges transmission delays and helps to further reduce bandwidth requirements. For the transmission of state changes we employ IP-Multicasting, the most efficient method for transferring information to many destinations over the Internet. As the robot's environment is changing dynamically (people walk around, doors are opened/closed, etc.), these changes in the real world have to be integrated into the world model, which forms the basis of the 3D visualisation. RTL can be easily extended by specialised sensor interpretation modules, each of them performing particular subtasks as part of the overall system goal.

The strength of these concepts has been demonstrated during a museum tourguide project. During this experiment, RHINO operated for six days as a tourguide in a populated museum and was tele-operated over the Internet by more than 600 virtual visitors. The Web interface of the tourguide system was the first application of RTL technology, which will be introduced in the second half of this paper. Due to limitations of the Internet communication facilities of the WWW, some differences between the RTL architecture and the tourguide interface exist and these will also be explained.

2 Related Work

So far, research on tele-operated autonomous robots has focused mainly on robots exploring dangerous environments [HHF+95, FPW+95] and on the design of autonomous robot systems for space missions [HBJJ94, Sto96]. In contrast to RTL, these systems use leased lines and satellite links for communication. High bandwidth is permanently available and transmission delays are nearly constant. Visualisation is carried out mainly by video transmission and is supported by 3D computer graphics to bridge the very large transmission delays of up to several minutes. The environment of the robot is assumed to be static in these systems.

The Internet communication architecture of RTL is based on NPSNET-IV [MBZ+95], a distributed, interactive virtual 3D multi-user environment, connecting different training simulators over the Internet. From the NPSNET-IV system RTL adopts the use synchronous predictive simulations and the use of IP-Multicasting. NPSNET-IV is a pure virtual environment. The RTL system on the other hand is designed to keep its virtual environment synchronised with the actual environment of a real robot.

3 Components of RTL

From an abstract point of view, RTL has a client-server architecture. The server resides on a computer in the robotics laboratory and its task is to integrate all information available from the robot (e.g. position, velocity, state of all actuators and sensor data) into its internal world model. Significant changes in the state of the world will be transferred to all connected RTL clients. The clients will update their own copy of the world model according to the incoming state information and visualise the actual laboratory environment using 3D computer graphics. In the following sections we will briefly explain the main components of the RTL system: Internet communication, clients, servers and the synchronisation of the virtual robot with the real robot. Please note that actual control of the robot is not part of the system itself because its main purpose is to test and demonstrate new robot control software.

3.1 Internet Communication

A big difference between RTL and typical client-server systems, for example the WWW, is the network communication technology used. In typical client-server systems, the server sends information to a single client only on request. The RTL server broadcasts state changes to all connected clients at once. Broadcasting is achieved using IP-Multicasting over the multicast backbone (MBone) [Dee89] of the Internet. Clients register at the so-called multicast address of the server. Together the server and clients form a multicast group. In multicast groups every message sent by one group member is received by all the other group members. The use of IP-Multicasting has at least two advantages.

1. The communication expenditure of the server is independent of the number of clients. For this reason, the architecture is scalable to a large number of clients listening to the server at the same time.

2. Since the clients register at a multicast address and not at the server directly, the server can be split up into separate modules, each handling distinct parts of the complex world update task.

3.2 Clients and Servers

We will now describe the basic building blocks of RTL clients and servers: the world database, the predictive simulations, the visualisations on the client side and the synchronisation of the virtual robot with the real robot. In addition we will explain how they interact.

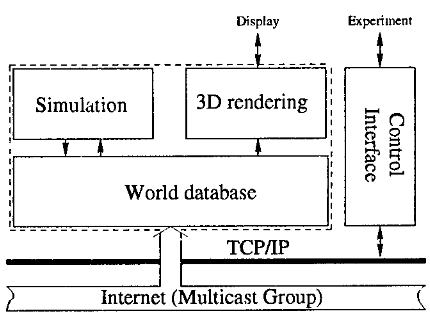

Figure 1.1: Block diagram of an RTL client

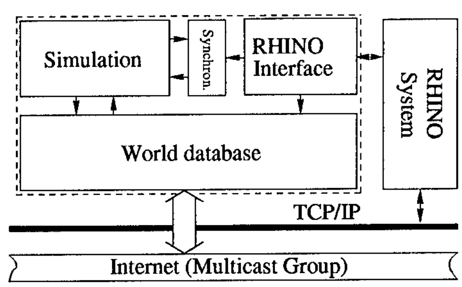

Figure 1.2: Block diagram of an RTL server

World database: The central part of the RTL server and the clients is the world database. This object oriented database contains the 3D world model of the RTL system. The same model is used for the clients and the servers. Every object in this model refers to a real object in the operating environment, for example a piece of furniture or RHINO itself. It is the job of the RTL server to integrate changes in the state of the world into the database. These changes are either recognised by dedicated sensor interpretation modules, for example in the case where a door has been closed, or are announced directly by the object whose state has changed. One example of this type is the robot's navigation system. Every object inside the server's database contains a method which transfers changes of its attribute values to its twin objects inside the clients' databases. This way all databases will agree upon their state over time. Internet communication is completely hidden from the remaining parts of the system.

The world database distinguishes active and passive objects. Passive objects are furniture, doors and other parts of the world which do not change their state by themselves. Attribute values of passive objects are only changed by the sensor interpretation modules every time they detect a change of the real object's state. Every change is transferred to all twin objects in the clients' databases.

Examples of active objects are the robot itself and humans. In contrast to passive objects active objects change their states by themselves. Inside the world database these changes are carried out by special simulation procedures, one for each type of active object.

Simulation: A simulation procedure changes the state of the active object, every few milliseconds. Simulation takes place in the server's database as well as in the clients' databases. The simulation fulfils two purposes. (1) It is able to predict the behaviour of the robot for several seconds, thus bridging the varying transmission delays of the Internet. (2) As simulation takes place inside the server and inside the clients, database updates for active objects are only sent if the predicted state of the object differs significantly from the real state of the object. This dead reckoning simulation keeps all the databases nearly synchronised over time and it also considerably reduces the bandwidth requirements of the system. Watching the robot move in a static environment produces a maximum Internet traffic of only 480 bytes per second and the average traffic is less than 200 bytes per second.

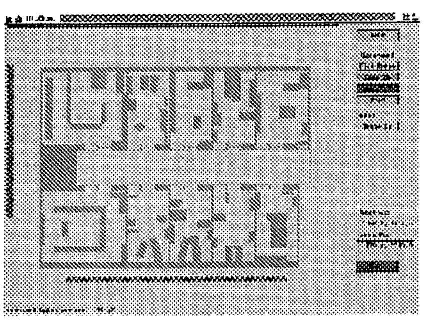

Figure 2: The 2D visualisation showing the robot's position

Visualisation: An RTL client contains a 2D and a 3D visualisation of the laboratory environment. These two visualisations form the tele-presence interface of the RTL system. The 2D visualisation shows a top view of the whole operating environment including the actual position of the robot (fig. 2). Since a robot marker is animated by the simulation according to the movements of the real robot, the user is able to observe the real robot's trajectory.

Using an OpenGL based 3D visualisation, users of the real robot can define virtual cameras, enabling them to view the virtual environment from various perspectives (fig. 3). A virtual camera can also be bound to the position of one of the robot's real cameras (fig. 4). Since the simulations are synchronised, the user will see the virtual environment from the perspective of the real robot, even while it is moving.

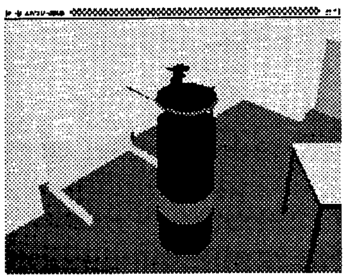

Figure 3.1: Virtual view of the robot

Figure 3.2: Real view of nearly the same position

Synchronisation: In this paragraph we will briefly explain how the RTL server is connected to the RHINO system [BBC95+, TBB+] and how the virtual robot's position is synchronised with RHINO's position. The RHINO system consists of the robot itself, an RWI B21 robot, and several software modules, each performing a specific navigation or planning task. The modules exchange information asynchronously via TCP/IP using the message passing library TCX [Fed93]. Two modules are employed for the synchronisation tasks:- (1) the navigation and collision avoidance module [FBT97] and (2) the localisation module [BFHS96]. The navigation module sends robot state information, position, velocities and accelerations, to the RTL server up to 4 times a second. These values are used by the RHINO interface of the server to re-initialise the simulation if the simulated values differ significantly from the real values. However, due to dead reckoning errors of the robot, the position information of the navigation module may not be correct. It is the task of the localisation module to find the robot's absolute position and to keep track of it. It is accurate to within 10 square cm. The RHINO interface of the RTL server uses correction parameters sent by the localisation module to compensate for the dead reckoning error of the navigation module.

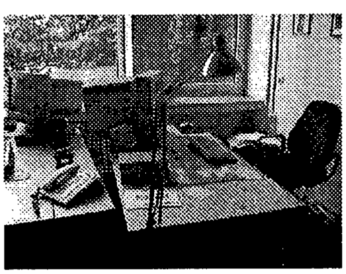

Figure 4.1: Real robot's view

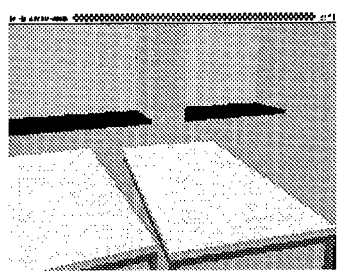

Figure 4.2: Virtual robot's view

As the RTL system is still in its early stages, only a first prototype implementation of the system as described above exists. We only carried out some small tests over our local department network. Although the system gave us a good impression about what was really going on in the laboratory, these tests can not be compared to tele-operation over the Internet, because network communication is much better over a local area network. However, the museum tourguide project proved that the underlying concepts scale to the

Internet as the communication link for tele-operation systems. Before we go on to describe this project, we want to suggest another possible application of the RTL system.

3.3 Simulation of multi-robot experiments

We want to explain the use of RTL as a simulation environment for multi-robot experiments. An RTL server can be used as a pure RHINO simulator. In this configuration the modules of the RHINO system are connected to the simulation inside the RTL server instead of to the real robot. As the world database is not restricted to only one robot, several servers can be started as simulators, thus leading to a multi-robot simulation environment. Please note that every simulated robot is able to detect every other simulated robot with its simulated sensors, as soon as it comes within reach. The multicasting based communication architecture makes it easy to distribute the whole simulation environment over several workstations to gain the computation power needed. Thus experiments with control software for co-operating autonomous robots can be easily carried out.

For the museum tourguide project, a facility based on RTL's world database has been developed, allowing the navigation system of the real robot to detect objects with virtual sensors which could not be directly detected with its real sensors. Using this facility, simulated and real robots can also be used together in one experiment.

4 The museum tourguide project

From May 29. to June 1st 1997 and on the first two days of July, RHINO operated as a tourguide in the "Deutsches Museum Bonn". The goal of this experiment was to demonstrate the potential of the RHINO system to a large audience. Our tourguide can be used in two different modes: local mode and Internet mode. If it is operated in local mode, visitors to the museum can attend a guided tour to selected exhibits. The robot will move to the exhibits, by-passing other visitors, and will play back pre-recorded information about particular exhibits when they are reached. If the robot is operated in Internet mode, WWW users are able to send it to one or more of the exhibits listed on the "Tell RHINO where to go" page (fig. 5) and the tourguide system schedules the incoming requests into a tour through the museum. Independent of the mode of operation, new pictures from one of the robot's cameras, and from a fixed camera observing the exhibition, are placed on a WWW server every 5 seconds.

The WWW interface of the tourguide employs techniques developed for the RTL system. However the communication architecture had to be considerably changed because of some deficiencies of WWW technology. The main purpose of the WWW is still to make static information available. Current Web browsers only have restricted facilities for displaying dynamic Web pages. We will first discuss these opportunities before we go on to describe the actual design of the Web interface of the museum tourguide.

Client pull: An annotation in the head of the HTML page informs the browser, that it has to reload the page after a given time interval. However, it has to be taken into account, that the server has no possibility of synchronising these updates with external events such as the robot reaching an exhibit.

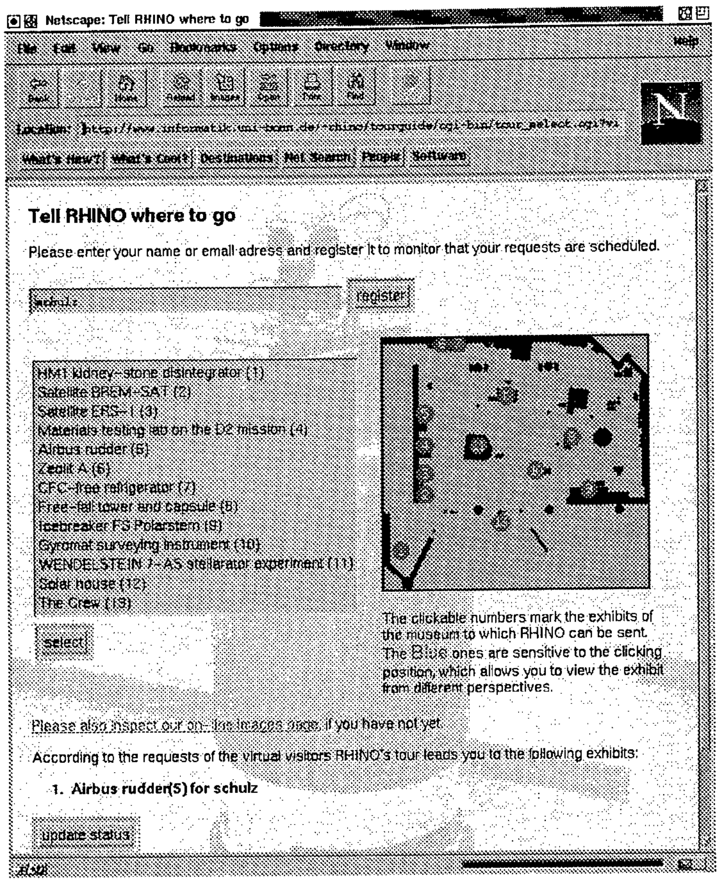

Figure 5: The "Tell RHINO where to go" page

Server push: This facility makes use of multi-part documents. A multi-part document consists of the concatenation of a sequence of simple documents. A multi-part JPEG document, for example, consists of a sequence of JPEG images. The browser displays every part of a multi-part document as soon as it arrives. Using server push, the server has control over the point in time when an update is sent to the client. However, it gets no feedback about when the new content has actually arrived at the client. On slow Internet connections this may lead to old information accumulating and, as a result, the virtual visitor will get outdated information. We did not use server push for the Web interface of the tourguide for these reasons.

Java Applets: A Java applet is a Java program, running in a Web browser. Using Java we are not bound to proprietary client server communication facilities, but are able to implement our own communication scheme. However, there are two restrictions. (1) For security reasons Java applets are only allowed to contact the computer from which they have been loaded. (2) At the time of the tourguide project, most Web browsers were not capable of multicasting. For these reasons it was not possible to simply adopt the communication scheme used by RTL.

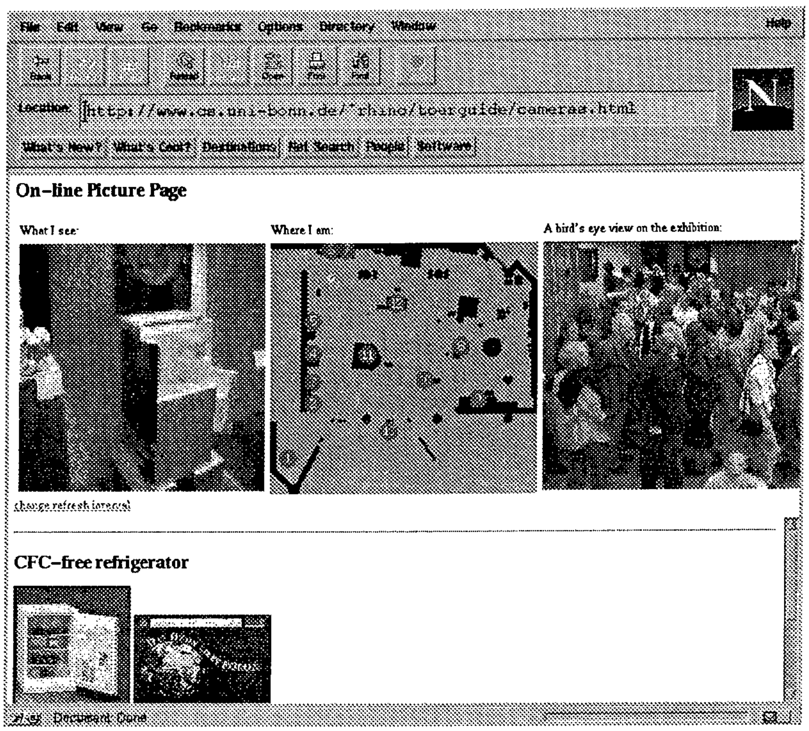

Figure 6: Pictures from the exhibition

We employed client pull and Java applets for the Web interface. Client pull is used to reload the images on the "Online Picture Page" at regular intervals. Together with these images a GIF picture is displayed, containing a top view of the exhibition and the robot's position at the time of image capture (fig. 6). Every time these three images are reloaded, approximately 15000 bytes have to be transmitted and, because of this, only low update rates are possible. The update rate is individually configurable by the virtual visitors and most of them tuned it to 30 seconds. Obviously it is not possible to observe the robot's behaviour under these conditions and so we implemented a simplified version of the 2D visualisation of an RTL client in Java which could be viewed on a separate Web page. This applet achieves a smooth animation of the robot and additionally explains the robot's actions in one line of scrolled text (fig. 7). Instead of IP-Multicasting, the applet communicates over a simple unicast UDP connection with the server.

More than 630 different virtual visitors used this Web interface during the experiment. They sent RHINO to 1264 target points. In only three cases, was the robot unable to complete its job. In all three cases failure was caused by minor hardware problems like empty batteries. The large number of completed jobs demonstrates the high reliability of the whole system. The tourguide experiment proves that, thanks to contemporary AI technology, autonomous robots can safely be tele-operated over the Internet and even over the WWW.

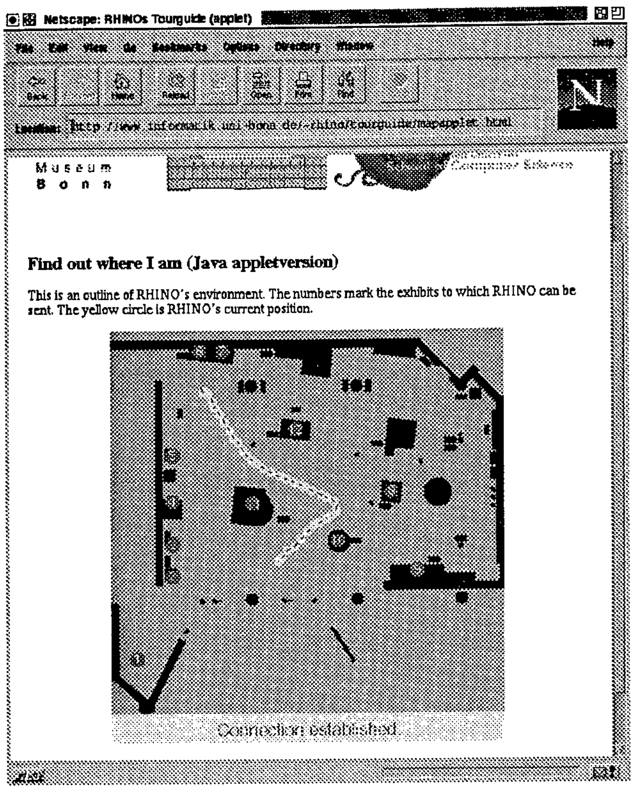

Figure 7: The Java applet. The trace of the robot's trajectory shows the smoothness of the animation.

5 Conclusions

This paper introduced the ''Robotic Tele Lab", a tele-operation system allowing researchers all over the world to test and demonstrate robot control systems via Internet. RTL demonstrates, that the Internet is a suitable communication medium for tele-operation systems, despite its poor communication properties. We managed to overcome these problems using the combination of the three key concepts of RTL: a distributed virtual environment, synchronised predictive simulations and a task-level controlled robot with advanced sensor interpretation capabilities.

Development of the RTL system is still at an early stage: work has until now mainly been focused on the network communication and visualisation part of the system and on the tourguide interface. The environment is still assumed to be static in the current implementation. One of the next steps will therefore be the development of sensor interpretation modules. Modules which detect the state of doors and the position of furniture have to developed as well as a module, which detects humans and computes their walking direction and walking speed.

In addition we want to extend the RTL system so that different researchers can carry out experiments with new robot control software over the Internet together, each researcher checking their own part of the new software. For this goal to be achieved, we want to implement an access control mechanism on top of the RHINO system because we believe, that such experiments are particularly prone to access errors, such as two control components trying to drive the robot to two different destinations at the same time.

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A 3D Interface for a mobile robot using standard Internet tools

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Abstract

Because of their relative simplicity, ultrasonic sensors have been widely used in the robotics community for measuring distances. With the development of always more accurate video cameras and powerful image processing systems, ultrasonic sensors have become less popular. However, in nuclear applications for example, ultrasonic sensors have proved to resist very well to radiations and are thus still widely used.
But these sensors have a lot of shortcomings and sophisticated algorithms have to be used to obtain reliable results. We present in this paper several algorithms that temporally filter the data and fuse them to build a map of the environment.
Furthermore, as video cameras cannot be used due to poor resistance of electronics against high level of radiations, an alternative solution is needed to help the user to remotely control the robot or the arm for manipulation. In this case a 3D representation of the environment is needed. We propose here a solution based on today Internet tools: VRML and Java. We demonstrate the application on a mobile robot Nomad200.

Keywords: robotics, sensors, VRML, Java.

Introduction

Maintenance, repair, and dismantling operations in nuclear facilities must be performed remotely to minimize contamination risks and occupational doses to the operators. Sensor-based teleoperation enhances safety, reliability and performance by helping the operator in difficult tasks when remote perception is difficult. Mobile robots can be used to explore contaminated sites for maintenance purposes or after an incident.
One major problem is the poor resistance of common sensors to radiations. The video cameras generally used in robotics applications do not resist very well to high radiation doses. In this case, special radiation-hardened sensors have to be used: specific ultrasonic, force and optical fiber optics sensors have been studied and developed for many years.[1]
Ultrasonic sensors are used to detect obstacles and to measure distances; they can be used on a mobile robot or on a teleoperated arm. They offer a good resistance in such conditions but they return very limited information, such as distance to a point, unlike video cameras which deliver high-level very comprehensive (for a human) information. Ultrasonic sensors have a relatively good precision but offer a lot of uncertainties and we need intelligent data processing to extract useful information.
When looking at the raw data acquired during the motion of a mobile robot, we can see that some measurements are completely wrong. It is difficult to detect these erroneous values when the data are spatially combined, but if a temporal sequence is recorded, we can more easily find and reject it.

In our laboratory, we use an electrical mobile robot Nomad200 to develop and test the algorithms. This system can be controlled remotely via a HP-UNIX or PC-Linux workstation. The data acquired by the sensors can be viewed in different windows but the user can only see a 2D representation of the world. This is perhaps enough in a well-known laboratory but not in a real world. We have then developed a 3D virtual representation of the robot and of its environment. This application is based on the new tools offered by the Internet technology VRML and Java.

We will begin with a short presentation of the robot Nomad and the sensors we use. We will then present the solution we have developed to improve the measurements of the ultrasonic sensors. The tools and the 3D application will then be presented.

A robot called "Nomad"

General description

The Nomad200 is an integrated mobile robot system with four sensing modules: tactile, infrared, ultrasonic and 2D laser (Figure 1). The Nomad200 has an on-board multiprocessor system consisting of a 80486 computer and multiple slave microcontrollers. This system performs sensor and motor control, host computer communication, and supports on-board programming. The Nomad200 offers an integrated software development package for the host computer including a graphic interface and a robot simulator.

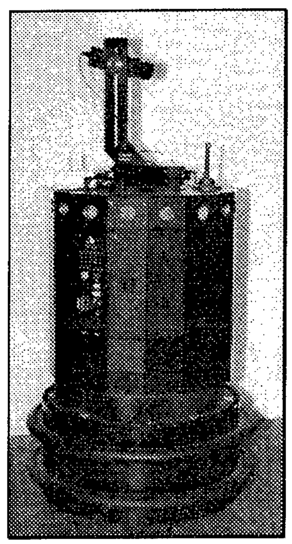


Figure 1: The Nomad200

Programming the Nomad200

The Nomad200 can be programmed and controlled in two ways: directly via the on-board PC card or remotely via a UNIX workstation.
In the first case, no communications are possible between the robot and the remote station and the user has no idea of what its program is doing.

In the late case, commands and data are transmitted by an Ethernet radio link. The application program called 'client program' runs on the workstation and sends commands, via the host interface (Nserver), to a communication program running on the robot (Robot Demon or *robotd*)[1]. This program interprets the packets sent by the station and sends itself the data of the sensors to the workstation. The programmer is able to see not only what its program is doing but also the movements of the robots and the values of the sensors.

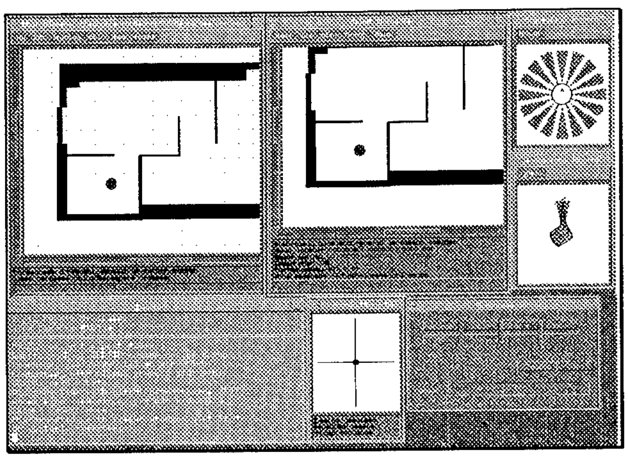


Figure 2: The Nserver GUI

The ultrasonic sensors

The system called "Sensus 200" is a ring of 16 Polaroid 6500 sonar ranging modules. The Polaroid 6500 is an acoustic range finding device that has been widely used in the mobile robotics community. It can measures distances from 6 inches to 35 feet, with a typical absolute accuracy of +/- 1 percent over the entire range.
The transducer do not emits energy homogeneously in all directions, but instead form lobes of decreasing intensity, as illustrated in figure 3.

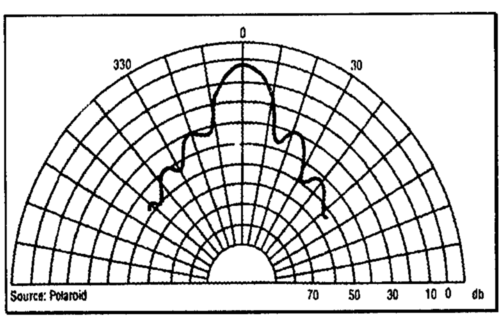


Figure 3: A typical Emission diagram of a sonar sensor

These sensors generate a lot of uncertainties in the measurements. The main sources of errors are the characteristics and the position of the target. Most of the indoor surfaces act as mirrors with respect to sound waves. One consequence of the reflective properties of surfaces is the multiple echo effect: the sound wave bounces around, and eventually reaches the receiver after several reflections.

[1] A distributed control mode have been developed and presented in [2]

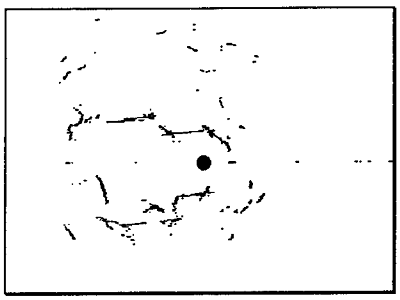


Figure 4: A typical sonar scan

A good representation of sonar data is the sonar scan: a dot representing the measured distance is drawn on the sonar axis. Repeated measurements over a given angular range give a sonar scan. Sonar scans are the basic data that can be used for map building or navigation purposes.
You can see on figure 4 a typical map build using sonar data.

The mapping of the environment
In order to obtain a usable map of the environment, several sensors are used together and successive measurements are accumulated, or better fused, in a spatial 2D map. Several methods exist to fused sonar data: probabilistic or statistical combination, heuristics rules, fuzzy logic, etc.
The idea here is to rejects wrong data as soon as possible, with other words before the spatial mapping. Two different methods have been developed: the first one uses the well-known statistical median function [3], the second one is based on linear regression and the estimation of future readings [4]. The processing is made for each sensor independently.

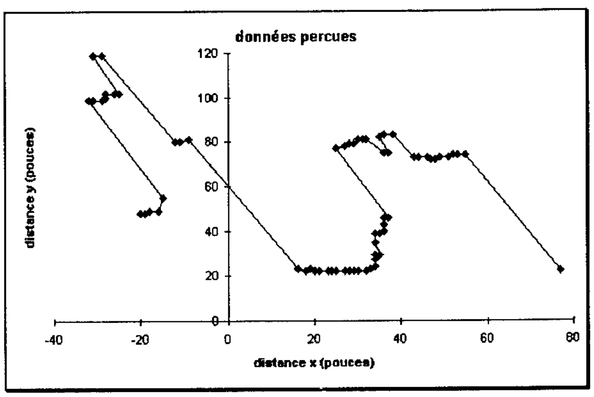
The time sequence median filtering
The idea is to remove fast measurements variations by regarding the mean evolution of the data. This processing has to be done during the motion of the robot and in real-time.
If we look at a typical time sequence recorded during a motion of the robot we see that some values are completely different from their neighbor values. The median function is a statistical function that is commonly used in image processing to smooth the image. It acts like a low-pass filter and has the property to remove some noise while preserving edges.
In our case we record a time sequence and the values are then ordered. The measured value is then replaced by the middle value of the sequence. You can see several examples here below.

Time sequence						Ordered sequence						
12	15	15	16	12	⇒	12	12	15	15	16	15	
16	15	35	15	14	⇒	14	15	15	16	35	15	false data rejected
14	15	15	35	35	⇒	14	15	15	35	35	15	preservation of
15	15	35	35	36	⇒	15	15	35	35	35	35	edges
		⇑ Value to be replaced						⇑ Middle value			⇑ New value	

In a spatial filtering, there is no difficulties to consider the values surrounding the center value (the value to which we applied the filter). But in a time filtering we must process the data recorded before and after the value we want to replace. The consequence is that the corrected data are only available after a certain delay. The duration of the delay

depends on the firing rate of the sensors and on the length of the sequence you consider for the filtering.
The length of the sequence also influences the size of the wrong data we can reject. If we consider a sequence of N elements, we can eliminate wrong sequence which size is < (N+1)/2. Otherwise, the value will be replace by a wrong value.

In the figures 5 we can see the results of a processing with a size of 7 elements.



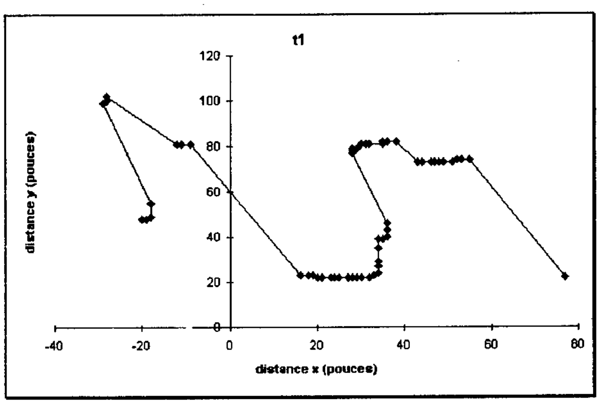


Figure 5a and 5b: original and processed data

The best results were generally obtained with this length. In this case we can reject a sequence of 3 successive false measurements and the delay introduced is not to important.

We see on the next figure a complete map built with corrected data.

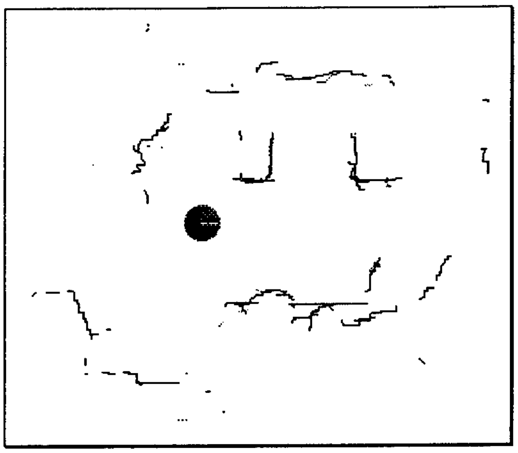


Figure 6: Map made with corrected data

In order to suppress the delay we developed the method explained in the next paragraph.

The time sequence filtering by linear regression and estimation of future readings

With this processing we want to reject the wrong data generated by false echoes. The goal is to correct the data in real time and with no delay. To achieve this goal, we consider the three last measurements and we compute the straight line that best fits these points (Least square method). We can now compute one hypothesis for the next reading and compare with the real value. If the next measurement differs too much from the hypothesis, we cannot just drop it; several cases have to be considered because this new point could perhaps own to a new obstacle. So we have to compute new hypothesis and compare the next data with these hypothesis. We repeat this procedure three times and if the last point does not match one hypothesis we stop the processing and we restart with new data. You can see on figure 7 one example of corrected data.

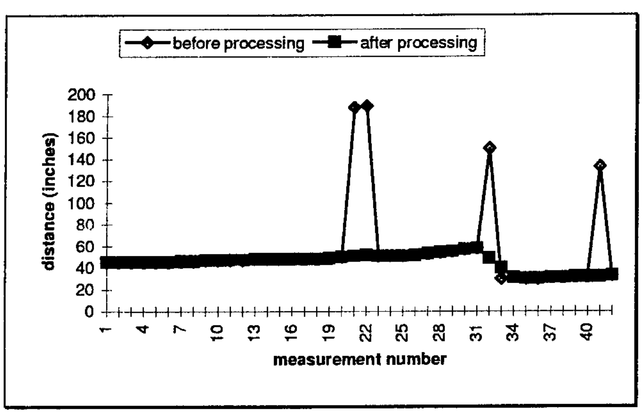


Figure 7: Raw and corrected data for one sensor

We can also compare a map built with raw and corrected data:

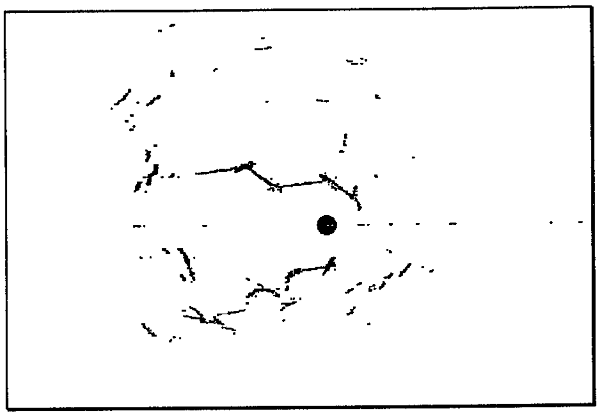


Figure 8: Without correction

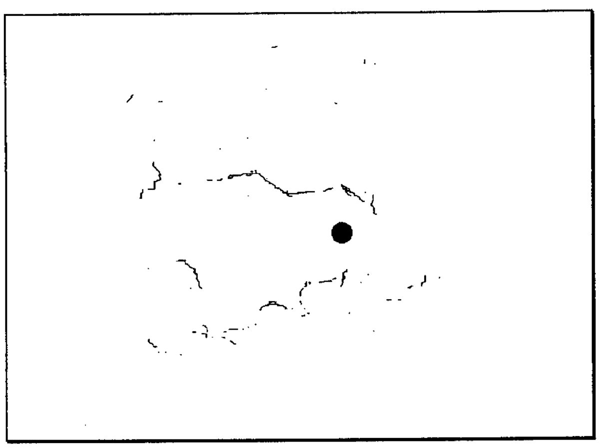


Figure 9: With correction

We see that some noise remains. These isolated points can now be eliminated (if wanted) by a simple image processing (low pass filtering or something like that...).

The 3D visualization

Motivation

As explained in the introduction, video cameras offer a poor resistance to high radiations level and an alternative solution is needed to help the user to remotely control the robot or the arm for manipulation. A 3D representation of the environment of the robot is certainly required. The data acquired by the ultrasonic sensors can be fused with existing 3D representation of the installations to indicate parts and obstacles.

Other requirements for this application were to use low cost computer to perform the visualization and to get rapidly an usable system. The solution we propose is based on today Internet tools: VRML[2] and Java. The best motivation was the existence of viewer/browser and the portability of the applications written in Java.

[2] Similar developments are made at the kiss-lab [5]

VRML
The Virtual Reality Modeling Language (VRML) is a file format for describing 3D interactive worlds and objects[3]. It may be used in conjunction with the World Wide Web. It may be used to create three-dimensional representations of complex scenes such as illustrations, product definition and virtual reality presentations.

VRML is capable of representing static and animated objects and it can have hyperlinks to other media such as sound, movies and images. Interpreters (browsers) for VRML are widely available for many different platforms as well as authoring tools for the creation of VRML files.

VRML is a new standard that has known a rapid evolution since its apparition two years ago. VRML1.0 provided a means of creating and viewing 3D static worlds; VRML 2.0 adds interaction, animation and extension capabilities.
You can find viewers for all platforms and operating system (OS) but each of them runs on a limited number of computers. Some viewers can run as standalone application and others like plug-in in your favorite browser. At present day, no one viewer implements the complete VRML specifications.

In VRML2.0 you can use scripts to animate objects in a world or give them a semblance of intelligence. This script can be written in any programming language that the browser supports. In practice it is Java or Javascript.

JAVA - Applets and Applications
Java is an object-oriented programming language developed by Sun Microsystems. The main purposes of the developers were to create a language that let programmers write programs that can be executed on every computer whatever its processor or OS.
Sun introduced the concept of Java Virtual Machine. When you compile a program written in Java, you produce *bytecode* that will be interpreted by the Java interpreter during its execution. Another goal was to create a language that will permit to write distributed and network applications more easily. Java can be used to write serious big applications (see Corel Wordperfect suite for Java) or simple applet to enhance WEB pages. Applets are Java programs that are embedded in Web pages. The code is downloaded with the page and executed on the computer of the netsurfer. Of course to do this you must have a compatible Java browser.
Javascript is totally different from Java. It is a scripting language that is interpreted by the browser and was introduced by Netscape; commands are embedded in HTML pages as text.

In the following table you can see a summary of the principal viewer/plug-ins for VRML that will run with Linux:[4]

Name	Works as:	for:	on platform:	developer
LiquidReality	plug-in Applets/Application	MS IE JDK Appletviewer	Win95 Linux/Win95/Sun/SGI	DimensionX
Vrwave (beta)	Application	JDK	Linux/SGI/Sun	IICM

[3] See the complete specifications at http://www.vrml.org/VRML97/DIS
[4] For a complete review see: http://www.sdsc.edu/vrml

We opted for the LiquidReality (Lr) package because of existing versions for Linux and Windows95 and the possibility to write standalone applications.

Liquid Reality is a set of Java classes that implement the VRML2.0 specifications. It adds the capabilities of 3D technology to the power of Java. It provides a rich set of function calls from Java that allow the developers to create and manipulate simple or complex 3D scenes as an integral part of their applications.
With the 3D programming interface for Java, the developer has the ability to create applications that can read in and allow the user to view and interact with VRML2.0 worlds. In addition, the developer has a new level of control over these worlds. Nodes can be crated, deleted and modified at runtime. Complex behaviors can be triggered when VRML or standard window events are generated.

The visualization application: 3DApp
The main functionality of our application is to visualize the motion of our robot in 3D. This program communicates with the Nserver program (see $2.2) and continuously reads the coordinates of the robot and its orientation; the drawing is updated at each iteration.
Normally, to command the robot via the Nserver, we have to write a C program. The Java language offers the possibility to call native functions, that is, functions written in an other language (C,C++,...). So the developer can use optimized rendering functions or existing specialized API (loosing the portability).
The solution we adopted was to implement the function that permits the communication with the Nserver as a library and to call it from a Java program.

Java offers different solution for the implementation: the 3DApp can be executed as a stand-alone application or as an applet in a browser (or in Appletviewer). Due to security and access permissions, an application is easier to write.
An usual client program for the Nserver communicates with it via sockets, consequently, it can run on the same or on a different computer (but with Linux) than the Nserver. So the 3Dapp application can run on a remote computer (if this computer has a Java Virtual Machine).

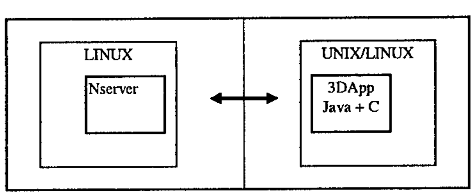


Figure 10: Simple communication: the 2 applications can run on the same or on different machines.

If we want to let our program run on different computers and different operating systems, we can implement one of these solutions:
On the Linux server machine we can write a mix Java/C program that will act as a server for the 3DApp program or 3DApplet applet.

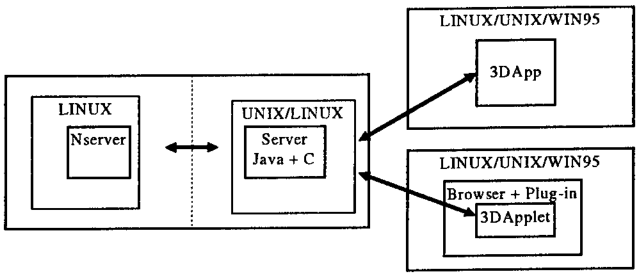
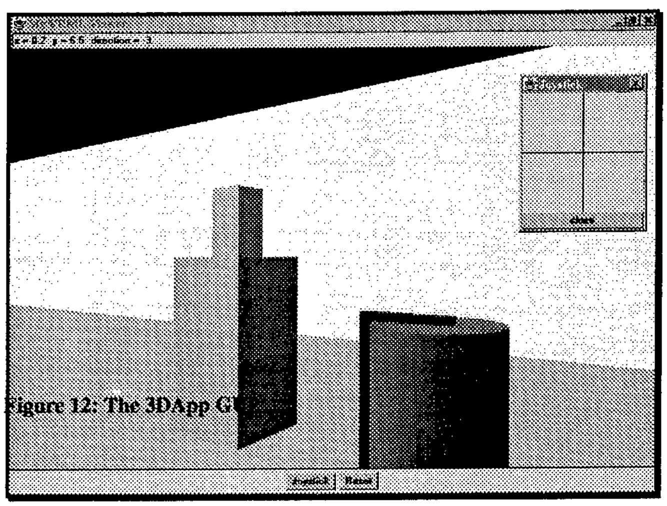


Figure 11: Communication via a server

With this configuration we can chose an other viewer/plug-in, if we want for example make the visualization on a MS-Windows computer. In this case the speed of the drawing could be improve using a JIT[5] compiler (not yet available for Linux)
The 3Dapp can also be used as a standalone application (not connected to the Nserver). The user has the possibility to drive the robot with a virtual joystick. You can see a screen capture of the interface in the figure 12.

Future developments
The developments we have planned are the following:



- the implementation of the second communication solution (see above),
- the command of the real robot via the 3D GUI,

[5] A Just-in-Time compiler compiles the Java bytecode into machine code.

- The VRML standard does not handle collisions between objects but only between the viewer (called avatar) and objects. In order to use this application as simulator this behavior should be added to the objects.
- At this stage, the user can navigate freely into the scene. An interesting option should be the automatic following of objects and the automatic selection of the best viewpoint.

Conclusions

Today we see very sophisticated user-interfaces with multi cameras, HUD, etc... In nuclear applications quite simple sensors are used because they resist well to radiations doses. This work addresses two problems introduced by this restriction: the improvement of ultrasonic data by time filtering and the representation of the 3D environment of the robot.

The developed algorithms for the data filtering have proved to be robust and improve the quality of returned data.

The 3D representation is at the beginning of its development. It is based on today Internet standards and runs on several platforms.

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Performance Shaping Factors in Teleoperation Using a Six-Axis Active Hand Controller

Research on Efficient System Parameters in Bilateral Teleoperation

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Abstract

A six-axis hand controller designed to use the high sensitivity of the human hand-finger-system is presented. The applied input force is measured by a force/torque-sensor and proportionally transformed to control the motion and the output force of a six-axis industrial robot. The motor feedback of the robot position to the hand controller gives the operator the feeling of handling the robot's load with his own hand. By means of a simple task which is matching a cylindrical peg into nine holes with different diameters and chamfers the operator's performance is evaluated. The operator's forces and the peg positions are recorded while the task is carried out. The time required to complete the task (sequential match into each one of the holes) is the main indicator of the operator's performance.

Research has been made on the influence of some parameters like force / torque resolution (by time and value) on force measurement as well as translation and rotation scales on the position / orientation feedback. Results show best performance on scales that correspond to the finger workspace if the hand is supported. For the examined task, the orientation feedback comes out to be more important than the position feedback.

The force / torque transmission parameters might not be necessarily as precise as the human fingers performing the same task under optimum circumstances since the dynamics of the controlled manipulator is more restricting. Complementary inquiries have been made on knob size and shapes.

Introduction

The optic, acoustic, kinesthetic and haptic senses have evolved to constitute the most important information channels for people to perceive the environment. On controlling machines, some information can be perceived without technical displays (e.g. acceleration, noise, track while driving vehicles), others must be provided by those displays (e.g. velocity and height in airplanes). Conventional displays mostly use the optical and sometimes the acoustical channel (e.g. for speech output and alert signals).

The haptic channel is essentially used for recognition of forms and surfaces as well as to determine the force which is applied by or to the surroundings. Tasks like inserting screws into threads, cutting soft things on hard surfaces, or digging in non-homogenous soils are much harder to complete without the haptic information (= force and position information).

When controlling machines like cranes and power shovels, this haptic sense usually gives feedback on the information transmitted to the machine, but not about its internal state (e.g. position and forces). For effective application of the highly sophisticated haptic sense, whose reaction time and perception thresholds are significantly lower compared to the other senses, these machine states are displayed on active hand controllers. Thus, the operator handles his tool intuitively like if the tool was in his own hands. By the use of highly trained habituation patterns, learning time and mental work load are reduced, and at the same time dangerous situations can be overcome safer and faster.

Regarding the high motorial precision and sensitivity of the hand-finger-system for the control of many kinds of manipulators, near or distant, the Active Hand Controller „Spider" (Fig. 1) has been developed, constructed and tested at the Institute of Ergonomics. In comparison to typical manual input devices (joysticks, wheels, pedals) it can provide full haptical feedback. This is achieved by a force/torque-sensor which measures the applied force and a positioning unit which displays positions and orientations. It is designed as a 6-degrees-of-freedom device to be a universal platform for experiments and applications.

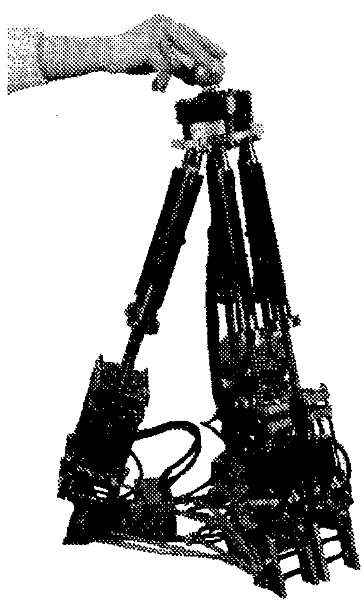


Figure 1: Active Hand Controller „Spider"

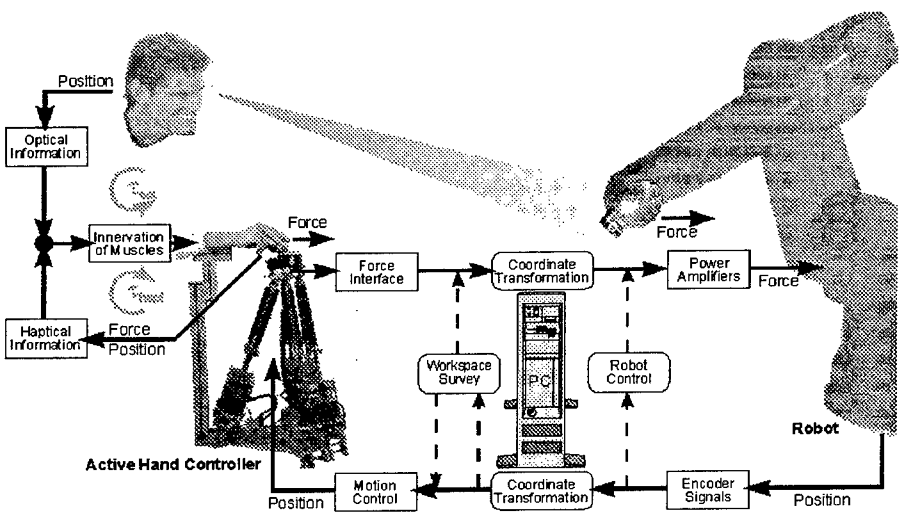
The advantages of force and position display in comparison to conventional controllers are well known. The aim is now to quantify the influence of single system parameters on human performance in bilateral teleoperation with haptic feedback. In this way, the extensive control and hardware needs can be reduced to a cost effective minimum without decrement of human control capabilities.

System Description

The used teleoperation setup consists of the Active Hand Controller „Spider" as the Master in combination with a Puma 560 industrial robot as the Slave. The setup involves principally two independent control chains:

- Proportional transfer of hand-/finger forces to the manipulator (Slave).
- Position / velocity feedback of the manipulator's action to the fingers of the operator.

The environment of the manipulator and the operator close the control chains to a control loop (Fig. 2).



(The dotted lines serve for keeping velocity limits and workspace)

Figure 2: Control scheme of the teleoperation system

Transmission of Forces from the Hand Controller to the Manipulator:

Forces and torques of the hand and fingers are measured by a 6-axis force/torque-sensor. They have to be output by the manipulator in two different manners:

- as a velocity (without environmental contact)
- as a force (in constrained motion)

The key point in the transmission control is to choose between velocity and force output. Therefore, the default velocity control is replaced by force control if the motor currents of the robot (which are proportional to the motor torque) exceed the value that the input force allows. The application of these two schemes provides controlled movement through the free space as well as relatively sensitive handling when in contact with objects.

Position Feedback from the Manipulator to the Hand Controller

The position of the robot´s tool center point is calculated from the built-in angle encoders. The joint positions are transformed separately by translation and rotation into Cartesian coordinates, which can be displayed proportionally by the hand controller.

Hand Controller Mechanics

The positioning unit of the hand controller is a complete robot with 6 degrees of freedom. The essential difference to typical industrial robots is the kinematics which is chosen following the mobility and sensitivity of the human hand-finger-system. It consists of linear units with universal joints at both sides, connecting a base plateau with a head plateau (Fig. 1). Special care has been taken to construct joints without play and wide angular limits at the head plateau.

The construction is based on a geometry optimized and checked by computer calculations. A postulation was a rotatory mobility of 30 degrees around any axis. Thus, the maximum workspace of the positioning unit is $2{,}3*10^6$ mm³ which contents a symmetrical workspace of $1{,}3*10^6$ mm³ (Fig. 3). This workspace is greater than the area a supported hand can reach.

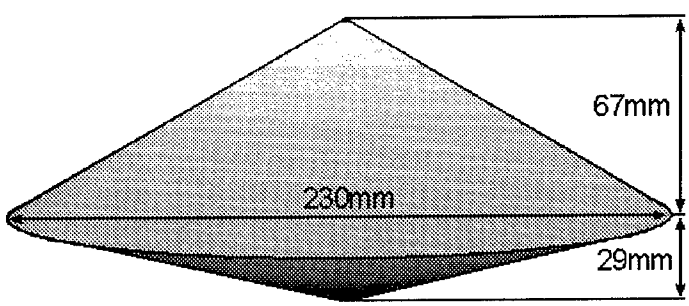


Figure 3: Maximum symmetrical workspace of the „Spider" (Mobility 30° around any axis)

The actuators are stepping motors. Damping elements suppress excessive noise and high frequency oscillations. The position accuracy is strongly depending from the actual position, but always better than 10 µm. Horizontal maximum speed is 125 mm/s, maximum acceleration and deceleration values are 5.1 m/s² and 41 m/s². Vertical rates are about the half of this figures. This high deceleration makes even hard impacts well recognizable haptically.

Experimental Setup

[Hannaford et al. (1991)] presented a frequently cited experiment for teleoperation. The task is to insert a peg (diameter 25.35mm) into 9 cylindrical holes. The holes are placed in a 3x3 matrix and differ by diameter (25.41mm to 25.47mm) and chamfer (0.4mm*45° to 1.6mm*45°). The task has a Fitts difficulty from 7.8 to 9. The time needed to insert the peg sequentially into the holes (twice for each pass) is an indicator for the operator´s

performance. It also depends on the system´s parameters and indicates the ergonomic aptitude of the parameters set.

For the experiments, an arm and hand support which is free movable horizontally is provided. The subjects have to train the task a certain number of times so that learning effects disappear. The holes to be inserted are indicated by LEDs. The task can not proceed if the desired insertion is not complete, so that missing or incomplete insertions never occur. The time needed to perform the whole cycle is reduced to a fit-in time, which is the remainder when the time from leaving the last hole to approaching (1cm) the next one is eliminated. This reduction (amounts an average of only 18% of the complete pass) is made to ignore unconstrained movements and single mistakes in the hole order made by the subjects.

Experiment 1: Scales

In this experiment, the influence of the scale in which robot movements are transformed into movements of the hand controller are examined. It can be distinguished between the scales of position and orientation. Four different scale combinations are tested:

- A: position 1:1, orientation 1:1
- B: position 3:1, orientation 3:1
- C: position 6:1 orientation 1:1
- D: position 16:1, orientation 16:1

Hereby, at combination A the workspace of the hand controller is widely utilized, while D represents almost an isometric controller with very small movements.

Results of Experiment 1:

There are 50 subjects with an average age of 27 years (σ=6.4) performing the task. Afterwards they are presented a questionnaire to judge the different scale combinations.

Fit-in times: The following times are achieved at the four combinations:

Scale combination	Fit-in time t [s]	Std.-Dev. σ [s]
A (Pos. 1:1, Or. 1:1)	102.1	26.9
B (Pos. 3:1, Or. 3:1)	101.4	25.9
C (Pos. 6:1, Or. 1:1)	75.0	19.0
D (Pos.16:1 Or. 16:1)	113.2	32.3

Table 1: Fit-in times for experiment 1

The null hypothesis „A does not differ from B“ must be accepted by a probability of 0.75. All other combinations are different by a very high degree of statistical significance.

Questionnaire:
The judgement on the order of preference constitutes the most relevant item in the questionnaire. 38 of 50 subjects vote for combination C as the most favorable one, 26 judge D as the least preferable one. The question about the necessary concentration at each one of the combinations show up similar results. Most concentration is needed at D, least at C. In both cases, the combinations A and B receive average judgements without significant differences.

Experiment 2: Force Parameters

This experiment covers some parameters of the force / torque measurement at the hand controller. As the implemented sensor is able to work at high sampling rates (up to 520 Hz) and a resolution of 10 bit, the point of interest is if lower precision would reduce the system´s overall performance. As it has been shown by some physiological experiments, the human fingers´ sensitivity can beat the above benchmarks under ideal circumstances. The following four force parameters are chosen for this experiment:

- E: (Ideal) Sampling rate 520 Hz, Force resolution 0.02N, Torque resolution 0.0002Nm
- F: Sampling rate 65 Hz, Force resolution 0.02N, Torque resolution 0.0002Nm
- G: Sampling rate 22 Hz, Force resolution 0.02N, Torque resolution 0.0002Nm
- H: Sampling rate 520 Hz, Force resolution 1N, Torque resolution 0.1Nm

The position scale is set according to the result of the previous experiment (6:1 for position, 1:1 for orientation). That is why the maximum speed of the manipulator is raised in this experiment in order to adjust it to the speed range of the hand controller.

Results of Experiment 2:

There are 24 subjects with an average age of 32 years (σ=10.5) performing the task. After the experiment, a similar questionnaire to experiment 1 has to be completed.

Fit-in times:
The subjects achieve the following fit-in times with the different force parameters:

Force Parameter	Fit-in time t [s]	Std.-Dev. σ [s]
E (Ideal)	58.6	19.7
F (Sampling Rate 65 Hz)	61.5	23.0
G (Sampling rate 22 Hz)	75.5	30.1
H (Force/Torque resolution 1 N / 0.1 Nm)	60.8	21.3

Table 2: Fit-in times for experiment 2

The null hypothesis must be accepted between the parameter sets E and H as well as F and H, and there is a very high significant difference between G and the other three parameter sets.

Questionnaire:
According to the objective data, subjects are able to judge G significantly as the worst parameter set, but can not state differences between the other ones.

Knob Judgement

During the two experiments mentioned above an accompanying inquiry concerning knob characteristic is made. The two utilized knobs are:

- A 43mm plastic ball with regular hollows (golf ball) in experiment 1
- A 60 mm wooden bowl in experiment 2

Questions are asked about the size and the surface of the knob. The judging criteria is a scale with 5 items ranging from too small to too big and too smooth to too rough, respectively.

The results are as follows:

Experiment 1 (50 Subj.)	**Size**	too small 30%	a bit too small 40%	right 24%	a bit to big 4%	too big 2%
43mm diameter „Golf Ball"	**Surface**	too smooth 10%	a bit to smooth 36%	right 52%	a bit too rough 2%	too rough 0%
Experiment 2 (24 Subj.)	**Size**	too small 0%	a bit too small 25%	right 41.7%	a bit to big 33.3%	too big 0%
60mm diameter „Wooden Bowl"	**Surface**	too smooth 16.7%	a bit to smooth 37.5%	right 41.7%	a bit too rough 4.2%	too rough 0%

Table 3: Judgements on knob sizes and surfaces

Regarding the form of the knob, there are two opposite judgements: about the half of the subjects would prefer some kind of cylindrical knob shape, the other half does not. Independently, most subjects would prefer some bigger grip-holes and a more anatomic shape to augment the perception of orientation.

Conclusions

In **Experiment 1**, scale combination C, the only one with scales different by position and orientation (6:1 resp. 1:1), is evaluated subjectively as well as objectively as the best combination. Following factors contribute to achieve this result:

1) Orientation feedback is more important for the performed task than position feedback, that is why combination B (3:1,3:1) and combination D (16:1,16:1) are less advantageous.

2) The workspace of the human hand-finger-system is well utilized. The arm support can be put under the ball of the hand so that full advantage can be taken of the finger sensitivity (not so in combination A (1:1,1:1)).
3) High velocities at the hand controller, especially translatory ones (like at A), interfere with the haptical feedback by out-of-round action of some linear units. These vibrations of about 15 Hz are transferred to the entire hand controller. Furthermore, the motion of the six units is not coordinated but each one is heading for its desired position as fast as possible. Thus, a maximum straightness of the movements is not guaranteed.

On comparing the scale combinations A, B and D the following conclusions can be drawn:

- The factor 1) balances the factors 2) and 3) comparing A with B
- The almost isometric combination D provides too less haptic information so that the superiority of hand controllers that reflect force and position has once more been proven.

Experiment 2 shows clearly that the force/torque parameters may not meet the requirements of the human sensitivity under optimum circumstances. The dynamics of the controlled manipulator and the control loop is supposed to be the benchmark for force parameters. In every case, a stable control of the system implies lowpassing of the input force so that even rough quantizations by time (65 Hz, „F") and value (1 N , 0.1 Nm, „H") do not impair human overall performance. Only a very slow sampling rate (22 Hz, „G") has a perceivable damping effect on manipulator control so that a difference in fit-in times and subjective rating can be measured.

Regarding the two experiments, some recommendations on the design of an active hand controller for teleoperation purposes with force input and position feedback can be formulated:

- The scale for rotation and translation should be chosen to fill the hand-finger workspace so that the hand can be supported. The separation of position and orientation scales is not problematic.
- The resolution (by time and value) of the force/torque sensor does not have to meet highest requirements. It can be oriented by the system´s overall dynamics.
- A knob size of 60mm (bowl) was judged convenient in average by all subjects. Some grip-hole like structures are desirable.

Further research is planned to be made on other force parameters (offset & hysteresis) and minimum requirements to the hand controller´s mechanical components to be functional without loss of human performance.

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Virtual Reality Usability Evaluation Techniques: RECMUVI and TILE VIZ

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Abstract

This paper is based on two case studies which gave the authors a great deal of insight into the development of Virtual Reality (VR) systems. The authors have chosen to differentiate two types of observations: those related to development process, and those related to design issues.

RECMUVI and TILE VIZ are VR systems. The first focuses on the environmental education of 10-12 year olds on urban solid waste recycling. The second focuses on the selection and 3D visualization of floor and wall ceramic tiles.

In both projects two different usability techniques were employed: heuristic evaluations, made by the authors, and participative evaluations, made by end-users. Each technique raised different (but sometimes overlapping) usability problems. The use of the 'thinking-aloud' technique was questioned, as the possible demands on cognitive resources affect subject's explorations of the virtual world (RECMUVI). Group interviews with end-users focusing on a checklist of usability evaluation criteria themes were made. These meetings proved useful because they enable end-users to report their experiences and discuss the central aspects of the interactions.

The main design problems were related to the need to generate virtual environments with cues that orientate the navigation and representation of the virtual space. The need to develop navigation systems that do not present cognitive overhead and the possibility of the co-existence of different navigation types, each one with different motor and cognitive requirements, was also raised.

Introduction

Human computer interaction evaluation is common practice in computer systems design. Through the use of evaluation tests designers want to assure systems adaptation to end-users. And this is true not only of ordinary computer systems but also of more innovative technology (Virtual Reality – VR – is only an example). These evaluations gain a growing importance when designers want to generalize innovative technology for non-expert users.

VR systems have special features very different from those of other computer systems, demanding complex interaction styles. First of all, one of the main goals of VR systems is the transmission to users of a feeling of presence in a computer-generated (virtual) world.

* The authors wish to thanks to Prof. António Sousa Câmara, Head of Environmental Systems Analysis Group (GASA) of Faculdade de Ciências e Tecnologia (New University of Lisbon), as RECMUVI was one of GASA's projects. We would like to express our gratitude for the valuable help of Celeste Duque and Angelique Chrisafis.

That feeling of immersion is the computer generated illusion of the user being inside a virtual environment. According to Hayward (1993), the brain is the last artifice of immersion. Furthermore, Varela (1995) argued that VR can be thought of as a process of excess of signification and the ability of the mind as a neuronal "narratives" generator. Pimentel and Teixeira (1993) consider *"The question isn't whether the created virtual world is as real as the physical world, but whether the created world is real enough for you to suspend your disbelief for a period of time."* (p. 15), a concept shared by Slater and Usoh (1993). These last authors stated that the human partner builds the world through those displays and acts in an extended virtual space generated through the interaction between perceptual system and computer-generated displays.

Second, and as a way to assure the feeling of presence, VR systems generally have complex user interfaces. Immersion, or the feeling of presence, in a virtual world almost always requires a visualization tool (e.g., a Head Mounted Display – HMD), coupled with a navigation and/or object manipulation tool.

Therefore, the need to better understand VR systems characteristics and their cognitive demands are essencial to design better VR systems, i.e. systems adapted to end-users. In this paper, we present two case-studies we followed during the past two years, where VR systems characteristics were analysed.

RECMUVI background

RECMUVI was a project to develop a VR game applied to environmental education on urban solid waste recycling, aiming to generate and develop skills in 10-12 years old on collecting and selection of recyclable materials (Caldeira, Dias, Otero, & Silva, 1995). The evaluation of the interface was made for the indoors situation, were the players should collect recyclable objects and put them in the respective boxes.

Tools. This game was developped in a Pentium 90, using WorldToolKit of Sense8. Due to technical restrictions the house was broken down into six models (each model representing a room – corridor and five other rooms).

The game used a HMD (Virtual Research) with a visual field of 90 degrees horizontal and 35 degrees vertical, a navigation tool (Trigger, Figure 1) with a button for object manipulation, and one (or two, depending on the prototype) Polhemus track sensors.

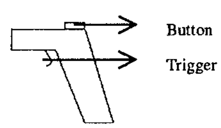

Figure 1. Trigger

Prototypes. *Prototype 1* representes three rooms in the virtual home: the kids' room, bathroom and corridor. The viewpoint is given through head movements. Navigation was controlled by two tools: the trigger control the navigation velocity (only forward movements), and the HMD control the navigation direction.

Object manipulation included a visual cue – a virtual hand – and two different actions:

approaching the object and touching it, or the surrounding area, with the virtual hand. This last action makes a yellow wire frame appear around the object. Only then should the user press the trigger button selecting the object (which became attached to the virtual hand). In order to drop the object, the user must press the same button a second time.

The corridor was the only model connected to the other models, the entrance and exit of rooms was made through a portal, with a waiting time filled with a fixed white image.

Prototype 2 includes all rooms: parents' room, kids' room, dining room, kitchen, bathroom, and corridor. This prototype differs from the first one in the following aspects: introduction of lights that simulate shadows and contrasts; different height-width ratio; introduction of various object and boxes in blue, green, yellow, and red colours; the white in portals changed into a less aggressive blue.

In *prototype 3* the corridor doors that where closed on the first two prototypes are now opened, with the visualization of each room interior.

The navigation scheme changed. The navigation direction is controlled by the trigger. Hand movement corresponds to changes in the visualization of an arrow – that replaced the virtual hand. This functionality was introduced with the help of another Polhemus sensor (one in the HMD – to the viewpoint – and the other one on the top of the trigger – to the navigation direction).

TILE VIZ background

TILE VIZ is the code name adopted for Virtual Decor™ 1.0[1] during the development process and is the name used throughout this paper. TILE VIZ is a tool to help users in selecting and visualizing ceramic tile patterns. Therefore, TILE VIZ is a design application of WC's and Kitchens where users can place typical objects and select and visualize these objects and wall/floor ceramic tiles.

The evolution of the project demanded the development of three interdependent modules. In the first one users can design the WC and/or the kitchen and place various typical objects in the designed room/s (doors, windows, lights, bathtub...).

In the second module users can select tile patterns. They can visualize the design rooms and selected objects and tiles in the last module, the real VR model. In this model users can navigate and do various tile manipulations.

Tools. TILE VIZ was developped in a Pentium 120, using a toolkit from Microsoft. The visualization tool (similar to the one used on RECMUVI) was a HMD from Virtual i-O.

In the first prototype, the navigation (with 6 degrees of freedom) was controled by two tools: the HMD controling the navigation direction; and the trigger controling the navigation velocity.

In the second prototype the trigger button is active and users can do several tile manipulations (e.g. change of patterns).

[1] Virtual Decor™ 1.0 is a trademark of Soexporta, Lda.

In the third prototype the trigger was replaced by a pad (Figure 2), with an extended set of functionalities: users can not only change tile patterns but also move bars and wall tiles upwards and downwards.

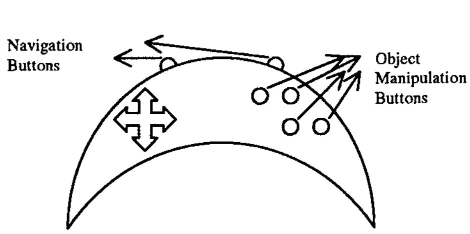

Figure 2. Pad

Prototypes. The first prototype (very primitive), was only a part of the final VR model: one room with a door, a panoramic window and four bare walls. The ceiling was the source of a diffuse light.

The second prototype again includes just the VR model (with kitchen and WC connected by a corridor and with several typical objects – bathtub, light, kitchen-sink – automatically generated by the system). This prototype had two different types of light: natural and artificial. Three types of navigation were implemented: free; fixed height; and separate view points..

The third prototype evaluations included all three modules. As the first two modules are typically Windows (point-and-click), this paper only reports the evaluations made of the VR module. The virtual world is identical to the last prototype (richer in objects) and the users are the ones that design the rooms, place the typical objects and select tile patterns that are going to be visualized in the VR model. The functionality of navigating backwards was added, in this prototype.

Development process

Design team. The design team constitution and ergonomist role in the team influenced the design and development processes of both projects. RECMUVI design team, with three computer scientists, three ergonomists, and two environmental engineers developed the project starting from computer solutions.

The lack of comprehension of the computer scientist ergonomists role on the design team led them to minimize the importance of heuristic and participative evaluations. In the heuristic evaluations (always *a posteriori* regarding computer implementation) suggestions made by ergonomists were followed only when they were easy to implement. Problems with software architecture were systematicaly ignored, as changes in structure pointed to a radicaly different design philosophy. For computer scientists interface was secondary regarding to programing problems and solutions.

In the participative evaluations, it was very interesting to observe the computer scientists change of behaviour regarding evaluation sessions. From the moment they saw subjects fighting with their design, several of them enthusiasticaly adhered to the evaluation sessions.

TILE VIZ design process followed a completely different philosophy. One of the authors was the manager of the design team, and that radicaly change the ergonomists' role. Their participation started from the beginning of process and the interface was the first thing to be defined. Therefore the system design followed the interface design. The goal was to simplify and potencialize users' performance.

Almost all changes proposed by ergonomists to other team members (three computer scientists) were accepted and implemented in the system. Participative evaluations were prepared by the design team and followed with attention by all of its members.

Methodology. The first question faced by the evaluation team was related to the validity of transfer to VR systems of traditional methodology of interface evaluation. Before the option for traditional methodology, the hypothesis of drama-based evaluations was considered as suggested by Brenda Laurel (1993), but those dramatizations were not chosen due to lack of resources.

Therefore, both projects were subject to usability iterative tests using three vertical prototypes (Hix & Hartson, 1993). In both projects heuristic evaluations were carried out by two ergonomists (2 evaluation points in RECMUVI and a continuous evaluation on TILE VIZ) and two tests with nine non-expert users. Subject numbers per session are those advised in literature for the two evaluation types (Nielsen, 1992; Virzi, 1990, respectively).

In TILE VIZ there was a third evaluation session in real context with 103 subjects testing the software during three days.

Design evolutions
RECMUVI

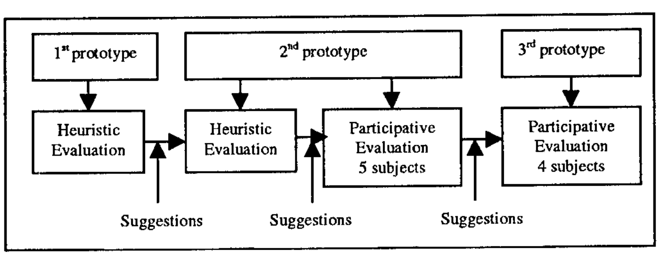

Figure 3. RECMUVI – Evaluations Scheme.

On heuristic evaluations Ravden and Johnson (1989) usability criteria were used as guidance. These criteria were also used to formulate questions during the evaluation sessions, especially in the 3rd prototype, where a group interview took place, with open questions.

Subjects had 15 minutes to explore the game. Then there was an individual interview (2nd prototype) or group interview (3rd prototype).

Some objective performance indicators were chosen and developed (e.g. number of picked up and dropped objects, execution times). Users were asked to draw the virtual home plan.

The instruction for the participative evaluations was simple: find the objects and drop them into the correct recipients. All the interactions were taped on video then analyzed by the authors.

On the participative evaluation made to the 2nd prototype some questions were asked during the interactions, as a means of promoting the thinking-aloud process. But both the thinking-aloud process and the questions revealed to be concurrent stimuli that interfere with users performance (e.g. interactions stops).

On the evaluation of the 3rd prototype the thinking-aloud technique and the questions during the interactions were substituted by a group interview a less intrusive technique.

TILE VIZ

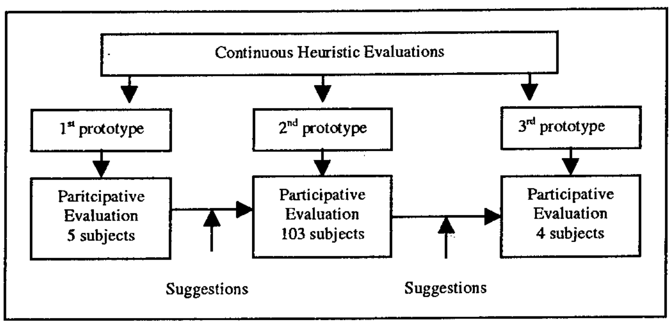

Figure 4. TILE VIZ – Evaluations Scheme.

In this project, authors used the techniques that they found most valid in RECMUVI. The interactions on the 1st participative evaluation were coded in a grid and taped on video for further analysis; after the interactions users were interviewed in group.

The criteria of Ravden and Johnson (1989) were again used for extracting useful information from users. Group interviews showed to be a good means of explaining clearly the problems that the subjects found, and precious ideas generators.

Some improvements were introduced. First, the heuristic evaluations were performed continuously, the ergonomists were always present when decisions were made regarding the interface style and interactions type.

Second, tasks were given to users. On the 1st participative evaluation, those tasks were specific, closely related to vision criteria (accuracy, color, distance measure) and locomotion (execution styles and times). On the 2nd evaluation, tasks were simply suggested, since the context required such an approach, and object manipulation criteria were added.

It should be noted that the 2nd evaluation was extremely useful, since the context where it took place was similar to the one of its final use. Authors were able to see the impact of context on system and users performance.

The final participative evaluation was a confirmation for the choice of the navigation and manipulation tool, following the template of the first evaluation, with individual interviews and without video recording.

Design Evolutions

The 1st considerations to be drawn were related to simple indicators, such as luminance, height/width ratio, that can be considered to be basic problems on the construction of virtual worlds. Although those problems seem rather evident, one should not take into account just psychophysiologic criteria, but also consider aesthetic aspects.

The next issue is the necessity to implement a medium height of navigation. One of the central elements of different difficulty stages could be the development of different types of navigation. So, in TILE VIZ, the second prototype includes three navigation types, that cover all system needs. In general, it seems that fixed height navigation and the free navigation require different cognitive resources, and this can be applied to all VR systems.

The search for a better navigation system can be viewed with the change introduced in 2nd to 3rd prototype of RECMUVI. The dissociation between viewpoint and moving direction implied the existence of two different sets of visual cues. On one hand we have the images actualization in response to head movements. On the other hand, we have the modifications on direction arrow in response to hand movements.

This solution introduced a greater complexity level, since users would have to control two position referentials, each one with their visual cues. Furthermore, the direction arrow is "linked" to the viewpoint since subject is always seeing the arrow, whatever the direction he is looking to; finally, the arrow takes the relative position of the direction (hand movement) and coordinates with the eyeing direction. So they are not completely independent.

The complexity of such solution should have been studied, introducing his characteristics gradually, allowing an evaluation of the cognitive capacities required.

The next point reports the inclusion of visual cues to guide the user in the virtual world. One first question concerns the reduction of the visual field and the discontinuity on the space apprehension, requiring bigger memory resources to its representation. A simple corridor with 6 different doors demands that the subject explore systematically the different parts that constitute that corridor, not apprehending it with one glance. The objects that go out of the limited visual field have to be retained in memory, especially their locations. These affirmations are, in part, supported by data obtained through plant drawings in RECMUVI project. After the corridor doors are opened, subjects present more correct plans, although the navigation is much more difficult and the exploring is then restricted (note that the subjects in the 3rd prototype enter less in the different rooms).

Table 1. Comparative results of RECMUVI prototypes 2 e 3.

	Mean Frequency of Picked Objects	Mean Frequency of Dropped Objects	Mean Number of Correct Spatial Identification	Mean Number of Correct Rooms	Average of Entries
Prototype 2	3	2,5	4	3	5,2
Prototype 3	1,8	0,8	4,5	4,3	4,5

The other issue in visual cues has to do with the difficulty to calculate distances in the virtual environment. The nature of the TILE VIZ itself solved the problem, since the simulation of tile application introduces a squad in the space that facilitates the navigation.

Finally, the last thing to report is the change of the navigation tool, from the trigger to a pad in TILE VIZ. On one hand, this decision was taken due to the end increase system functions. On the other, it was essential to implement the functionality of walking backwards.

Walking backwards is crucial since users had difficulties in executing a rotation of 180 degrees, necessary for driving away from an object, for instance. The pad allowed the existence of one button to move forward and another to move backwards.

Finally, since this pad is an infrared one, users showed less navigation difficulties, as wires, that were a constant embarassment were reduced.

Conclusions

The approaches concerned with the usability iterative tests are accepted to be the most effective, as suggested by Landauer (1988), Jeffries, Miller, Wharton, and Uyeda (1991), Bayley, Allan and Raiello (1992) and Virzi, Sorce e Herbert (1993). The application of heuristic evaluations and end users tests, as complementary methodologies, enables the correction of the gross majority of system problems. TILE VIZ project experience was truly helpful in clarifying this issue.

Barnard et al. (1986, in Barnard, 1991) raise doubts about the use of thinking-aloud techniques. On a first contact with a virtual environment, the interaction developed by the user is centered on action itself. Users search for correlations between body movements and the system states, paying less attention to verbal behaviors.

As the thinking-aloud technique demands cognitive resources needed for the interaction, it affects users ability to explore the virtual world (RECMUVI). This technique may be admitted as a good double task indicator.

Task definitions and group interviews revealed to be more productive techniques. On one hand, navigation and objects manipulation problems are clarified with task performances, evaluated with objective criteria. On the other, group interviews enable a sharing of individual experiences, a discussion about the central aspects of the interaction and proposals of solutions for recognized problems.

Another important problem raised by Bailey et al. (1992), is concerned with the abilities that should characterize the evaluator. This does not seems to restrict to different levels of technical knowledge about user interfaces, or systems, in spite of the importance it surely has (Nielsen, 1992). Barnard (1991) when referring that a significant share of the exploratory development methodologies depends on the evaluators intuition and expertise qualifications also sustain this fact.

Future research studies will focus on a VR interfaces development model with a sequential implementation of the characteristics and a recording of users' behaviors in minimal units.

Let us now look at VR issues. Following some ideas proposed by Varela (1995) it can be accepted that a cognitive system experience implies a linkage between a structure and an environment. Therefore, there is a context where the user, as a cognitive entity with a body, possess one perspective and relates to the VR system through a specific dynamic.

As is viewed by Steuer (1992, in Slater & Usoh, 1993) VR is created by individual consciousness mechanisms, revealing the importance of studying subjective variables and their effects on the interaction of the subject with the virtual world (e.g., presence feeling).

It is easy to create a virtual world sensation of presence because human cognitive system generates the illusion of immersion. This implies that, in a VR system, a careful conception of all aspects related with the interaction (which comprises vision, navigation and object manipulation) should be developed, especially when dealing with non-expert users. It follows that, if the feeling of presence is easy to obtain in a first stage, helped by the technology natural attractiveness, it is clear that the following interactions, if not intuitive and easy to learn, may kill the first impression.

Keeping the exciting aspect of VR demands intuitive and easy to learn systems able to generate comfort and safety feelings corresponding to users expectations. To accomplish that, users should get an added value from the interactions, and well defined objectives should be attained regarding learning, entertainment and decision-making.

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A Multimedia Archaeological Museum

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Abstract

This paper will present a project, which was first initated in 1994 as a graduate students seminar and is now being continued as a research project in a cooperation of computer scientists, architects and archaeologists. An ancient roman city (Colonia Ulpia Traiana near todays Xanten in Germany) has been reconstructed, using various levels of abstraction. On the coarsest level, a 3D-model of the whole city was established, distinguishing between different historical periods of the city. The second level picks places of special interest (temples, the forum, the amphitheater, the town-baths etc.) and reconstructs these buildings or groups of buildings. On the finest level important interior parts or functional details like the Hypocaustae in the town-baths are modelled. All econstructions are oriented as close as possible to results from excavations or other available documents.

All levels of the 3D-model have been visualized using photorealistic images and sequences of video animations. The 3D model is integrated into a multimedia environment, augmenting the visualization elements with plans of the city and individual buildings and with text documents. It is intended, that parts of the outlined system will be available at the site of the ancient city, where today a large public archaeological park is located.

Introduction

Museums are in many aspects a very suitable field of application for multimedia techniques. This contibution will focus on public information systems, which can be used as multimedia guides on CD-ROM or in a communication network as well as in the museum itself. There are already a couple of examples available in internet, e.g. a guide through the National Air and Space Museum in Washington D.C. (NASM 1995) with many image and text documents or through the Museum of History of Science, Florence (Berni and Guidi 1995). Applications in the museum itself range from orientation guides ('Where can I find which department, which exhibit ?') to multimedia informations at individual objects. Significant advantages over standard information charts and audio tapes arise especially, if visualization of dynamic processes (e.g. function or manufacturing of technical exhibits) support the visitors understanding. Moreover, an interested user can be supplied with nearly arbitrarily much information on details or on background.

Using the opportunity to individually select information, a visitor can thus play a much more active role in a multimedia supported exhibition than in classical concepts, where he is usually restricted to pure passive examination. The most attractive field of application of multimedia systems in museums may yet be all those areas, where objects being otherwise invisible can be shown.

An example for this application, a prototype of a multimedia archaeological museum, is presented in this paper.

In a graduate students seminar with the title 'Seeing the invisible ´reconstruction of an antique city by CAD´ 16 students of the Department of Architecture and Civil Engineering at the University

of Dortmund created, in cooperation with computer scientists and archaeologists, a huge 3D model of the ancient roman city 'Colonia Ulpia Traiana' near todays Xanten in Germany. A prototype for this seminar was Koobs pioneering reconstruction of the Cathedral of Cluny

(Cramer and Koob 1993). The primary goal of the seminar was to teach students in 3D-CAD modelling and visualization. They were challenged by the required modelling of very complex geometric objects and were, on the other hand, given enough freedom to use and to develop individual knowledge (and intuition) about classical culture and buildings. In examining *processes* of construction, students had to study thoroughly principles and techniques of anchient master builders. Thus, the use of CAD contributed much more to the architectural education of the students than only to the development of technical skills.

Our CAD model uses different levels of abstraction. On the coarsest level, a model of the whole city was established, giving the frame for the second level, where places of special interest (several temples, the amphitheater, the town-baths etc.) were elaborated. On the third level, important interior parts or functional details were modelled. All reconstructions were orientated as close as possible to results of excavations or to other available historical documents.

The integration of the CAD-model in a multimedia document and an example session of a 'tour' through the document will be outlined in the next sections.

System design and implementation

The implemented 'multimedia museum' (Rank 1995) is based on the 3D CAD-model, having been created using a commercially available CAAD-system (Nemetschek 1994) with powerful solid modelling capabilities.

Within this system, a large number of photorealistic images, using standard shading or ray-tracing techniques, was created and stored as gif- or jpeg-files. It was also possible to create video-sequences of selected parts of the model and to store these clips as mpeg-files. Images and videos

are integrated in a multimedia system, using html-version2-standard and public domain tools for browsing and visualisation. The overall structure of the document is, according to the structure of the underlying CAD-model hierachical, with some additional horizontal links between particular parts of the document.

We consider it especially important to design the structure of a multimedia document very carefully, so that a user of the document is able to understand this structure quickly and intuitively. For our application it is very natural to use images of the model as basic ordering elements, applying the concept of 'clickable maps' to select information on the next level of hierarchy. Considering for example the 'root'-level of the document, a birds eye view of the city is presented, and the user can select information on different buildings, clicking on these objects in the images.

Moreover, a unique box with available documents (floor plans, index, videos) is available on every layer of the document, preventing the user from 'getting lost' in the large amount of informations.

Examples

Since its opening in 1977 more than 4.5 million people have visited the Archaeological Park Xanten. The ancient monument Colonia Ulpia Traiana is open to scientific investigation, but in particular is presented to the public. Methods and results of archaeological research are displayed at the spot where history took place (from Rieche 1994). The design of the multimedia guide, being aligned to the general goals of the APX, is intended to serve as well as a first introduction to the Park and also as a system to provide background information.

Both ways of use start entering the system in a page shown in Figure 1, being composed of first textual information and a perspective view of the city.

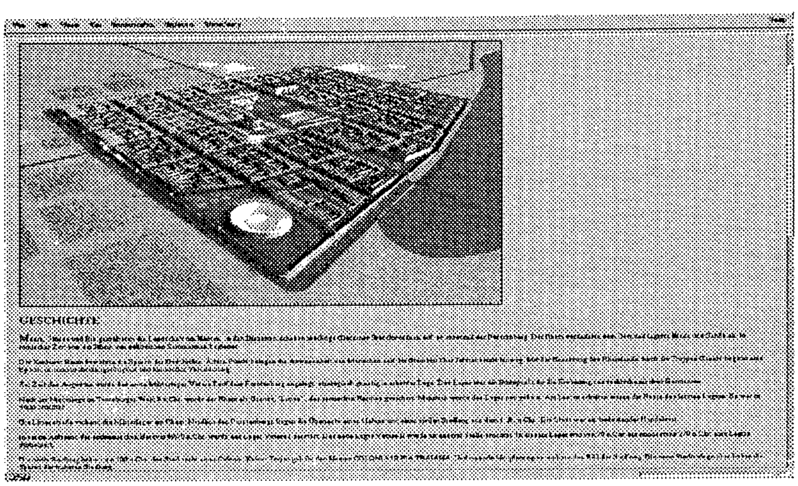

Figure 1 Clickable image of the whole Roman city

Selecting e.g. the amphitheater or the town-baths in the clickable map leads to branches with images and additional text information partially shown in Figures 2 and 3.

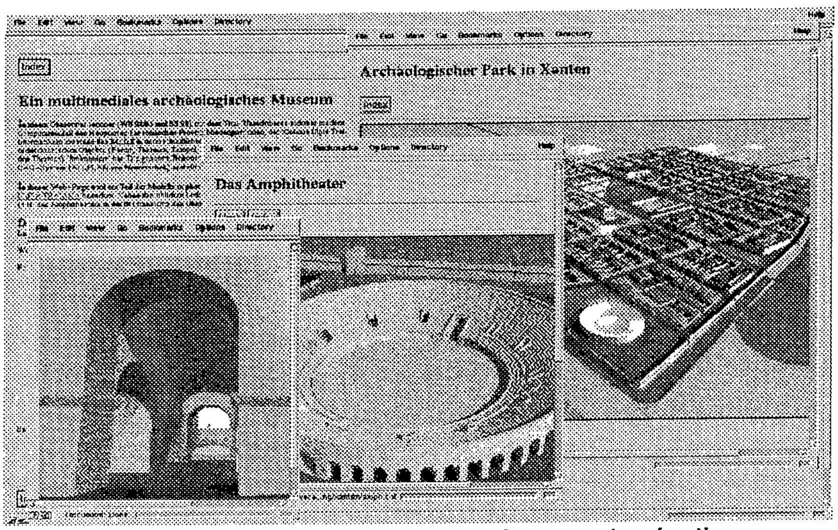

Figure 2 Amphitheater with image of construction details

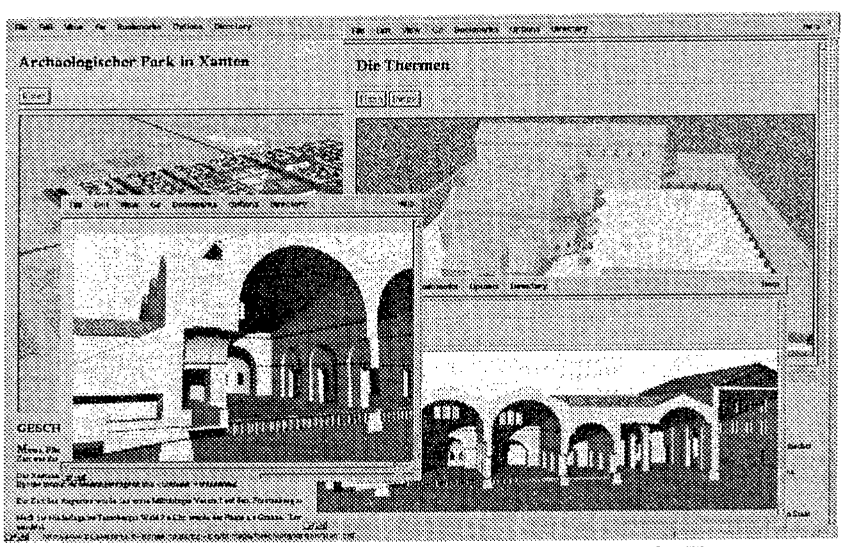

Figure 3 The town-baths with technical informations about the Hypocaustae

Discussing the branch assoziated to the capitoline temple it will be shown that a multimedia system based on a 3D CAD-model can easily provide a lot of additional information, being only implicitly related to the spacial model. The entrance point into this object is again a photorealistic image of the temple providing options to select more images in details (Figure 4). Also available is a floor plan (Figure 5) together with a scanned picture of the (very small) part of the fully excavated site (Figure 6). This part is marked in the floor plan (shaded area) and thus gives the user a very immediate idea of the size of the whole site of this temple. Other details are shown in Figure 7, where, derived from the 3D-model, construction parts of the front side and of the columns are plotted and explained in more detail. This image is used again as a *clickable map* to obtain perspective views of constitutional elements like a part of the roof construction with capitals, shown in Figure 8 as CAD-model and as a 1:1 reconstruction.

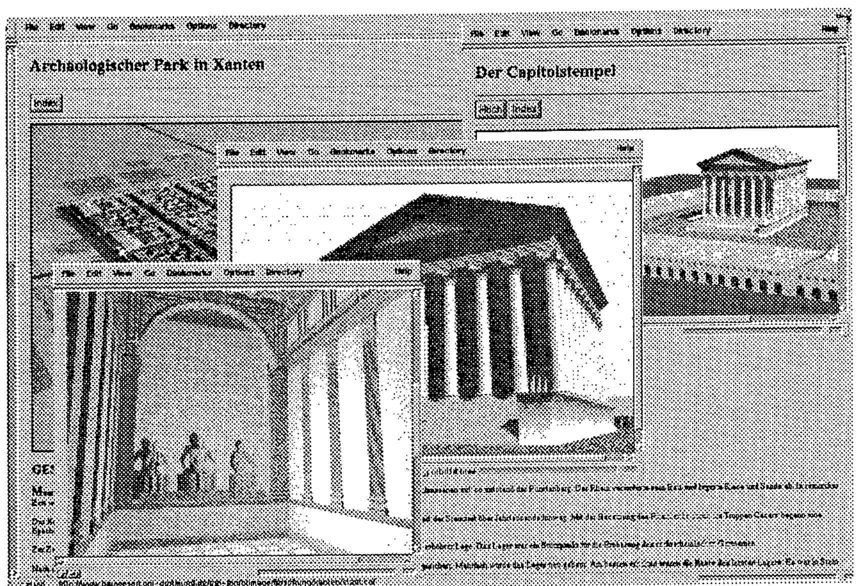

Figure 4 The capitoline temple: Based on 3D-CAD reconstructions it is possible to make a walk into the building

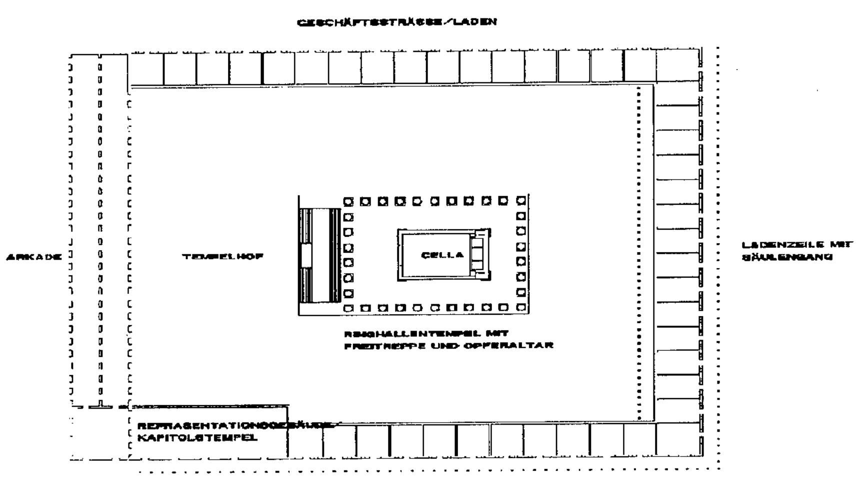

Figure 5 The capitoline temple: Floor plan with shaded excavated area

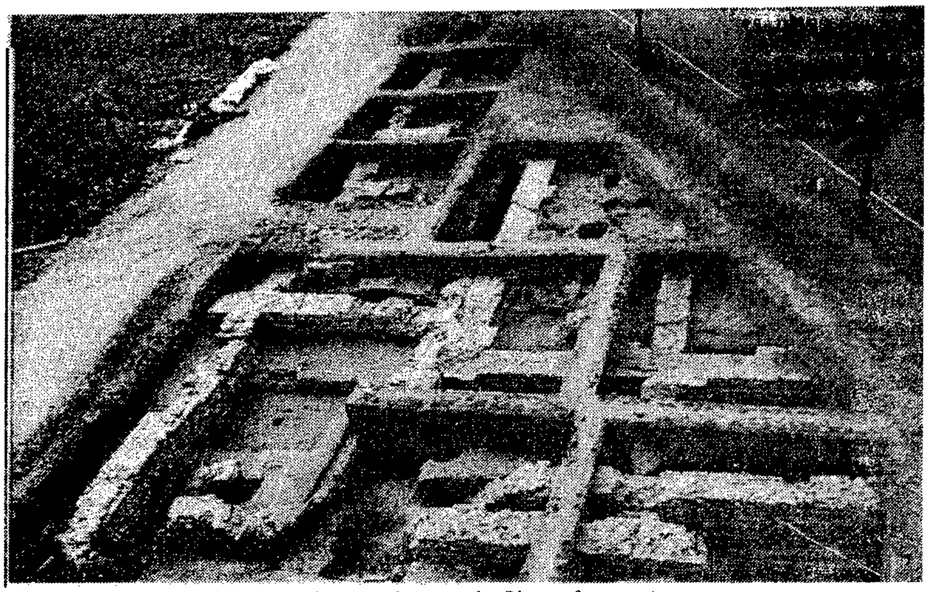

Figure 6 The capitoline temple: Photo of excavation

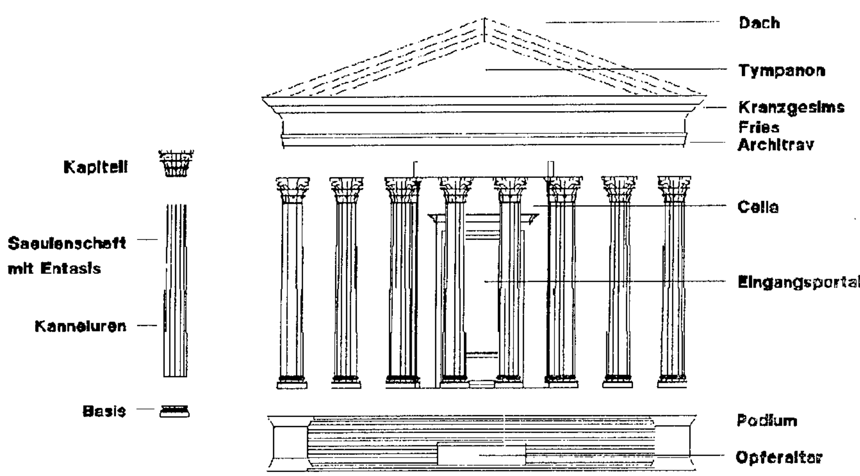

Figure 7 Construction details of the capitoline temple

Conclusions and future work

Based on a huge 3D CAD-model a prototype for a multimedia system to be used as a guide through an archaeological site has been outlined. The system offers opportunities to retrieve information, which go far beyond the possibilities of classical media. Up to now, the system is composed of text, high resolution photorealistic images, plans, photographs and sketches.

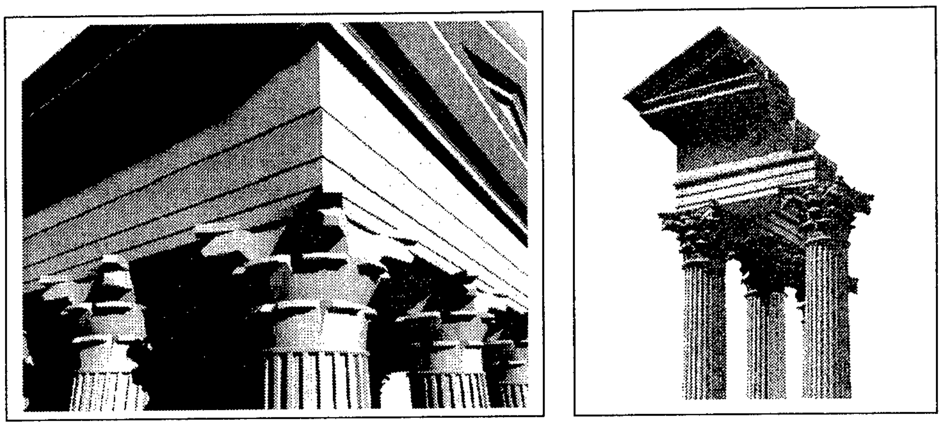

Figure 8 A detail of the CAD-model (left) and Photo of a 1:1 reconstruction (right)

With the availability of sufficiently powerful hardware it will be possible to allow a user an online animation of the full 3D-model, giving him the opportunity of a 'virtual walk' through the ancient city. Additionally, parts of the model have already been implemented on a '3D workbench' (Krueger and Froelich, 1994), presenting the model with the possibility of online interaction on a 'table' in stereo view. The most attractive perspective of the multimedia system is yet a presentation at the site of the ancient city itself, where today a large public archaeological park is located. The viscinity of 'real' excavation and 'virtual' reconstruction will give the visitor a much better chance to understand the site and the roman culture as a whole than any classical way of presentation of archaeology.

Acknowledgement:
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Subjective Realism in a Simulated Squash Game

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Abstract

Subjective realism is thought to play an important role in computer simulation. The purpose of several experiments was to assess to what degree subjective realism can be captured by well defined, task-relevant information such as time delays or resolution, and to what degree it has to be considered a psychological concept in its own right. We investigated immersive variables that were manipulated above and beyond the visual information necessary to carry out the task. Three experiments were conducted to compare performance measures with ratings of subjective realism within an engaging and demanding task. Observers were confronted with a simulated squash court. Accuracy of racket placement and timing were assessed as a function of gratuitous cues for compellingness (such as depth cueing, cast shadows) and as a function of objective disturbances in the ball's trajectory. Subjective realism proved to be a psychological variable in its own right that cannot be predicted by task performance. Pragmatic, task-specific criteria were found to be particularly important determinants of subjective realism.

Introduction

Subjective realism has been acknowledged to be a major aspect in the evaluation of visual simulations. The goal of this paper is to explore status of subjective realism form a psychological point of view. I demonstrated that subjective realism cannot be reduced to performance measures, that stimulus properties influencing compellingness should not be studied in isolation, and that subjective realism bears a complex, non-intuitive relationship with stimulus parameters of the simulation.

A taxonomy for testing reality or realism has been proposed by Kruse and Stadler (1990), who have attempted to establish a catalog of criteria that contribute to phenomenal realism. They suggest three broad categories of criteria for reality: (1) Syntactic criteria, such as contrast, starkness of object contours, richness of texture, three-dimensionality, intermodal congruence, motion, and spatial location. All primary and secondary depth cues would fall into this category. (2) Semantic criteria: Significance, expressiveness, and context congruity are addressed here. For example, a perfectly well-rendered object may not look compelling because it is placed in an inappropriate context. (3) Pragmatic criteria are the possibility of the object to become part of an action, the degree to which the event can be anticipated, and inter-subjective agreement on the object. An artificial situation, even if it does not attempt to replicate a maximal number of aspects associated with a real-world experience may be very compelling if it becomes a meaningful part of an action. To be able to differentiate between and separately manipulate syntactic, semantic, and pragmatic aspects of subjective realism, a squash game was simulated on a computer.

Experimental Setup

A simulation of a squash game was chosen and reduced to the following action sequence during the experimental trials: A ball was simulated to fly toward the far wall of the court (as if hit by an invisible opponent), rebound, and then move toward the observer. By manipulating the mouse, the observer could move a simulated racket and "hit" the oncoming ball. Independent variables were shadow, amount of detail, texture, fog, and sound effects. Pragmatic variables were success rate as manipulated by racket size, random path deflections and delayed mouse action. On all trials, positioning of the racket and timing of the action were used as performance measures, a compellingness rating was added to directly assess subjective realism.

The stimuli were generated on a Silicon Graphics Indigo 2 XZ workstation with a resolution of 1280 x1024 pixels and a refresh rate of 72 Hz (non-interlaced). The animation update rate was 18 frames/second. Observers sat with their eye-point 27 cm away from the screen such that their line-of-sight was centered on the 20" display screen The monitor was 38 cm wide and 29 cm high resulting in a visual field of 70° by 56°. The stimulus displays consisted of a 3-D rendition of a squash court. A ball would fly toward the back wall as if hit by an invisible opponent. After it rebounded it moved toward the observer, whose task was to intercept it with her/his racket. The racket could only be moved on the invisible front wall but not in depth (2-D movement) by using the computer mouse. The viewpoint of the observer was fixed thus simulating a stationary observer with a very long arm. A thin line was drawn from the edge of the racket to the floor to provide additional visual support for the fact that the racket never moved into the court but remained on the front wall.

Various Experimental Manipulations

First we probed into some parameters that are critical for a hitting task as well as into some parameters that offer more gratuitous embellishment, such as sound and lighting. To provide a standard to anchor judgments of subjective realism, some clearly unrealistic changes were introduced in some trials: The ball could deviate from its motion path in mid air, as if deflected by an unseen force. A large number of syntactic and semantic criteria were varied, while the task remained always identical. Surprisingly, some manipulations that were thought to have a strong influence on performance (e. g. the cast shadow of the ball) only affected judged realism, and vice versa.

Also, the consequences of the action were manipulated. Not the whole racket, but only a cross hair indicating its center was visible. At the same time the actual size of the invisible racket was varied. Thus, the number of successful hits could be changed independently from parameters of the simulation. The success of the action, above and beyond all other manipulations, had a strong positive effect on judged realism.

Both sound and the shadow cast by the ball produced an informative asymmetry between performance and realism. Sound effects were not exploited to fine-tune action, not even to reduce timing errors. However, trials with sound effects were judged to be more realistic than those without. Shadow had the opposite effect: It increased the racket positioning error but had no effect on judged realism. The fact that shadow distracted in the proper positioning of the racket without affecting hit rates or timing of the ball suggests that shadow was used to fine tune the racket position, albeit with negative effects. Shadows are known to exert a strong influence on the perceived depths of objects and may even override other depth cues and create powerful illusions (Kersten, Tarr, & Bülthoff, 1995). Thus, the negative shadow effect is in accordance with the literature.

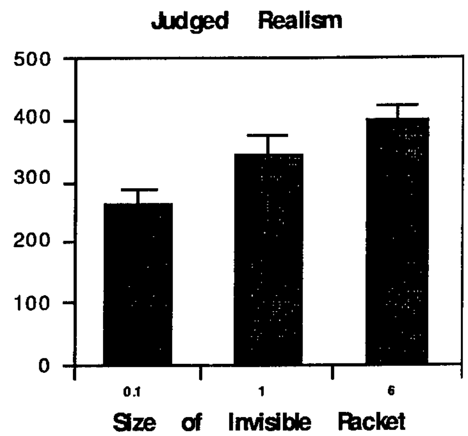
Observers did not receive explicit feedback, but they could use the effect of their action (hit versus miss) to judge the positioning accuracy of their action. Timing errors, on the other hand, could not be perceived at all. We considered making a successful hit and rebound dependent and correct positioning and timing, but pilot subjects, including the experimenter, found it very frustrating. Also, it should be avoided that the ball flew through the racket in order not to create another variable affecting realism. The fact that variability in performance was carried by positioning was a function of focusing the observer's attention on hitting the ball, which was much harder than in Experiment 1. This effect was desirable since timing errors might have been hard to interpret given the rather slow update rate of 13 Hz.

Changing the light transmittance inside the squash court (fog) produced no significant effects, neither did it affect performance nor judged realism. This indicates that observers could do without the information contained in the initial phase of the balls trajectory after leaving the rear wall. They might have extrapolated the ball's motion during the period where it practically merged with the dark background. It seems plausible, that observers considered fog as a natural effect while they treated pervasive effects like sound as necessary for a realistic rendition.

In sum, the decoupling of performance and judged realism in the case of sound and shadow shows that the former interact in non-trivial ways. It is thus unlikely, that any given performance measure is able to capture realism.

In another experiment, the pragmatic factor was more thoroughly explored by making it independent of parameters of the simulation. This was achieved by making the racket invisible except for a cross-hair indicating its center. The size of the invisible racket was changed unpredictably from trial to trial. That is, a well executed placement of the racket could lead to failure to hit the ball (as well as to success); and a sloppily executed racket placement could lead to a success (as well as to a miss). Success rate was thus decoupled from quality of the animation, precision of the action, and other possible confounds. In all other respects the experimental setup remained unchanged with the exception that the shadow manipulation was dropped, mouse action was always instantaneous, and visibility was changed by introducing fog to the display on some trials.

Manipulating the success rate of the motor response had the hypothesized effects (see Figure 1). The pragmatic factor of success exerted a strong influence on judged realism. Trials in which balls rebounded from the invisible racket looked more natural and realistic to observers compared to trials where the ball went past the racket. This effect cannot be attributed to any syntactic or context effects of the simulation but solely on the outcome of the action. A roughly linear trend between judged realism and racket size indicates that, ceteris paribus, realism is a more or less linear function of success.



<u>Figure 1.</u> *Mean judged realism as a function of racket size. Note that the racket was invisible and displays were identical in all cases. The racket's center was marked by a cross hair and could be 10 %, 100 %, or 600 % of its standard size. Timing and positioning accuracy were identical in these conditions. Thus, identical actions based on identical visual stimulation yield different realism as a function of their outcome.*

Discussion

The results support the notion that judged realism can neither be confined to pure performance measures nor to display parameters of the simulation. In addition to these factors, the observer's action context and the outcome of the event have been shown to be critical for the degree of subjective realism in the simulated scene. In hindsight, these results justify the unified measure of subjective realism that was employed.

When confronted with the task to compare two pictures or two computer simulations, it is hard to imagine a difference between them that does not also reflect a difference in realism. For instance, if an observer is confronted with two displays that vary in only one aspect, let's say stereo, and if he/she is then asked which display was nicer or more realistic, the display with stereo is usually preferred (e. g. Hendrix & Barfield, 1996). However, by itself, this judgment is rather worthless because a different reference object or reference class can completely change the judgment. Moreover, if stimuli vary on one dimension only then the observer is maximally constrained and will therefore accept almost any label for the difference. One could probably replace realistic with words like cozy, strong, or heavy and still get the same results. Thus, to interpret the results as a difference in judged realism an additional argument has to be made to connect the rating to a content.

As Gestalt psychologists have shown, this depends on the hierarchical nesting of the stimuli in their context. From our results it is clear, that factors such as the success of the action are part of this context. It is therefore questionable if much is learned if only one or two parameters are varied simultaneously. The concept of realism appears to be too complex to be fully grasped by studying aspects of it in isolation. Thus, in the case of subjective realism, complex experimental situations may well be a virtue rather than a vice. At the same time, results obtained with small parameter sets have to be interpreted very carefully. The rating scales that were used in the present experiments did not rely on a small set of parameters, but they reflect considerable variability in syntactic, semantic, and pragmatic aspects of the action and its simulated environment. The fact that they produced interpretable results justifies the choice of a rating scale that required a single rating after each trial. Moreover, the simultaneous significant effects of several independent variables (sound, success, mouse delay, and path deflection) on judged realism indicates that observers do not just focus on one salient aspect of the simulation, but that they do integrate - knowingly or not - many aspects of the display into one meaningful judgment. The lack of significant interactions between the different independent variables revealed that the resolution of the compound judgment was limited to main effects.

Possible alternatives to the realism ratings could have been (1) cue trade-off studies and (2) successive addition models. Trade-off studies place two cues in conflict. The cue that wins is the stronger one. Underlying this model is a static view of cue strength that is very situation specific. As a function of this model typical empirical results are that, depending on situation and observer, different cues win. However, these methods could not be used here for two reasons. First, too little is known about variables or cues that contribute to subjective realism. Second, compellingness or realism are integral concepts that have to be assessed in a complex (non-additive) fashion. This was achieved in the present study, since no explicit understanding of the concept of realism was necessary for the task. The required rating scale of compellingness or realism was anchored in the first trial blocks relative to the variability in the stimuli

In sum, the importance of pragmatic criteria for subjective realism has been demonstrated. Time delay of consequences caused by the motor action (mouse manipulation) had a strong negative effect on judged realism. Likewise did outcome of the action (hit or miss) influence judged realism. This entails that it is not very useful to define subjective realism, or presence for that matter, as a dimension that is independent of interactivity or that does not play a role in standard displays, as was suggested by Zeltzer (1992).

Conclusions

The findings suggest that the taxonomy devised by Kruse & Stadler (1990) is very useful when evaluating subjective realism of visual simulations. Moreover, the results are in agreement with hypotheses by Loomis (1992) that distal attribution of events is crucial in subjective realism. The results also are compatible with and extend findings by Welch et al. (1996). The particular implications for our thinking about subjective realism can be summarized as follows:

1. Subjective realism cannot be reduced to the fidelity of the graphical rendition
2. Subjective realism cannot be reduced to performance measures
3. Violations of physical laws often do not affect subjective realism

4. Subjective realism is context specific
5. Subjective realism is highly dependent on the action the observer is involved in as well as the consequences of this action

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Virtual Reality as an Aid to Document and Inventorize Historical Buildings

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Abstract

Working with models and simulations has a long tradition in the building industry. The models are used for visualising the drawings of the architect and to discuss possible problems during construction.

Due to the introduction of CAD-Systems visualisation has been expanded potentially.

The geometry of an architectural project is digitised to create a three dimensional model within the computer. Virtual Reality and it's possibility to compute 3D-data in real time, interactive control mechanisms and free movability inside Cyberspace opens new perspectives in architectural modelling.

By using the techniques of virtual reality it is possible to document different stages of a buildings history, enabling the viewer to interactively walk through time. This could be used for research and reconstruction of historic buildings, with the possibility to show different stages of completion and changes through time.

"House Moven" in the Westfalian Outdoor Museum at Detmold has been modelled in this way and is to show the potential of virtual reality. It is possible to walk through the three dimensional model and to pick out certain aspects of construction to analyse more closely.

Furthermore, changes throughout different historic periods and building stages since it's construction in the 16th century are made visible. The analysis of the user interface between man and machine which is to be used by academically trained and by people with little or no knowledge of computer modelling is of great interest.

Introduction

The task of combining two very different disciplines has a particular attraction for an engineer. On the one hand there is the preservation and documentation of historic monuments - a very old discipline with roots in Historicism and in Enlightenment (Germann 1980). Virtual Reality or Cyberspace on the other hand are rather new terms. Their exact meaning has not yet been fixed. Cyberspace is a word that was first used in Science Fiction Literature (Gibson 1987). The objective of combining those disciplines is to look for a man computer interface that facilitates research of building historians by allowing a simple interactive and immersive navigation through historic buildings.

Documentation of historic monuments

The way generations of historians documented their work is measuring the building with the conventional measuring methods of the surveyors (Cramer 1993) and making drawings of them - usually drawn to a scale of 1: 20, 1:50 or 1:100 and in four different grades of precision (Gebeßler 1986). Results of research were marked with different colours.

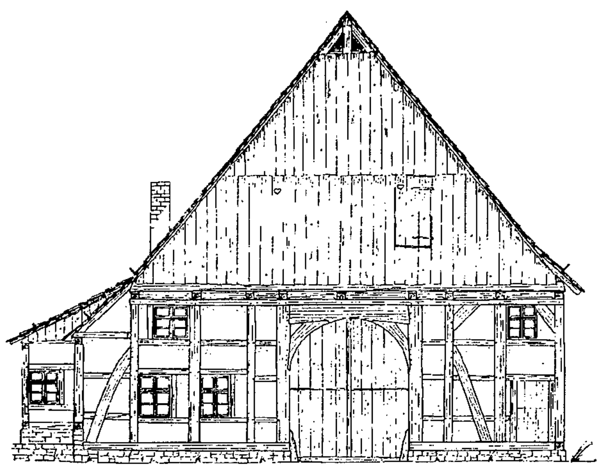

Figure 1: Manually Drawn Plan of House Moven

New techniques of measuring like for instance photogrammetry were naturally adopted. As they supplied three dimensional data in x-y-z co-ordinates it was obvious to use them for building a three dimensional computer model.

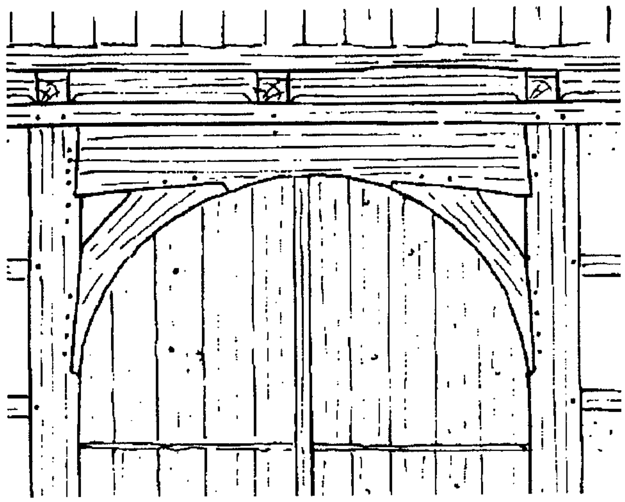

Figure 2: Detail of Manually Drawn Plan

There are excellent examples to be visited in the Internet as for instance the Amiens Cathedral Media Centre For Art History of the Columbia University in New York (Columbia 1997). Another excellent example of the possibilities is the reconstruction of the Archaeological Park - Xanten by the "Institut für Numerische Methoden und Informationsverarbeitung" - University of Dortmund (Rank 1995)

Virtual Reality

The term "Virtual Reality" often seems to be woolly and vague. Even a dictionary is not very helpful, as virtual there is defined as "almost" , "nearly" or "seeming". So I will try to give an example.

Man's left and right eye have different angles of view so they produce two different "pictures". Our brain is able to blend two 2-dimensional pictures into one 3-dimensional image of our surroundings. What we can see is a 3-dimensional image of the space - there brain forms a "virtual space". This virtual space is shaped by our natural experience. Our brain adds the information of our sense of touch, taste and hearing extending our image of the space. Since we are born we are living in a virtual space.

Our image of space seems natural to us because we are living in it from birth. All our experience is based on the information this image of space provides. The painting of René Magritte, the surrealistic painter, entitled "c' est ne pas une pipe" shows us the dilemma of our mind: What we see on the painting is a pipe but the title tells us it's only the image of a item of practical use as the artist saw it. And - to bring this idea to an end - the pipe I am smoking in the evening is also a virtual image of a pipe that is created by my sense of sight, taste and touch.

The term "Virtual Space" or "Virtual Reality" changes it's meaning when used in context with computers. It describes a new way to create a man - computer interface. In this context interface means all units that let man manipulate the computer.

The object of research on virtual reality is to improve man - computer interface even more. Many problems and tasks we have to solve with computers are located in the 3-dimensional space. An architect for example wants to show the planned building to his client, so that he can judge proportions, light and materials.

Virtual Reality with computers means the simultaneous existence of

3D-input and -output,
real time behaviour,
autonomous objects and
immersion.

More detailed:

3D-input and -output means that the representation as well as the sensors of the VR system are designed for three dimensions. Suitable equipment is for instance a data glove, space mouse, head mounted displays and tracker, stereo glasses.

Real time behaviour means that the VR-System reacts on user's input or movement with a delay less than 10 to 50 milliseconds.

Autonomous objects are characterised by owning properties that are independent of the current reaction of the user and by the possibility to interact with them.

Immersion is the effect that the user is mentally completely immersed in the virtual world.

The Task

A historic building is rarely found in the state it was built centuries ago. The buildings we consider have changed their use several times. They have partly been broken down and extended in other parts. With changing fashion they got new facades - up to seven times in six centuries. Therefore it is extremely difficult to decide which historic state of the building is to be reconstructed. The earlier and later states of this building can only be documented. There seems to be a need for a system that supports the decision by visualising the different states of the building in an easily understood way. We are looking for an economic solution for this problem as a compromise between costs and performance.We suppose that Virtual Reality can serve as a tool do visualise different stages of a building and can be used even by inexperienced computer users. The aims of the project are:

- to find a way to document and inventarize the different states of a historical building for research in a 3-dimensional way,
- to make visible the different states of a building to visitors of the museum that are not experienced in using computers,
- to test different man - computer interfaces for their suitability

The Tools

As we had to regard the economic efficiency we chose a PC-based System as a workstation:

- Dual processor Pentium 200 MHz,
- 256 MB memory,
- 4 GB harddisk,

- Diamond Fire GL 1000 8MB graphic card, Diamond Monster 3Dfx graphics accelerator,
- Windows NT 4.0 operating system.

Space mouse and stereo glasses will complete the "virtual" equipment.

Although all used to design with the CAD system MicroStation and Triforma we decided to do all construction work with 3D Studio MAX by Kinetix. Mainly designed as a program for visualisation and animation it has the capability to export the animated model to VRML 2.0, the common description language for Virtual Reality. Where necessary we improved and optimised the VR model with the help of the program Realimation by Datapath.

Users can immerse in the Model using the viewers of Realimation or Superscape even within the WWW. For this purpose one will to have to install the Cosmo Player plug-in for Netscape Navigator by Silicon Graphics or the World View plug-in for Netscape Navigator by Intervista.

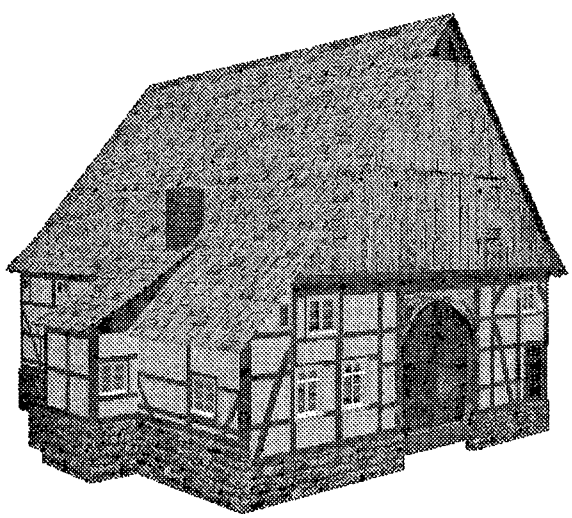

Figure 3: Virtual View of House Moven

An Example

House Moven is part of the "Paderborn Village" in the Westfalian Outdoor Museum at Detmold. In 1980 it was pulled down at it's original site in Bruchhausen and rebuilt 1982 to 1986 in Detmold. It is a typical half timbered construction of this region. House Moven was built in 1651 by Peter Moven, a farmer. He used the foundations of a former building.

The original ground plan of 1651 is to make the history easier to understand.

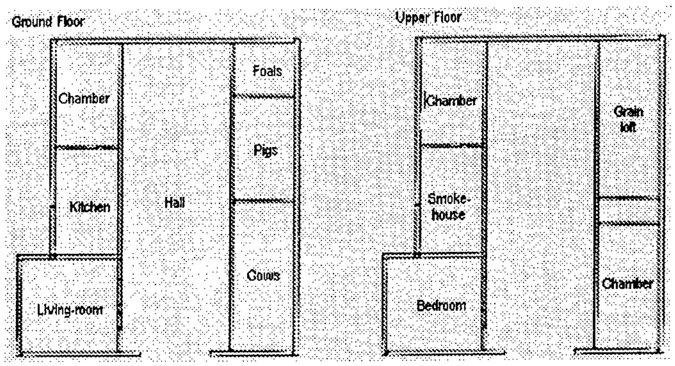

Figure 4: Ground-plan 1651

First changes were made in the 18th century:

The original cellar was placed below the living - room. Owing to frequent flooding by the silver stream, it was given up about 1800. In place of the old one a new cellar was built below the back chamber. It could be accessed from the kitchen next to it. As the fireplace was exactly where the staircase to the cellar was to be built, the fireplace was moved to the opposite corner.

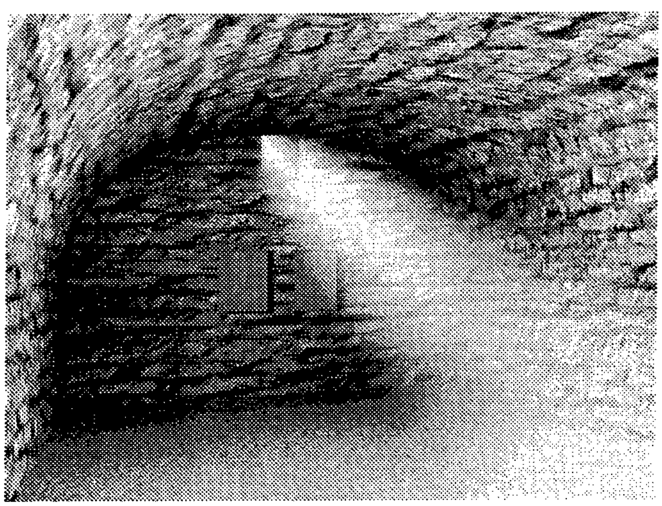

Figure 5: Virtual View into the Cellar of the 18th Century

In the mid-18th-century the value of the house was increased by replacing the old roof thatched with straw by a roof of sandstone slabs. Additional rafters were built in order to take the additional weight of the stone slabs.

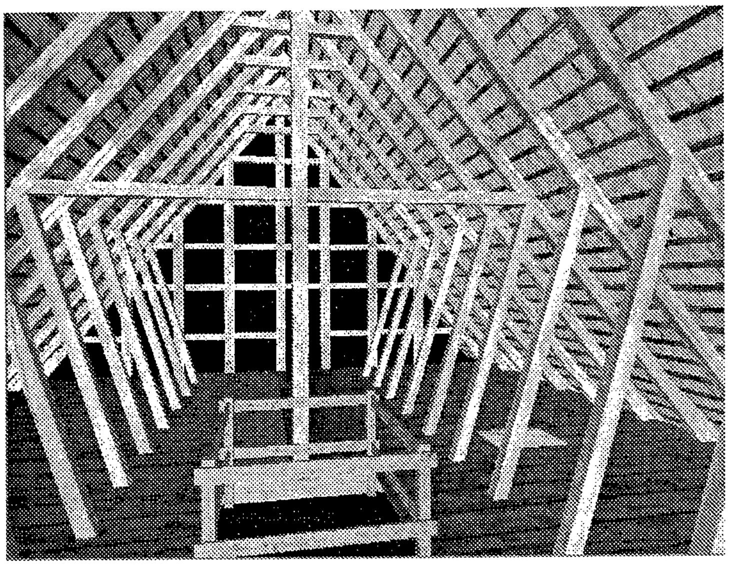

Figure 6: Roof with additional rafters

Substantial changes took place in the third phase of rebuilding in the 19th century.

The filling of the gable that originally was made of straw and loam was replaced by wooden boards. The inhabitants obviously wanted to reduce maintenance of the house. The living room was expanded by building a bedroom on the ground floor behind the kitchen. A half timbered wall was built to separate the kitchen from the hall. As smoke from the fireplace could no longer pass through the hall and the roof, a chimney had to be built. At the back gable an extension for a cowshed was added to the house. The place won in the old cowshed was used to install a staircase instead of the old ladder to the grain loft.

All those changes were reconstructed out of the observations made when taking down the house. The other sources were old documents, letters and bills. They are documented in drawings and sketches true to scale but without dimensions.

Working Method

In a first step the existing building that was reconstructed in the state of 1860 was redesigned using 3D Studio MAX. Dimensions were taken from the documentation of the museum and whenever there was a contradiction they were taken in place.

The textures of wood, loam, stone and the other material were gathered from digitised photographs. They were rectified and colour corrected. The reachable speed of movement in the VR model strongly depends on the size of the texture files. So rather a big effort had to be made to process the textures. Finally they were stored in JPEG format and linked to the geometry to get a realistic impression. The figures in this paper were generated synthetically by means of this 3D-model.

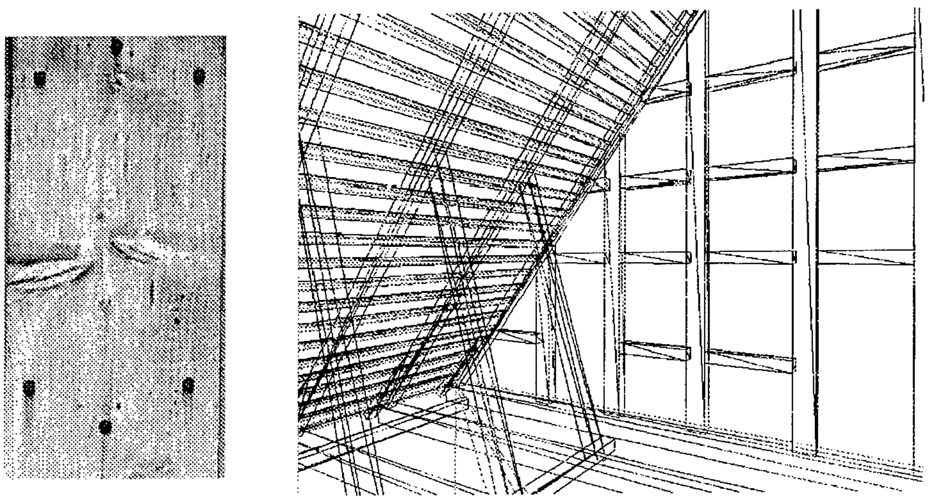

Figure 7: Texture of a Board and Geometry of the Roof

The reconstruction of the other stages required intensive discussion with the building historians because their findings when taking down the house needed interpretation. This interpretation was facilitated as designer and historian could refer to the VR model. Contradictions in the conventional plans could be resolved by consulting the 3D-model too.

Elements that were lost during the centuries like for instance windows were replaced by elements of other houses which are typical for the period to be shown.

Results

We succeeded in building VR models of the most important stages of house Moven. One can walk through the house, look at details, climb up to the upper floor, leave the house and walk around, using mouse and screen. The model was transferred to a SGI equipped with space mouse and shutter glasses and provided a rather realistic impression.

Links in the VR model lead to explaining text about the history of the house and it's inhabitants. They also lead to animations of important details. As other links also lead back to the VR model, all the information is connected to a Hypermedia document.

Conclusions

The example of house Moven proves that it is possible to reproduce an old half timbered house and his different stages through the time as a VR model. Even if the workflow for producing the model should be improved for further projects, the described method of working is a suitable way to generate a VR model out of conventional documents.

With about 70 000 polygons in the model the PC based workstation has reached it's limit so it is not yet possible to reach a grade of precision that allows to consider the deformations of a building. Whereas a PC-based workstation is sufficient for designing the VR model and doing historical research, one should consider to use faster computers for presentation.

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Designing for Telecommunication on the Internet

Expanding Human Factors to Community Research

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Abstract

We describe a series of related research projects investigating the adoption of Internet technologies in a small town. In one project we used an ethnographic framework to understand communication patterns in the town and how knowledge about and use of the Internet was disseminated. The ethnographic project set the stage for two other projects we did in the same town. Here, we reflect on the advantages of conducting long-term qualitative research in the area of communications technologies, how the ethnographic project informed and influenced the shape and findings from the two other projects.

Introduction

The Winona Projects were undertaken by U S WEST Advanced Technologies in an effort to understand how the technology of the Internet disseminates into a community, to understand what factors and what technologies facilitate and impede Internet adoption by individuals, families, schools, businesses, governments, and other institutions. We also hoped to cultivate a well-understood testbed for numerous products and services that we imagined would be delivered by way of the Internet in the coming years. The projects spanned a period of 18 months during 1995 and 1996. They encompassed several different research and development efforts, three of which are discussed in this paper: 1) Networked Community Ethnographic Project; 2) Virtual School Project; and 3) Communications Rich Web Site Project.

The three projects can be seen on a continuum of complexity and level of detail. The Networked Community Ethnographic Project was an ethnographic study of technology diffusion in the town of Winona, providing insights into the complex organizational and individual factors contributing to the genesis of an on-line community. The Virtual School Project focused on the use of the Internet by a school and its families. The Communications Rich Web Site project introduced Internet collaboration technology into a maturing Web environment for use by community leaders in town meetings.

We discuss both the findings from the research we did in Winona and the importance of the ethnographic component of the work. The ethnographic project, which was first, informed and influenced focus, data analysis, and evaluation of the other projects we carried out in Winona. The data collected in the Virtual School and Communications Rich Web Site studies revealed their full meaning only in the context of our involvement with the community as a whole.

Identification of early adopter individuals using traditional marketing criteria, such as demographic and consumer characteristics in an organization did not adequately predict adoption of the technology. While individual early adopters played key roles in Winona, it was critical to understand how Winona's various social institutions supported and influenced each other. An assumed value of the Internet was the access it gives to non-local information resources. We were surprised to find that Winonans were drawn to the Internet initially for its ability to facilitate communication of local information within the community, and secondarily for access to remote resources, commerce, and long-distance communication. We hold that the study of communication technologies, like the Internet, necessitates an approach that takes social complexity into account. Using an ethnographic, whole-community, approach provided us with a framework for understanding what and who was communicated with, and how adoption proceeded, and would be likely to proceed under similar circumstances.

The Winona projects and their interrelations are discussed in greater detail below. We begin with a discussion of the history of the projects before launching into each project individually.

THE WINONA PROJECTS

Background: Why Winona?

"Breaking Ground" is an apt metaphor for what happened in Winona, Minnesota, when, in 1994, U S WEST supported a grass-roots initiative to install a fiber-optic network throughout the town of Winona, Minnesota, linking eight of the town's most prominent social institutions. The initiative began when a prominent business leader offered a seed grant to put Winona on the Internet, the "information superhighway." Years before, Winona had been passed over for a place on an Interstate highway, and they wanted to make sure that they did not miss another opportunity to enhance their economic base.

Early in 1995, after the fiber installation had been completed by U S WEST, but before WWW/Internet service was commercially and locally available in the town, we learned about Winona. We saw this as an opportunity to watch adoption of a new technology from the ground up.

Winona is a small town with approximately 25,000 residents. It is located about two-and-a-half hours south of Minneapolis on the Mississippi River. We made our first foray into our new fieldsite two months prior to widespread availability of the Internet in Winona.

In May of 1995, Luminet, a local Internet Service Provider (ISP), began offering service to residents, businesses and other organizations. Within one year, about ten percent of private households had gained Internet access[1], and community organizations and businesses had embraced the WWW as a new publication and communication medium [1].

In the fall of 1995 an educational initiative called The Virtual School™ (TVS) began, bringing 240 families from a private high school on-line [2]. TVS now links more than 500 families whose children attend parochial schools in Winona. Two goals of the TVS initiative were to make communication between parents and school staff easier, and to free the educational enterprise from the constraints of the school building and extend it into homes and the broader community.

[1] This number only represents subscribers to Luminet; it does not include those who had Internet access through an on-line service, one of the universities, K-12 educational institutions, work, or public computing facilities.

NETWORKED COMMUNITY ETHNOGRAPHIC PROJECT

Breaking New Ground

Although ethnographic techniques have been used in the field of human computer interaction (HCI) since the 1980s [3, 4, 5], only a few HCI researchers have attempted, or seen a need for conducting long-term ethnographic research of a more anthropological nature in complex communities comprised of multiple, interrelated, and interacting social organizations. The Networked Community Ethnographic Project was such an effort.

The Networked Community Ethnographic Project set the stage for the other Winona Projects. Initially, we wanted to understand how information about the Internet is disseminated in the context of a town, what beliefs, if any, people in Winona held about the Internet, and how the use of the technology itself would proceed. We were interested in understanding this at both the organizational and individual levels.

One of the concerns we had in doing our research in Winona was its representativeness. After all, it is a small rural town that is relatively homogenous demographically compared with many of the more urban areas served by our company. Although there were no equivalent studies with which we could compare our findings, we kept a close watch on the various data collection activities surrounding the Blacksburg Electronic Village (BEV)[6], the HomeNet Project [7], and the Boulder Valley Internet Project [8, 9]. This helped us discern idiosyncratic findings from those findings that were more generalizeable. With few exceptions, our findings in Winona were consistent with what researchers in these other contexts were finding.

At the outset, we felt that if we were later going to be able to understand any changes in communication patterns related to the Internet, we needed to first understand modes of communication used in the town without it. To this end, we documented public forms of communication of local information, including bulletin boards, flyers, newspapers, radio, television, and so forth. We documented the form of the communication, the content, the location, and the intended audience for the information (e.g., students, women, tourists, etc.). This data collecting activity was fruitful, because it gave us a good overview of the town and the issues and events that were of public importance. The two local newspapers were invaluable. From them we learned critical political information, as well as received an introduction to a cast of characters with whom we would later form important relationships. We knew in advance where to tread lightly, and where we would likely be welcomed with open arms. Information we collected during this phase also gave us plenty of conversational content, so that when we were talking with Winonans we could understand tangential references and subtle nuances of what people were saying.

During the early phase of the ethnographic study we wanted to learn how aware of the Internet people in Winona were: if they had heard of it, if they had used it, if they had any beliefs about it or technology in general. To collect data on this we informally "interviewed" people we met on the street, people we met in restaurants and bars, shop owners, and whatever Winonan crossed our path. These interviews were more like directed conversations than interviews. Typically they would begin as any conversation between strangers, with an exchange of pleasantries about the weather, a comment on how nice the town was, leading into the fact that we were visiting, working for U S WEST on a project having to do with the Internet. From here, the conversation would diverge in many directions depending on the interests of the person we were talking to.

When we first arrived in Winona in the Spring of 1995, awareness of the Internet was limited. The majority of the people we spoke with had heard of it through local media, but had never used it in any way. For most people the Internet, the World Wide Web, and Luminet, the local ISP, were synonymous. A small percentage of Winona households subscribed to on-line services (AOL, CompuServe). Most of those people who had used the Internet to send email or had used an on-line service had never seen the World Wide Web. There were already a couple of Web sites hosted in the town. The most extensive site was at St. Mary's University of Minnesota (then St. Mary's College). Winona State University did not have a web site, but they were using the email capacities of the Internet, and were heavily involved in the Luminet initiative. They also hosted a gopher server for the campus. In both universities, Internet access was limited primarily to faculty, but both schools had plans for expansion to their entire student bodies, as well as expansion of their networks into the residential halls. Only two larger businesses in Winona had Web sites, but these were hosted in large metropolitan areas outside of Winona. There was also a private not-for-profit technology company, Vanguard Technology Group, that had just begun selling its services for Web hosting and page development, but initially their only client was Cotter High School (discussed in detail below).

As the Luminet launch date loomed nearer, public awareness of the Internet grew. The newspapers ran articles almost daily on Luminet developments and activities surrounding it. The radio stations publicized these events as well. At this point, we concentrated our efforts on understanding what visions, if any, people in the town had for the technology, and whether they were acting on their visions in any way. As the technology matured, we tracked developments so that we might gain a better understanding of barriers and catalysts of adoption. We formally interviewed individuals in all of the major social institutions with direct drops into the network (hospital, city hall, Winona Technical College, Winona State University, Winona Middle School, Winona High School, Cotter High School) as well as individuals from social institutions without connections (e.g., the chamber of commerce, public library, and the senior center), proprietors of small businesses, and employees of medium, and larger businesses.

Adoption of the Internet

We learned that having direct connectivity to the fiber-optic network did not necessarily predispose organizational adoption of the technology, nor did technical knowledge. For example, in the months preceding the launch of Luminet, there was much talk about the benefits of the network to the social institutions with direct drops to the network. Everyone assumed that these institutions would be the first to adopt the technology and to use it in innovative ways. This did not turn out to be the case. For example, numerous articles were published in the local papers on how telemedicine would enhance the hospital's ability to serve the health needs of rural patients; the hospital would have a direct link to the Mayo Clinic in neighboring Rochester, using the two-way video capabilities provided by Luminet. Other visions included on-line patient registration, and consultations. Today, these visions have still not been realized. When we interviewed various stakeholders at the hospital, we discovered these visions emanated from a single technology champion. The hospital administrator and systems support staff, however, were skeptical about the Web and the role it would play for them. Lack of security was a concern as well as the expense of equipment that would be required to make these visions a reality.

On the other hand, at the Winona Senior Friendship Center (a city department without direct connectivity), the director and a senior volunteer had more modest visions of what the Internet could do for the aging population of Winona. They envisioned a scenario where senior citizens would serve as mentors to young people over the Internet. The director of the center did not need previous technology exposure to understand the great value that the Internet could bring to the seniors in her center . She collaborated with a volunteer at the center who had more technical experience. Together, they went to local businesses to raise money for their computer lab. Local businesses immediately perceived the value of the project and were willing to donate to the cause. Also, because the senior center fell under the auspices of the city government, City Hall's support was a critical factor in making the Sr. Friendship Center computer lab a reality. They installed a small computer lab with dial-up Luminet service, and had made arrangements for members of the senior center to get free email through a state university. Seniors literally lined up outside the door before the center opened to claim their spot at a terminal, and membership at the center doubled in a short period. Visionaries and champions of the technologies emerged from unlikely places.

What happened at the Sr. Friendship Center illustrates that adoption of the Internet not only occurs in technologically prepared organizations, but also in places where individual visions are met with the support of the community. We quickly understood that adoption of the technology was not going to occur in institutions that lacked individual champions of the technology, or institutions where political and bureaucratic barriers were difficult to overcome.

Another institution that was critical to raising Internet awareness was the Winona Daily News, which launched an experimental "on-line newspaper" linking to a plethora of community and regional information. City Hall, and some of its associated organizations also played an important role in fostering Internet adoption. Although City Hall had expansive visions of how to use the Internet to facilitate community involvement in city government, it has not been able to bring its visions to light yet. The city manager, and a number of other city officials constantly championed technology efforts in the town. The visions and accomplishments of both the newspaper and City Hall are described in greater detail in our discussion of the Communications Rich Web Site below.

It was the synergy of efforts in three main sectors–the public, businesses, and the educational sector--that turned Winona into an active on-line community during the groundbreaking phase. Businesses expected revenue and therefore invested not only in their own systems but provided financial help to public institutions. Schools disseminated access to the Internet into the families and thus created an audience and active participants.

THE VIRTUAL SCHOOL PROJECT
Schools as Sources of Technology Diffusion

The Virtual School Project was a natural extension of the ethnographic study of the town, and indeed overlapped. The goal of the Virtual School Project was to understand Internet adoption at a more detailed level; to focus on a single organization–the school–and, also to understand some of the dynamics of Internet adoption at the family level. From the ethnographic research that preceded the Virtual School Project we knew that schools in Winona were key points of dissemination of information about the Internet, and also provided Winonans with their first hands-on experiences with the WWW. This was also apparent nationally; there had been an almost exponential growth of school entries in the on-line school registry Web66, and Clinton's administration had issued a challenge to businesses to provide on-line access in every classroom by the year 2000.

In Winona, educators in the public school system showed an early interest in the Internet, mainly because it promised access to unlimited teaching materials. The main concerns were that most of the public schools had outdated systems, and many teachers felt they lacked the preparation and skills required to use the Internet. This is not unlike the situation at many public schools, at that time [11]. Another Winona project, not described here, provided educators at the public middle school with the needed resources.

During the summer of 1995, while we continued ethnographic data collection, we established a good working relationship with individuals at the Vanguard Technology Group, a non-profit business that was founded to support technology efforts at the Catholic Cotter High School. Cotter was ahead of most other schools, both inside and outside of Winona, with respect to the use of technology. Even at the beginning of the study, the school boasted broadcast cable connectivity into every classroom, a computer lab with 30+ well-equipped Apple Macintoshes, a classroom equipped for collaborative work on Apple workstations, ethernet connectivity across campus into the dorms, and its own multimedia production lab, run by Vanguard. Clearly, "access" itself was a non-issue at this institution.

Integrating Learning with Community Citizenship

Vanguard's vision for using the new town network was more far-reaching than what had been installed into the school. It was to extend Cotter's educational reach from the campus into the students' homes, and thus, into the community by providing all student families with in-home Internet connectivity. The educational goal was to contextualize education, to provide access to educational means to the whole community, and to teach the students in the rich context of that community instead of the bounds of the physical campus. During our first six months of work in Winona, this project was born out as the 'Virtual School™ Project" (TVS).

In more concrete terms, this translated into the goal of equipping all four-hundred families of Cotter students with Macintosh Performa's™ and modems, and all family members with individual email accounts. The families would also have access to the World Wide Web through Netscape™ browsers. The Vanguard staff had started developing the TVS Website that would serve as the "virtual campus." These pages included a school calendar published weekly with daily curricular and extra-curricular activities, and the school menu, also updated weekly. Faculty and student directories were planned, with pictures, some personal information and email addresses. Teachers would be able to publish assignments and class materials on-line, and students could post their assignments even from their home computers. A forum would provide opportunity to discuss topics of interest to the school or community in an open fashion. Finally, there was an area for "Hot News" where school cancellations, or announcements of PTA meetings and the like could be posted. There was also an area showing exceptional student work, and a student art exhibition. In essence, TVS Web site was planned to be the communication switchboard for Cotter High School, see Figure 1.

During the first year, participation in this trial was seen as voluntary; however, eventually in-home connectivity would become a requisite for becoming a Cotter student. Parent meetings to kick off the trial were full of controversy: Would families with older computers, and especially those with PC's, be able to participate, and who would provide technical support for those? Was the lease for the Performa's provided by the school really a good deal? How would parents protect their children from accessing unwanted material, and would this program eventually discriminate against children from less affluent households? Finally, was the school's heritage–to provide good, basic Catholic education to all families who wanted it–be threatened by this new turn towards technology? However, after all was said and done, about 250 families (over 60 percent of all Cotter families) had signed up to be members of the trial in the first year alone!

The research project

It was through our work with Vanguard, during the Networked Community Ethnographic Project phase that we succeeded at recruiting fifty families (155 individuals) to participate in an in-depth study of Internet adoption and use. The Virtual School Project, unlike the ethnographic project, relied more heavily upon quantitative data collection techniques, but we used qualitative approaches as well. This project focused on the experience, attitudes, and use of the Internet of fifty families as they came on-line.

Our plan was to roll out a questionnaire, tracking family members' attitudes toward technology, their interests, self-reported Internet activities, use of other media, and attitudes toward their community several times during the trial, starting a few weeks after the official kick-off in the fall of 1995. These data were to be used as predictors of the on-line tracking data we planned to collect. We collected data on email activities, as well as URL accesses of each individual family member. Finally, we planned to do in-home interviews with the families participating in our study, to follow up on any interesting data patterns that we observed, and to learn more about in-home dynamics of Internet adoption.

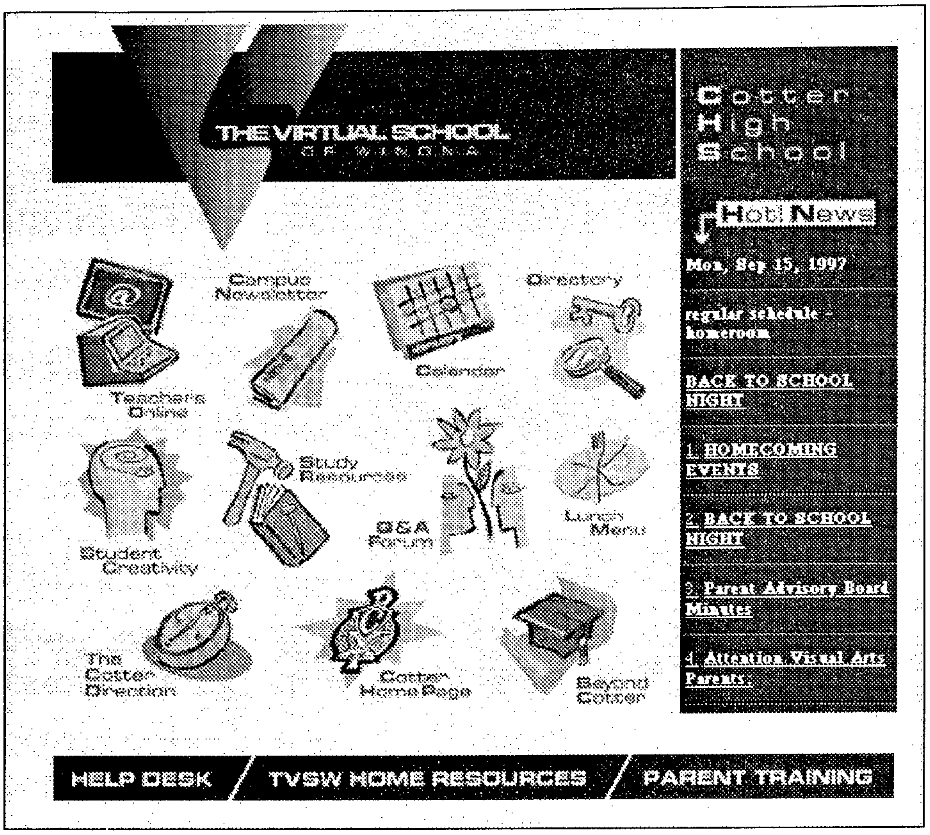

Figure 1: Cotter's Virtual School home page. Printed with permission of The Virtual School™ of Winona

Connecting 250 families

To facilitate family participation in our study, and to collect observational data on parents' first experiences, we helped out in eight parent training sessions held by Vanguard. In these sessions parents were introduced to the Internet, the use of email and the Webbrowser. They were guided through everything from taking their equipment out of the boxes to connecting the modem. Modem configurations were pre-loaded on all machines that were leased to the families. A few months into the trial, however, we still had not recruited many families to participate in our study. Also, email accounts had not been set up in a manner that allowed us to track individual use; we could only track family use. We finally resorted to calling the 250 families by phone to elicit participation, and found that a large majority of families had not yet established a reliable connection to the Internet.

Technical problems abounded, and while family members had explored their help options (calling the local ISP, Luminet, and the TVS staff), many had not been able to resolve their difficulties. Nobody, including ourselves, had been able to estimate the amount of technical support that connecting 250 families would bring along. Server outages and other operational problems added to the confusion. Help material and hints had been sent by email to users who were still struggling to configure their modems, but because they hadn't been able to configure their modems, they couldn't get to this information. Phones in the offices rang hot, and family members grew frustrated, because they could rarely talk to somebody and work at the problem at the same time; problem solving required using the only phone line in many households. At the end of our project, about 20% of the families had ordered second phone lines. Finally, many of the families required a quick visit to diagnose and fix problems; however nobody was available during evenings and weekends, when the family members were at home and had time to work on their computers.

We responded by hiring a local college student who provided help to study participants during off-business hours, when they most needed the help. He was a local who knew many of the parents and understood how react to their fear of the new family appliance. Most of the problems resided in the area of modem configurations, but often family members just needed some help setting up passwords, or using their email. In June, most families had recovered from the initial difficulties, and our two questionnaires (one sent out at the very end of 1995, and the second in May 1996) documented this success.

Problem solvers

Our first questionnaire (answered by 65% of the study participants, the second questionnaire was answered by 46%) showed that parents and teens both found the set-up tasks of connecting the modem and configuring their machines relatively difficult, even though the teens, especially the boys, found no problems with the actual Internet tasks: sending and receiving e-mail and web-browsing. Parents admitted to having some problems with both. Here, we also found strong indication, that overall, the teens were more self-sufficient in solving problems by trial-and-error, or by simply relying on their social network for support [12].

From follow-up interviews we learned that parents usually lacked a knowledgeable social network on which they could call for help. We had anticipated that the teens would become the resident experts, but often they could not solve the initial configuration problems either, and our family interviews revealed that they were impatient with their parents' questions and concerns, leaving the parents looking for help in other places.

Figure 2 shows that it was the mothers who made most of the help calls during the first months, even though mothers expressed the greatest degree of difficulty with the new technology. We believe that mothers took on this responsibility to a larger degree because only 53% of the mothers worked full-time, compared to 96% of the fathers, thus giving them greater access to the home and computer during business hours. Figure 2 also shows that local support lines were called most often, and over a longer time period than help lines of far-off computer, software, or modem manufacturers.

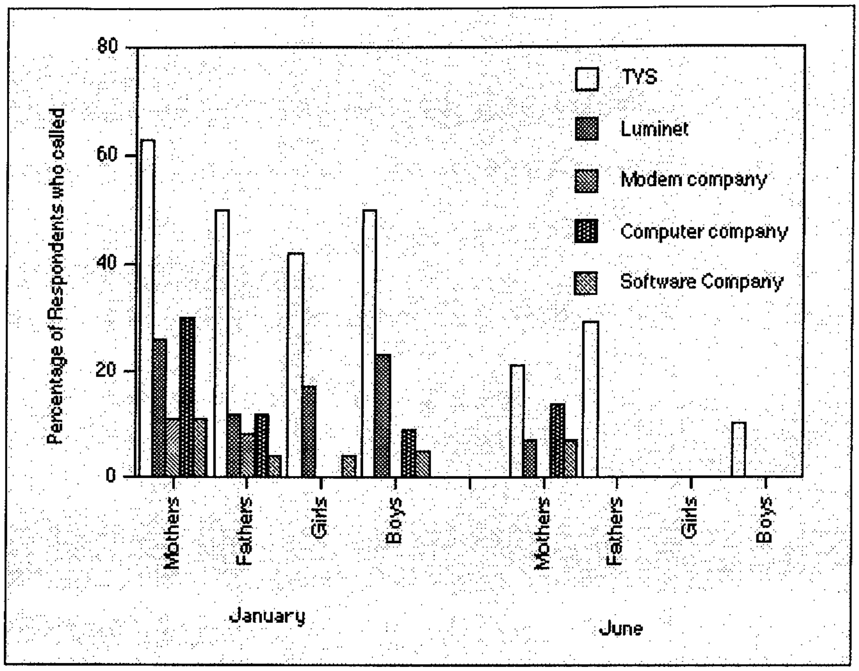

Figure 2: Family members' reports of calling 5 help lines during January and June

Cruising along

By June, these initial difficulties had been overcome by most families, so that their and our attention was shifted to the Internet content and function. Unfortunately for us, this marked the end of our Internet study, but in the last few months we had been able to collect some information about what seemed valuable and intriguing to study participants.

Email enjoyed great popularity with almost all family members; however an analysis of the logged email activity showed that parents with higher levels of education and with office jobs were more active than parents with lower levels of education and in non-office professions. In the interviews we found out that for the teens, checking email after school had become a new ritual (similar to checking the answering machine). The parents were checking their email less frequently; however they did express great excitement about re-connecting with old friends and family members in other parts of the United States, and even in other parts of the world. They also found email a welcome medium for communicating with teachers who were otherwise hard to reach, for keeping in touch with their older college-bound children, and even for maintaining a "conversation" with children living with them, when busy schedules had made meaningful communication a rarity.

WWW use, logged by us, varied greatly with the school day, and with the school year, suggesting that the teens were the actual users of this medium. The family interviews supported this: parents often complained that the children were occupying the computer during the evening hours. The Virtual School pages were the most frequently accessed pages that we were able to monitor. Children and parents alike reported using the pages to check homework assignments and school schedules. Parents even complained that the pages were not updated more frequently by the teachers and more diligently by all the teachers.

Chat rooms were especially popular with the teens. A cursory content analysis conducted on the posts to the chat rooms suggested that the teens were actually playing a virtual hide and seek within their peer group. Several Cotter students seemed to hang out in a chat room and give off clues about their identities. Strangers were of little interest compared to the possibility of talking to somebody well-known, in a different setting, under different rules of communication. In interviews, many of teens told us that their siblings were using chat rooms a lot, but since the parents were always present in these interviews, we never had a chance to gain more insight into these activities.

On the whole, the Virtual School Project provided us with important insights into how the use of Internet technology would diffuse from a school trial into the homes of families. The Winona families, in spite of their initial doubts about this trial, were remarkably willing to invest in what they believed to be an important educational tool for their children. But once these "educational tools" had entered the households, the parents quickly discovered what their children had already known from their previous experience with the networked school computers: that they were great tools for social, but also professional communication, and a great source of entertainment along with the educational application. Even though many parents eventually gave up on the use, parents with higher levels of education became regular fans of email, and some of them developed an interest in Web surfing as well.

Most complaints we heard were in the form of wanting to have more–better access, a second phone line, faster modems and more bandwidth (several parents inquired about the availability of ISDN), and even more information at the Virtual School site. Few, if any, families entertained thoughts of getting rid of the new appliance, despite the technical hassles they had experienced.

The greatest challenge for the Virtual School project on the whole was not the technical hurdle of initial connections but the necessity of involving all teachers and administrators at Cotter for the full success of the project. The communication switchboard could only be successful if the end nodes (all teachers and students) were active. Not all Cotter teachers were enthusiastic about The Virtual School. Some of them felt that updating materials and the requirement of posting lesson plans was burdensome, and time-consuming, and Internet communications with the parents had not become routine enough to help reduce time spent in parent meetings. While the Virtual School Project was successful in its first year, some parents noticed that their expectations may have been unrealistic. They had anticipated even more information and more widespread use of the medium. These insights gained from the TVS project provide another piece of evidence for our argument that support of the community, in this case the Cotter community, is just as important for networked technology projects as access to technology, vision, and early adopting individuals.

COMMUNICATIONS RICH WEB SITE

The third study, the Communications Rich Web Site project, was of a different nature from its predecessors; it was more applied. The ethnographic work we had already done in Winona set the stage.

The goal of this project was to explore how leaders in the community responded to trials of new Internet collaboration technology integrated into their now maturing Internet/Web environment. We envisioned that community groups would use communication-rich Web sites to participate in real-time forums using low bandwidth video conferencing, audio conference calls, shared white boards, group synchronized tours of web pages, voting, and text chat. They would also have tools for asynchronous communication: bulletin board discussion groups, document transfer, and electronic mail. We wanted to determine whether these groups would get some of the same benefits that businesses received in a previous study of desktop conferencing over broadband ATM networks that U S WEST carried out in the State of Oregon [13]. But we also hoped to understand how the social dynamics of the community influenced the design, and support requirements for the services.

Visions of Collaboration - Collecting Requirements

During the Networked Community Ethnographic Project, we had identified a variety of public and private communication forums in the community that played important roles in education, political decision making, and creating and maintaining various business coalitions. And we had tracked the role that the two local newspapers played in communicating the local educational, political, and business issues as well as attitudes toward and visions for use of the Internet. We had seen how the World Wide Web was augmenting this existing communication matrix and wanted to determine how real-time conferencing tools might extend this communication.

We supplied the collaborative tools to three community organizations that we had interviewed more extensively: the Chamber of Commerce, the City Council, and the Winona Daily News on-line newspaper and affiliated Home 101 radio station. Leaders in each of these organizations agreed to champion on-line meetings in which they would attempt to complete their ongoing work.

Chamber of Commerce

We had gained a preliminary understanding of some of the groups' needs and visions from our earlier interviews. The Chamber of Commerce, as in any town, supported the needs of local businesses. An important goal for Winona was to attract both local tourists and far Eastern tourists who found a sleepy river town particularly attractive. They had already established a web site describing Winona's value as a tourist destination. But they also had visions of improving communication at other levels. They envisioned holding their state-wide meetings with other Chambers using desktop conferencing to avoid extensive travel. And when they saw a demonstration of the conferencing technology integrated into a web site, they extended their vision to new local communications opportunities. They now saw the web as an opportunity for educating local employees that served the tourist populations about the tourist attractions in the town so they could refer business. They also saw it as a way to recruit local students to take jobs in the local tourist industry.

Winona Daily News

The local Winona Daily newspaper had now established an on-line Web-based newspaper that was attracting significant readership as well as business from advertising. The readership was both local and geographically distributed. "Ex Winonans" checked the site to stay in touch with what was going on. The on-line newspaper staff recognized that there were new, unexplored opportunities for attracting both types of business by including real-time interactive communication. They had already extended the traditional Letter to the Editor pages to on-line Bulletin Board Forums. Now they envisioned live-interactive competitions in activities like card games that newspaper readers could observe or participate in.

Winona City Council

The City Council had a far-reaching vision of the role of the Internet: community access to leaders and the issues. But they considered very carefully the implications of a trial of an on-line forum. Both public and private on-line meetings would have to be carefully managed and would have to conform to ethics standards including assuring all public meetings were announced in advance in various accepted venues and that any private meetings didn't result in any thing that might appear to be hidden collusions. But there was one area where a trial use of the conferencing tools seemed straightforward -- the local quality council met privately to discuss issues of quality of life in the town, and their current topic was education standards. They were in the process of soliciting expert advice on education standards from a town expert and integrating it with their own goals for the community. Their vision was that on-line conferencing would allow the diverse voluntary members of their council to meet without traveling to a meeting place. Once they had a specific proposal for the community they could present it via an on-line forum to the community as a whole.

We discussed in detail each of these groups' current usage of Internet Technology and then educated the leaders about emerging conferencing tools that were on the brink of being ready to bring to market. Because these community leaders had already taken major strides in the use of the Internet within their community they were more than ready to extend their visions of use to the additional conferencing tools.

Using the Tools

These three groups seemed to easily understand the idea of going to a Web page within the context of an overall Web site, which we called the Forum Center, and to enter an area where they would meet with other users in rooms similar to chat rooms. In fact, the Web conference room made it easier for them to connect because it placed the responsibility on each individual to show up at the right time, rather than forcing users to call each other individually as in some desktop conferencing systems.

It was important to make meetings visible on the Web with effective placement of links and a directory of meetings, as shown in Figure 3. Our interviews made it clear that meeting privacy was a critical need, despite the assumption of public access that many people make about web sites. Users did not seem bothered by the listing of public and private meetings in the same place but understood that there were meetings they might not be able to attend unless they registered.

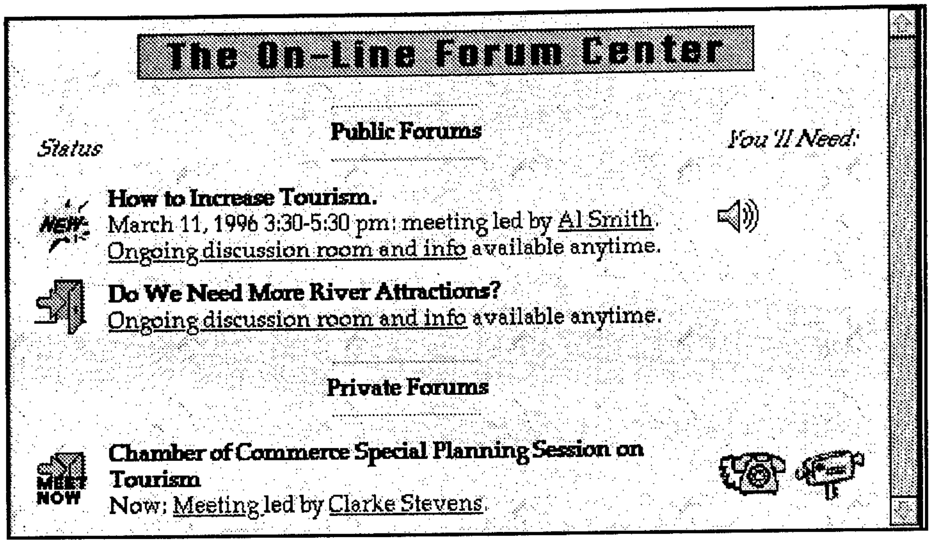

Figure 3: The Communications Rich Web Site Forum Center

Entering a meeting took users to a web page designed by the meeting leader. This page included a control panel for access to the desktop conferencing tools. An example is shown in Figure 4.

The desktop conferencing tools played varying roles across the different groups depending on what they were trying to accomplish at the time. All of the groups used audio conferencing to run the meetings and video conferencing to see each others' faces. The Chamber of Commerce met with local businesses to brainstorm ways of improving their site to attract more tourists so they made extensive use of the Web tour capability to jointly review other sites. The on-line newspaper and radio station met to evaluate methods for improving their on-line newspaper to attract more readership. They also used the Web tour but also spent substantial time sharing preexisting documentation. The Quality Council meet to compare expert education standards with their own emerging standards based on community goals. They used the white board extensively to diagram differences in standards.

Visual Sharing

These three examples demonstrate the value of visual sharing at a distance. For example, because the Winona Chamber of Commerce was in the process of revising their own Web site, they shared photographs of visitor attractions, movies etc. The City Council group used video clips to introduce absent members to the team and identified video tape segments from other meetings to show the team.

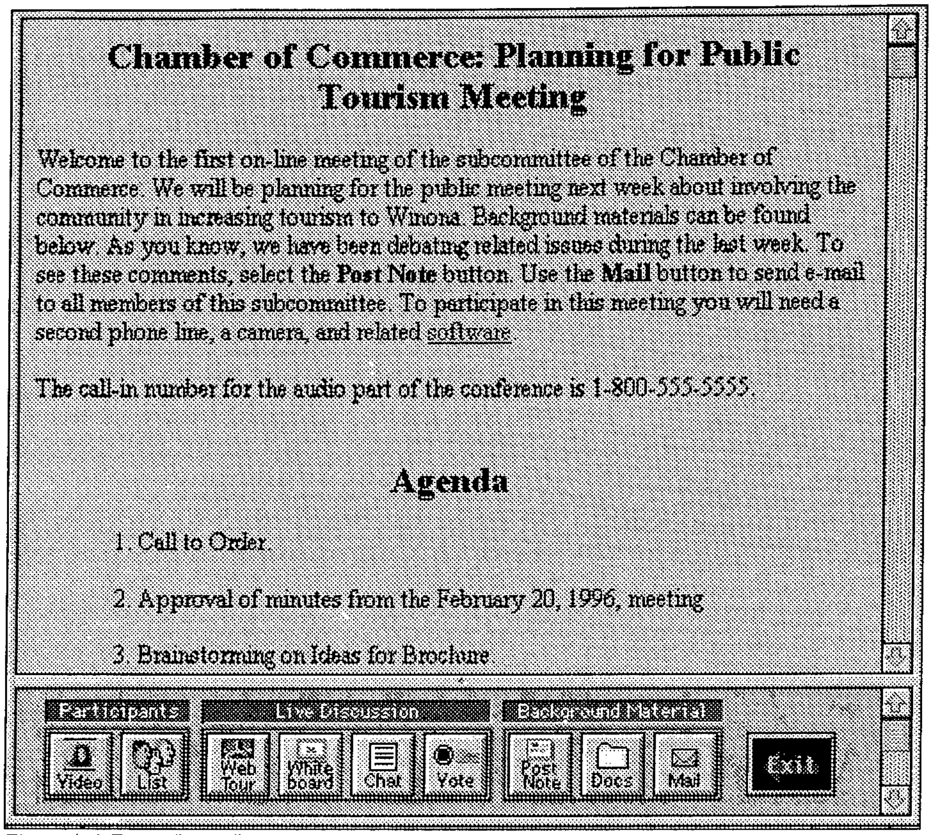

Figure 4: A Forum "Room"

Transitions between asynchronous and real time collaboration

The groups also needed smooth transitions between asynchronous and real time collaboration. All groups used email to communicate with each other. They learned to share much of their planning documentation and messages during the live meetings. New uses of traditionally asynchronous tools emerged including meeting planning in bulletin boards, agenda, photograph, and documentation storage for "handouts" in the file sharing tool, and use of chat for side conversations during audio meetings.

New meeting protocols

We observed new meeting protocols emerge as participants experimented with a variety of new practices. They identified key roles and responsibilities for meeting management and leadership as well as for training the group on tool use. The collaboration tools themselves had few inherent turn-taking mechanisms, and participants explored a variety of options for coordinating use of the tools: for taking turns, speaking, controlling the white board, and especially coordinating multi-party tours.

All three groups ended up wanting support for both local and extended group collaboration. While they regularly met in these local groups they also all participated in state-wide and national groups on similar topics using overlapping materials. Many of the materials used at the state and national level were already available on the Web, and each group used these materials as they planned their own agendas. Thus, extending collaboration to geographically broader groups seemed natural.

These trial meetings with community leaders showed in substantial detail how the real-time Internet collaboration capabilities might be integrated into the pre-existing communication matrix of the local community and extend that community to state, national, and international forums. Because we worked with the community as a whole as well as its functional parts, we were able to discover specific design requirements for integrating the tools into the community's existing web sites, methods for managing privacy and open forum registration to respect information boundaries, and methods for organizing sites so they did not challenge various social constraints. We also discovered needs for training and consulting to help groups like this not only learn to use the software, but to understand how to avoid socially significant blunders. We anticipated that with this depth of understanding, the community leaders would now share more detailed visions of the future with the schools and the families who were quickly adopting the technology.

Conclusions

Traditional ways of identifying early adopters focus on individual characteristics that predispose one to adopting a technology. For example, typical market segmentation studies reveal demographic and consumer characteristics that describe likely adopters [10]. In contrast, we found that it is not enough to identify individual early adopters. While individuals play key roles in getting the community to adopt, their efforts would be futile without the support and vision of other entities in the community. The adoption of the Internet at the Senior Friendship Center in Winona illustrates this.

While a key value of the Internet for people in Winona was in the access it gave them to remote information resources and the ability to communicate with distant experts and family members, we found a surprising amount of interest in local communication and information access across all three projects. The fact that there was local information on-line through the Winona Daily News, City Hall, and the schools was a key driver in adoption of the Internet for the average Winona resident. That individuals and organization could publish information to the web and easily access town officials was empowering. Familiar names and faces on the web created a friendly place from which novices could begin their journey into the wider world of the web and the Internet.

Had we not approached Winona as a community, using an ethnographic framework, we never would have understood the ways in which its social organizations supported and influenced each other in adopting the Internet. It would have been difficult to identify key players and organizations that would be open to our scrutiny throughout the duration of the Virtual School and Communications Rich Web Site projects. Our long-term presence in the town gave us an understanding of the complex interrelationships between individuals and social organizations, and it helped us understand nuances in the content of their communications.

Working with communities before technology introduction can provide telecommunications companies key insights about needs for new telecommunication technologies at the individual, group, and community level. Working with a community as Internet technologies were introduced gave us opportunities to observe reactions to this new communications medium. The implications for business are not only understanding preliminary requirements for services at the three levels, but also understanding strategies for introducing and marketing the technology to communities during and after their first adoption. Because these strategies derive from community-based research, they can take into account the social structure, vested interest, and temporary deterrents of the community, and can support the integration of technology into the community through vehicles such as help desks, training packages, user group support, and consulting services.

Acknowledgments

We would like to thank the people of Winona who patiently put up with our endless questions and always welcomed us into their lives and community. We would also like to thank Rosemary Nelson from the U S WEST Business and Government Services for her support, interest, and cooperation throughout our research.

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Digital Multimedia Broadcasting Transmission of Video and High Data Rate Signals into Moving Vehicles

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Abstract

Broadcasting Services (Radio (Audio only) and TV) are the last telecommunication services to be changed from analog to digital transmission schemes. Within an EUREKA-project (EU 147) a Digital Audio Broadcasting standard (DAB) has been defined and agreed upon. Field trials have started as soon as 1995, already. Decisions for introduction have been taken in UK, Canada and the United States, already. In Germany regular services start end of 1997. So, by the end of this year about 100 Mio people worldwide will have access to DAB, already.

Its merits are Performance and quality comparable to CD-reproduction, even for mobile reception at up to 300 km/h, no deterioration from multipath reception and interference effects, and reserves for many data services available.

DAB uses a regular 7 or 8 MHz -TV-channel which is divided in 4 blocks of 1,5 MHz each, allowing a gross data rate of 2,3 Mbit/s. 6 audio programs can be put into every block. Instead of 6 audio programs just one digital TV-program of about 1,3 Mbit/s for the video can be transmitted. This allows for the very first time to receive a clear and absolutely stable, undisturbed TV-picture or other digital data stream of up to about 1,5 Mbit/s net even in moving vehicles - the solution to a problem which is more than 60 years old. So a new and growing group of customers can be reached which have not been accessible, yet - the mobile customers.

Starting some time later, Digital Video Broadcasting for terrestrial distribution (DVB-T) has been designed using about the same schemes as DAB but with a higher data rate and greater bandwidth requirement. It is not capable for mobile reception at higher speeds, yet. DAB has been installed, already. In case further transmitters chains for DVT-T are intended to be installed, we recommend a convergence of DAB and DVB-T to a compatible standard is recommended.

In any circumstance, only "Digital Multimedia Broadcasting" explains all the possibilities, a new digital standard can cover: Text, voice, music, still frame pictures, television and all other one-way-data services. The standards will be explained and compared. For DAB/DMB hardware products and software-services will be demonstrated for DAB/DMB in operation.

Introduction

Surveys have revealed that highly mobile people nowadays are most interested in having the services they use at home or at the office available to them while on the road, too. The widespread use of paging and mobile phones proves this - or the well established reception of AM and FM radio broadcasting in motorcars.

In towns or hilly areas, the terrestrial transmission of voice or music into moving vehicles suffers sometimes from interference effects due to multipath propagation: The signal is fading, and the amplitude of the reproduced sound may oscillate or sometimes even vanish.

This is disturbing despite the fact that most often the human ear helps to smoothen - it integrates and levels off effects of less than about 20 ms duration.

But even if the voice is rather well received, the transmission of signals which are sensitive to short drop-outs and interference effects often give poor results: A fax transmitted via the same audio channel may be blurred from horizontal dark lines if drop-outs just cancelled those bits which control the line synchronization.

The reception of TV-signals is even worse if there is some multipath propagation: Line and frame synchronization get instable, the color disappears from time to time, the picture becomes unclear from ghosts.

Obviously: The international standards for analog TV-distribution (NTSC, PAL, SECAM) are totally inadequate to transmit television into fast moving vehicles or even to portable television sets while they are carried around.

Consequently, up to now the mobile user cannot be served with TV or any high data rate digital service. So, a totally new transmission scheme has to be applied. We found a multi-tiered solution which masters the problems:

- digitization and strong data compression of audio and video signals,
- transmissions using a modulation which is insensitive to multipath propagation (COFDM = Coded Orthogonal Frequency Division Multiplexing),
- use of unoccupied frequencies (taboo-channels) within the broadcast bands which is possible because then the COFDM-modulation does not disturb the established television programs, and
- receivers for the users which allow reception and decoding of these new types of signals.

This is basically an extension of the Digital Audio Broadcasting (DAB) - a new radio system specifically developed to serve the mobile user: A television channel is divided in blocks of 1.5 MHz bandwidth each. Every block can then transport a gross data rate of up to 2.3 Mbit/s. Error protection reduces this to about 1.7 Mbit/s. For audio transmission this data rate is then split into 6 audio channels each of 392 kbit/s. The audio compression according to ISO MPEG 11172 is so well performing as to allow then a sound reproduction comparable to the quality of CD. The modulation scheme makes the wireless transmission as good and secure as through a wired line.

Digital Audio Broadcasting widens to "Digital Multimedia Broadcasting"

We made this DAB-system more versatile using the full data stream as a "reliable wireless data highway" of up to 1.7 Mbit/s. This is 30 times faster than wire-bound ISDN, 60 times faster than fax, and about 40 times faster than the serial input of most PCs accepts.

With 1.7 Mbit/s a complete television signal can be transmitted when compressed firstly using the internationally standardized MPEG 1 and MPEG 2 schemes (Motion Picture Expert Group). We use 0.94 Mbit/s for the picture and again 392 kbit/s for the sound. This results in 1.152 Mbit/s for the total package. Error protection bits fill the data stream up to the 1.7 Mbit/s.

The reception with mobile receivers is convincing: Stable picture, no flicker, no synchronization defects, no switching from color to monochrome.

The subjective picture quality is often better even than with PAL or NTSC: Outlines and color transitions do not show cross-color distortion - as otherwise seen on newsreader's striped jacket. Colored noise as noticed generally in large areas of a single color is also gone. Even if the mere dot resolution is comparable to the output of video recorders, the excellent color contrast and the sharp outlines make a "brilliant" picture.

It is obvious that the system can handle all possible digital data streams - not only for sound but also for all other multimedia applications such as text, still frame or slowly moving pictures, video and television.

So the name "Digital Multimedia Broadcasting" (DMB) is describing very well these overall capabilities.

DAB infrastructure can be used for DMB

The DAB-transmitters can be used for the transmission of moving pictures. Additional equipment are a MPEG 2 source encoder, inserter for the channel error protection and a multiplexer to combine the sound and vision data streams.

Mobile DMB receivers

The receivers developed by Bosch and delivered under the Blaupunkt brand name to numerous projects in interested countries were designed already to decode the total data stream out of the 1.5 MHz-block.

The complete system consists at the time being from

- a modified DAB-receiver with integrated decoders for sound and vision to be mounted into the trunk compartment because the size of these very first sets are comparable to a CD-changer,
- a regular Blaupunkt car radio for tuning, volume adjustment and a bus interface to control the DAB/DMB-receiver,
- one ore more color monitors to be mounted within the vehicle, and
- a single rod antenna (no antenna diversity required any more!).

Still frame or even moving-picture information for drivers?

Critics obviously will ask: Do people need full-motion picture reception in their cars? Wouldn't it distract the driver? Well, no one thinks that any driver should watch television while driving. But being able to watch news, information or entertainment programs while riding on public transportation such as busses, subways or trams, or in trains or even in the back seat of a van would be an interesting alternative for passengers.

This new DMB-system also opens up opportunities for providing drivers with relevant information in visual or spoken form: Traffic conditions, recommended detours, departure schedules for public transport utilities, loading of parking facilities and a wealth of other useful information.

So, autonomous navigation and route guidance systems in cars will become even more effective if their digital data base gets updated automatically or when entering a town - the fastest route will then be selected avoiding construction sites or traffic jams.

In any case, an adequate display of a navigation system may be very well used as the video output of the Digital Multimedia Broadcasting, too.

Introduction of Digital Multimedia Broadcasting

In many countries, DAB is already decided to get introduced as an audio service. So the extension to Digital Multimedia Broadcasting (DMB) as a digital broad band service is rather straightforward. Digital Video Broadcasting (DVB) as being propagated via satellite or via cable does not allow mobile reception.

The acceptance of the mobile DMB-services by the customers will grow with the availability of programs and with the coverage of the country with regular services. The introduction will go even faster if specific applications and clients are served firstly.

So we install networks and regular services for the information and the entertainment of people travelling in railways, subways, taxis, busses or on boats and ferries. Most actual traffic information such as departure times of trains or airplanes will be transmitted as well as news, stock-exchange data, weather forecasts, advertising.

From this the potential users get well acquainted with the new possibilities. The consumer market will grow even faster as soon as truly portable, battery operated sets will become available.

We expect that DMB may then gradually replace other terrestrial television transmission because it makes no sense to operate one set of transmitters just to serve the fixed receivers when another transmission scheme can serve both the mobile and the stationary receivers.

In this situation our idea may be helpful to transmit via the same television transmitter both a regular NTSC-program and - filled into the gap between sound carrier and next higher picture carrier - a digital one of limited bandwidth. This has still to get formal approval but can ease the DMB-introduction significantly.

Demonstration

Figures 1 shows the quality of a PAL-Signal as received in a moving vehicle. Figure 2 shows the same picture if transmitted and received using DMB. During the conference it is planned to have an on-site demonstration of the DMB-system in a driving vehicle.

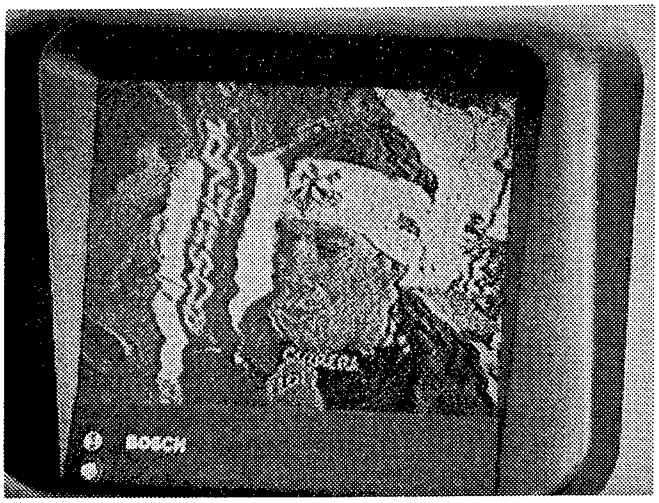

Figure 1: Reception of PAL-Signals in Moving Vehicles

Figure 2: Digital Multimedia Broadcasting - Reception in Moving Vehicles

The Interface - An Invitation To Communication

Input & Output Devices for the Human Body in VR Environments

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Introduction

The speed at which information is conveyed and the quantities involved can be overwhelming for the individual. Can the arts work with science and technology to counteract this feeling of disorientation? To combat disorientation and the omnipresence of technological power we resolve to design artificial worlds in which we can 'navigate' as if in a game. Interactive artistic work is a synthesis of theory, technology, design and play. In this paper different human machine interfaces are described and various fields of application are presented, showing scenarios already realized as well as a variety of possibilities for future use.

Principles

Our work is based on recounting a story in space. Three elements determine the structure - the spectator, the story and the (virtual) space. The area of conflict is the relationship that exists between man and his world of experience. The immersion into a story which is presented virtually and interactively as a framework for human actions has a fundamentally different purpose than film or theatre. The basic form of the theatre is dialogue and contemplation of the various ways of thinking and behaving. Film is the modern form of dramatic art and represents a progression from the static image to the moving one. Interactive media art has the task of bringing the qualities of the theatre and film into confrontation and of intermeshing these qualities. The audience is given an unusual responsibility in this regard. They play an important role in the story. The poetry of the interface determines the dimension of interaction and one's own experience. What am I experiencing, feeling? Stroking my hand over the digital water, coming face to face with myself, flying through surrealistic landscapes, looking from a bird's or a mouse' point of view, crossing real and virtual space. What does it all mean? The visitor is invited to examine these questions. It is an invitation to communication.

Basic concepts

Virtual Environments still suffer from input and output devices that work against the human body and mind. The body with its communication channels (skin, eyes, ears, voice) opens imagination spaces. Body motion is fundamental to learning and living. Interaction and feedback intensify capabilities of perception. Artistic dance, medical and therapeutic methods [FEL78] aim to improve the awareness and the movability of the body.

The authors' main interest is to develop systems that focus on the immersion of the viewer in a virtual environment without restrictions like heavy interface devices and cables. This aim is also reflected in their earlier work: In *Berlin - Cyber City* [STRA91] we play the "let you finger do the walking" game and use an electronic thimble (Polhemus) to move around, show and visualise. With the *Spatial Navigator* [FLE95] we play "looking with the feet" and use a treadmill where the viewer walks through a virtual castle. The *Responsive Workbench* [KRU95] is "thinking with the hand". The Workbench has put the conventional dialogue concept for man-machine communication into a user-oriented shape. Virtual objects and tools are projected stereoscopically on a real workbench as a virtual design environment. The *Skywriter* [STRA96] is able to fly through virtual landscapes without any effort. To do this, he uses neither mouse, joystick or virtual reality glove, but a *Virtual Balance* [FLE97]. This is a platform with 3 weight sensors, which is controlled solely by the changes in the position of the human body's centre of gravity. The computer art installations *Rigid Waves* [FLE96], a mirror based on image processing and *Liquid Views* [FLE93], a water surface based on a touch screen stride new ways in man-machine-communication, where the interface with the machine is imperceptible.

Conclusion and Outlook

The key research and development issues are not just the design of better individual interfaces to information, but rather the design of spaces of activity that enable people to interact with information and each other in new ways. The spaces need not depend on geographical proximity of the participants and thus have the potential for enabling new forms of meaningful collective interaction to take place on a global scale.

For further development we will observe the following directions:

- the unconscious navigation with free movement of the body
- the conscious navigation with directed movements
- the navigation of two or more people in a distributed virtual environment.

Future applications may include:

Marketplace/Teleshopping
- to navigate the World Wide Webspace (VRML)
- to surf through desired shopping malls

- Games/Scene parks
  - to offer interactive entertainment in distributed virtual worlds.
  - to train cooperative behaviour for navigation
  - to invent a panoramic environment for real or virtual worlds
- Museums/Learning Centers
  - to present the simulation of real and artistic worlds
  - to develop interactive 3D learning environments.
- Hospitals/Medical Training Centers
  - to train motoric disabled people
  - to support a dialogue with autistic people
  - to improve patients suffering on disturbance of equilibrium
- Performance
  - to train the body for non-oral communication
  - to find new body expression for choreography

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The development of future communication

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Abstract

o.tel.o, the telecommunication company of RWE and Veba is carrying out a multimedia trial in the western part of Germany. The cities Cologne, Düsseldorf, Gelsenkirchen and Dortmund are included in this technical and economical trial of a multimedia network and its services.

This trial, which is organized by the „Multimedia Competence Center" at o.tel.o, consists of two basic parts, the realization of hard- and software on one hand and the contents and acquisition of research on users´ behaviour on the other hand.

The realization of the technical part is devided into the design of a wide area network (WAN) and a metropolitan network (MAN) with a high bandwidth based on TCP/IP over ATM.

The realization of the non-technical part consists of the acquisition of multimedia content including features such as realaudio, videostreaming applications, video on demand, teleconferencing and telecooperation and the research of users´ behaviour when interacting with this content. The determinition of the main application for customer care, billing and accounting provides for the right choice of a biling and accounting software tool.

This multimedia trial will be the based on an open market-place in order to locate different contents and offers into the internet network, which uses the capacity of the whole network.

Introduction

The future will provide us with many changes and progress in telecommunications and its lines of business like multimedia and online services. The technical development in this area of telecommunications changes so quickly that the market of multimedia is still not ready for a use of these professional services. Therefore, o.tel.o communications GmbH, the telecommunication company of Veba and RWE, is carrying out a multimedia trial in Gelsenkirchen, which is called „Pilotprojekt Multimedia Gelsenkirchen", a city in the Ruhr area in the western part of Germany and a trial in Cologne, Düsseldorf, Gelsenkirchen and Dortmund, which is called „InfoCity NRW".

Both trials which are organized in the „Mulimedia Competence Center" of o.tel.o consist of the two basic parts, the realization of hard- and software on the one hand and the contents and acquisition of research on users´ behaviour on the other hand.

The magic triangle

The magic triangle of future multimedia communication consists of three principal ingredients: the content, the bandwidth and the local loop. Those three edges are connected by dependencies.

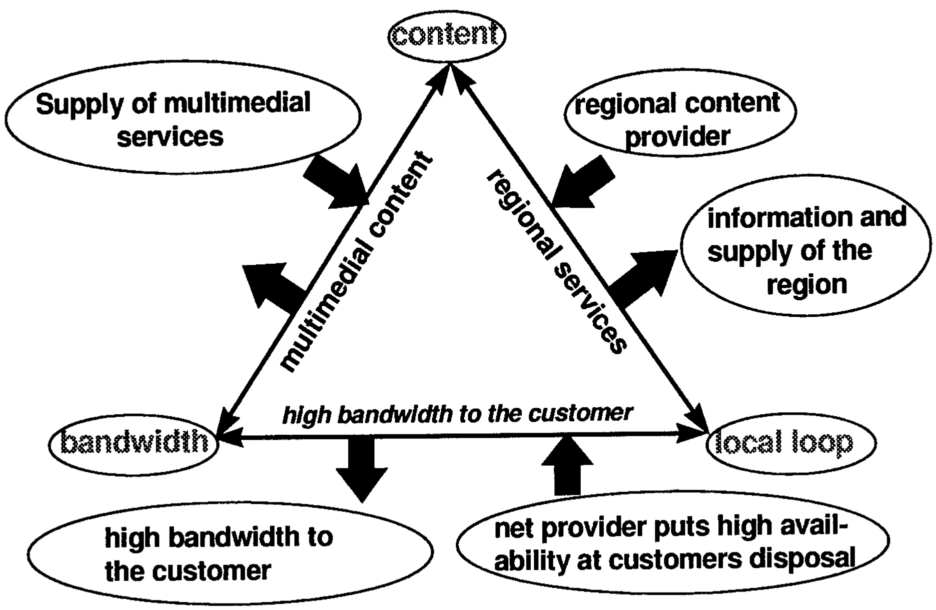

Figure 1. The relationship of content, bandwidth and local loop

The content and the bandwidth of the transport network as well as the multimedial content are bundled together to an inseparable unit.

Every content should be a value added content. The creation of multimedial contents like videos is quite expensive so the claim at a value added multimedial content is very high. Not every content has enough value to be presented as a video clip but the lines of business like holidays, teleshopping or infotainment are attractive multimedial contents.

In order to transport multimedial contents to the customer, the network performance should have a broad bandwidth without any bottleneck. As well the infrastructure of this multimedial network should use existing lines like coax-networks or twisted pair networks in order to lower the investment costs of the whole network. Mostly the network leads to a hybrid network (HFC=hybrid fibre coax).

The relationship between the local loop, i.e. the customer in a regional area, and the content leads to regional services. A regional content provider enters his regional information and services into the network so that the customer is supported in his everyday life.

The main task of the near future is the construction of a bandwidth network to the customer and the transfer of important content, which must be interesting enough for the customer to spend some money for this value added information.

Realization of a future backbone-network

The trial has the goal to transfer data over a local and metropolitan network on a fibre network with 155 Mbit/s up to 622 Mbit/s.

Depending on the distance, different methods of transportation are available:

a) wide area network (WAN)
- use of pipline routes
- use of railway routes
- use of high voltage overhead lines

b) metropolitan area network (MAN)
- city carrier
- other telephone companies through interconnection
- other companies with private networks through interconnection

The integration of the potential network supply depends on the position of the partners. It is easier to cooperate with partners who have large networks and who are interested in using their routes additional by another medium. Therefore big power supply companies are quite interested in this kind of cooperation.

The high voltage overhead network of RWE with dark fibre covers the heavily inhabited areas of the rivers Rhein and Ruhr. o.tel.o communications can utilize the lines of RWE Energie and Preußen Elektra, the power supplier of Veba. The network of the trial of o.tel.o consists of the dark fibre lines of different city carriers RWE Energie AG and the German railway company, Deutsche Bundesbahn, which has a private fibre network for own use.

System configuration of a metropolitan area

The city network of Gelsenkirchen is operated by the municipal city supplier, the Stadtwerke Gelsenkirchen and RWE Energie. It appears that every new private carrier who has no lines of its own is forced to cooperate with city carriers to supply their new clients with value added services.

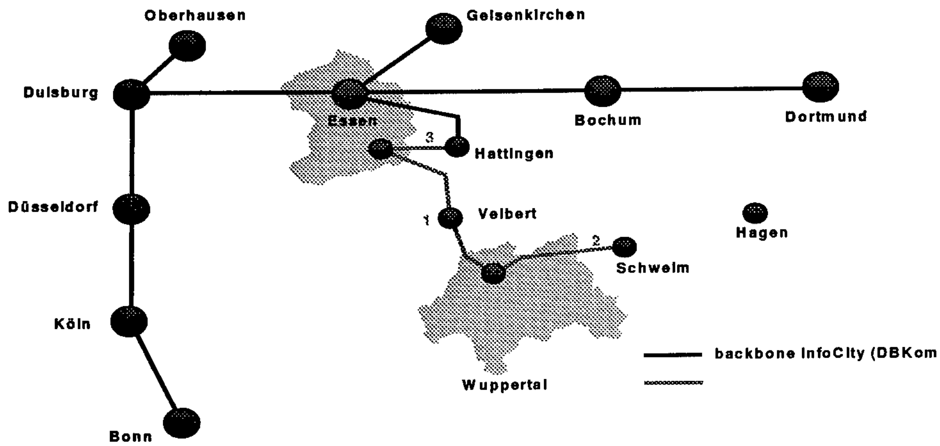

Figure 2 InfoCity NRW backbone based on the routes of the german railway company

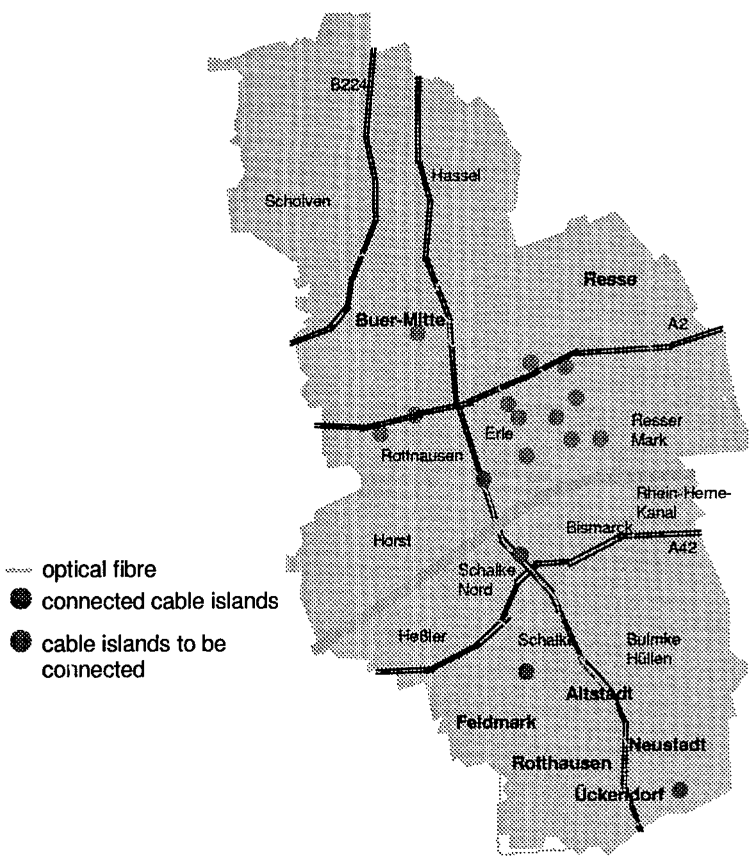

Figure 3 system configuration of Gelsenkirchen

Future services over a network expect a broad bandwidth connection to the customer. All services like data, voice or video are mixed on one network because there will be no difference in the transport medium of a fibre line.

services	data	voice	video
realaudio	X	-	-
video-streaming	X	-	-
video on demand	X		X
videocooperation	X	-	X
chatting	X	-	-
telephoning	-	X	-
videoconferencing	-	X	X
telehealth	X	-	X
teleshopping	X	-	X
teleworking	X	X	X

Chart 1. Future services need a bandwidth network

All digital data is based on a package oriented service (e.g. TCP/IP over ATM). ATM (asynchronous transfer mode) is suitable for this mixture of different services. ATM is a transmission protocol (second level of the ISO/OSI-model) which is used in WAN and MAN networks, but still not in connection of residential clients. In Germany a lot of residential districts are connected to a coax-network which supplies the households with television and radio. This trial uses this network. This requires that the amplifiers must be changed into amplifiers with a backchannel. The base of this network for these heterogeneous services is a hybrid (coax/fibre) network.

The „last mile" to the customer

The solution of the last-mile-problem deals with the harmonization between the customer´s access with a broad bandwidth and a lot of individual convenient value added services. The following chart shows, which bandwidth is necessary to supply the different value added services.

Convenient content as a base for permanent acceptance

The future service providers expect a broad bandwidth connection to their clients. Apart from the technical realization only, the „right" content will lead to permanent customer´s acceptance. But a killer application of the „right" content does not exist. The physical network with its equipment forms a plattform for an „open market-place" for all providers of services and information. That means the broad bandwidth network is still the basic instrument to spread contents like information, advertising or other value added services. The consumer needs a complete portfolio of online services including solid accounting, billing and customer care for a permanent relationship.

The system will succeed economically if the provider is able to solve the technical problem of broad bandwidth as well as the problem regarding the sensible use of multimedia and interactivity.

value added services	necessary bandwidth downstream	upstream
house management (light, house alarm, heating)	< 64 kbit/s	< 64 kbit/s
management system of supply activities (remote meter reading, energy mangagement	< 64 kbit/s	< 64 kbit/s
picture-phone (value added phone services)	≥ 64 kbit/s	≥ 64 kbit/s
(interactive) television (video on demand, broad-casting, entertainment, value added teleshopping, telebanking	> 1,5 Mbit/s	< 64 kbit/s
high fidelity set (real audio, audio on demand)	< 622 kbit/s	< 64 kbit/s
personal computer (teleshopping, telebanking, internet services, videoconferencing)	> 1,5 Mbit/s	> 1,5 Mbit/s
services for older or sick people (videoconferencing, alarm systems)	> 1,5 Mbit/s	> 1,5 Mbit/s

Chart 2. convenient value added services

The main ideas for a continous customers´s acceptance can be summerized:

- the content leads to value added service for every user, who pays for the services
- customers´s data is safe, personal data will be encrypted and authentified
- the bandwidth will be dynamically allocated by a management system
- the infrastructure of fibre lines and TV-cables is able to be payed by the local players who rent the lines for their customers

The main problem of future businesss is the generation of value added contents and a big number of customers paying for the service. The more customers are interested in the service the more providers will offer their content on the network.

Conclusions

The results of this big trial of o.tel.o will provide the answers to all these questions so that we can still expect that the future will bring us a variety of telecommunication links which use broad bandwidth. Today we can establish that the market for all these services is correlated to the offer of value added contents and the drop of the price for its use.

High quality content needs an infrastructure with a high bandwidth and a users´ acceptance, to spend money for these value added services. The future will bring us a change of content which needs a narrow bandwidth to a content with broad bandwidth full of multimedial components. Both narrow and broad bandwidth content will coexist in dependence of its special application.

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Implementational and Perceptual Aspects of an Immersive Auditory/Tactile Virtual Environment

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Abstract

Most of today's commercially available virtual environment systems place great emphasis on vision but still fail to adequately address the auditory and tactile domains. Since virtual environments are, by their very nature, multi-modal applications, appropriate consideration of modalities other than the visual modalities is vital in order to achieve a convincing perception of immersion. The effect of immersion can significantly be improved by including auditory, tactile/thermal and force-feedback perceptions. The virtual environment system developed within the ESPRIT basic research project #6358 SCATIS (*Spatially Coordinated Auditory/Tactile Interactive Scenario*), funded by the European Union, has demonstrated the feasibility of an immersive auditory/tactile virtual environment implemented as a modular multi-process simulation system running on a heterogeneous UNIX network. It was particularly designed as a tool for multi-modal psychophysics research and, furthermore, it was built to serve as a platform for future refinements and optimization of the simulation- and signal processing methods applied. Some aspects of the implementational concept with a particular emphasis on the auditory subsystem as well as the major results achieved within the project in terms of physical performance and perceptual parameter thresholds are presented in this paper. Experiments carried out with the so-called SCAT-Lab yielded quite promising results with respect to the auditory subsystem whereas, due to technological difficulties, the tactile effector hardware turned out to be yet widely insufficient to render plausible perceptions of virtual objects.

Introduction

VR systems provide the potential to expose human beings to a computer-generated and/or computer-controlled artificial environment in a way that they feel and act as if they were in their natural environment. Many otherwise complicated tasks can be performed intuitively in such a state of mind. We call the impression of a subject of feeling present in a natural environment while actually being exposed to a virtual one: Telepresence. In order to achieve Telepresence, physiologically adequate signals have to be delivered to the subject's senses. The most important senses to be addressed in this context are vision, audition and the tactile modality - plus kinesthetic coordination.

Today's commercial VR systems are seen to place a great emphasis on vision, but they do not yet adequately deal with the auditory and tactile domains - although, to be sure, these domains essentially enhance Telepresence or can even create it by themselves. It is not a case of these facts not having been understood or of sophisticated auditory and/or tactile components being deliberately omitted. It is rather that there is a significant deficit in specialized basic knowledge & experience concerning these two modalities and in the technology necessary to deal with them.

Therefore, general aim of SCATIS was to perform specific basic research in order to investigate the role of the auditory/tactile modalities with respect to Telepresence in a selective and detailed way. To this end, an interactive experimental scenario was specified as follows:

"A subject is exposed to a virtual space with various (invisible) auditory/tactile objects distributed in it. He/she will localize and identify these virtual objects auditorily, and be able to reach towards them and grasp them individually. Upon tactile contact, contour, texture and thermal attributes of the virtual objects will be perceived. It is the task of the subject to manually move the objects around, i.e. to re-arrange their spatial position and orientation according to an experimental plan. Auditory feedback is given."

This scenario was considered to be representative of a variety of engineering problems in Multi-Media and/or VR applications, for example: control, guidance, surveillance, access or evaluation tasks - not to mention training, education and entertainment.

Vision was not explicitly addressed, but rather omitted most of the time in this project for the following two reasons: Visual cues to the experimental subject may cause distraction and mask effects due to sensory dominance. This would thus affect the selective analysis of the auditory/tactile modalities. Furthermore, there are many application possibilities in Information Technology for straight auditory/tactile virtual environment technologies, e.g., in situations where the eyes are busy or where vision is impeded, impaired or not available at all. This applies especially to Augmented Realities where e.g. warning signals or control parameters in an airplane can be presented auditorily so as to ease the pilot's visual sensory channel. Nevertheless, a simple visual feedback is provided for monitoring and software verification purposes and, due to the modular structure of the system, binocular-visors can easily be interfaced. It should be mentioned that considerable risks were involved in realizing the tactile display. Since an effective technology for implementing a tactile feedback system had not been previously established, it was rather uncertain whether a system capable of providing the necessary perceptual spatial and temporal resolution could be completed within the limited framework of SCATIS. The project was carried out in close collaboration with Massimo Bergamasco (Scuola Superiore S. Anna, Pisa, I), Dorte Hammershøi (University of Aalborg, DK) and the industrial partners S.M. Scienzia Machinale s.r.l. Pisa, I, and Head acoustics GmbH, Herzogenrath, D.

The System's General Architecture

The architecture of the SCATIS VE-system (the so-called SCAT-Lab) was designed in a hierarchical and modular manner so as to provide the maximum possible flexibility with regard to utilizing hardware and extending the system in the future. The modular structure, which is depicted in Figure 1, is similar to the architecture proposed by Appino (Appino et al., 1992). All the important components of the SCAT-Lab were realized as separate UNIX processes which can be deliberately distributed among a network of workstations. Communication between these processes is provided by the Central Controller (CC) via a carefully designed number of messages (events). To this end a client-server architecture was realized, with the Central Controller being the only client and all other modules being server processes. This architecture enables the Central Controller to control the timing and synchronization of the connected processes. This is vital for a congruent rendering of all the addressed modalities. The client-server behavior is explicitly forced by the software protocol. The position and orientation of the head and hand are frequently measured by position tracking hardware, based on modulated electromagnetic fields, whereas the hand-finger configuration is tracked by a sensorized glove equipped with kinesthetic sensors measuring the movements of the proximal and medial joints of all the fingers on the right hand. Measured position, orientation and angle data acquired by these two devices are passed on to the *Head&Hand Tracking Renderer* (HHT) process that computes the actual position and orientation of each individual finger-joint, transforms all this data into the world coordinate system and buffers the data for immediate access by the central controller.

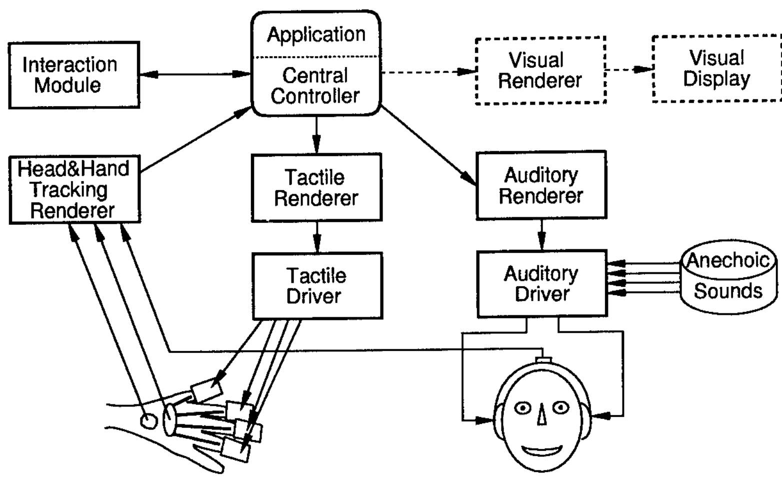

Figure 1: The system architecture of the SCAT-Lab virtual environment generator.

The *Central Controller* (CC) forms the link between the efferent[1] Head&Hand Tracking Renderer, the Interaction Module, and the afferent renderers of the modal pathways. It accepts movement events from the efferent renderer and from the Interaction Module, evaluates them according to the rules implemented by the *Application* and reacts by sending appropriate events resulting from the evaluation to the afferent renderers. These rules make up the protocol dynamics of a virtual environment application. For example in a multi-modal application the Central Controller could advise the auditory renderer to switch off the sound of a sound emitting object after it has been grasped in the virtual world.

The purpose of the *Interaction Module* (IM) is to model the interaction between the hand and a virtual object. This task includes detecting grasp and release and defining how a grasped object is moved when the hand moves.

[1] Following neurobiology, modal pathways that transfer information towards the subject are called *afferent* and those transferring information from the subject to the virtual world are called *efferent*.

The task of the afferent renderers is to render the virtual world for the human sense they are particularly dedicated to. In SCATIS these are auditory and tactile modalities. The rendering functions are distributed among several modules which can roughly be described as follows:

1. The *Tactile Renderer* (TR) detects intersections between the hand and other active virtual objects, calculates adequate excitation values for the tactile effectors, and transmits these values to the Tactile Driver.

2. The *Tactile Driver* (TD) interfaces the Tactile Renderer with the tactile effectors, i.e., it transforms the received data into hardware-dependent commands and implements the communication protocol according to which these commands are transmitted to the tactile effectors via a serial interface. The tactile effector consists of a routing board and 3 thermal-tactile actuator-units. Each unit incorporates 16 electromagnetically driven indentor pins for the tactile feedback and a Peltier cell to render thermal feedback. Emerging waist heat is drained off by a compressed-air cooling system.

3. The *Auditory Renderer* (AR) performs the sound field modeling by calculating the distribution of the secondary sound sources. This depends on the current positions and orientations of the head and sound sources inside the virtual environment. It determines the delay time, the directions of emittance and incidence, and the affiliated head-related transfer function (HRTF) for each direct sound source and, in addition to this, the wall reflection filters for each early reflection. This data is frequently transmitted to the Auditory Driver.

4. The task of the *Auditory Driver* (AD) is to auralize the various sound sources and reflections by delaying the audio input signals and convolving them with the appropriate impulse responses representing the source directivity, the wall reflections and HRTFs. Finally the filtered signals are added together and equalized for the transfer functions of the headphones employed. From this the binaural output signal is obtained. Concerning details of the auditory display hardware the section titled „Real-Time Auralization" should be referred to.

5. The *Visual Renderer* (VR), in its present state, is merely intended to provide a survey of the virtual scenery and to check the congruent behavior of the renderers assigned to the different modalities.

Nevertheless, as a consequence of the modular structure of the VE-system it did not prove to be a problem either to integrate additional afferent renderers, e.g. for the visual modality, or to exclude any renderer if the hardware resources are insufficient for the complete system or if a renderer is not needed for a certain application.

During the initialization phase each renderer sets up an internal database by parsing a file containing a complete description of all the objects that make up the virtual world. This database may be customized according to the needs of the particular renderer. The Auditory Renderer, for instance, is very interested in the spatial positions of the head and sound emitting or -reflecting objects, whereas the configuration of the hand is of less interest. Moreover, each afferent renderer keeps additional local databases containing information which does not interfere with the other renderers' domains. The common database refers to these local databases only by ids of their entries in order to keep the overall memory consumption at a reasonable level. The Tactile Renderer, e.g., maintains a database containing the haptic attributes of the surface materials involved and the Auditory Renderer needs additional information on the directivity of sound sources and about the reflecting properties of wall materials.

Two UNIX workstations (16MFlops, 85Mips), connected via Ethernet, were determined to execute all the processes mentioned above. Optimal utilization of the CPU's capacities can be achieved by appropriately distributing the processes among them. If necessary, additional workstations may be incorporated into the simulation to increase the overall performance of the VE-system.

This performance can partly be evaluated using the two characteristic quantities *frame rate* (or *update rate*) and *latent period* (also known as *time-lag* or *latency time*). According to ANSI/IEEE Std 100-1977, the latent period is defined as the time elapsing between the application of a stimulus and the first indication of a response. It responds to the perceptual attribute *responsiveness*, while the attribute *smoothness* can be assigned to the frame rate (Appino et al., 1991). The frame rate is the average number of discrete display updates that can be rendered per time interval. One objective of the research activities with the SCAT-Lab was to determine the perceptual thresholds of these quantities.

The Auditory Subsystem

The main principles of binaural room simulation, as applied in SCATIS, and their implementation in hard- and software are described in the following sections. Please refer to (Lehnert and Blauert, 1989), (Lehnert, 1992), (Lehnert and Blauert, 1992), and (Strauss and Blauert, 1995) for a detailed explanation of the basics of binaural room simulation and its application in real-time. Pompetzki (Pompetzki and Blauert, 1994) demonstrated the perceptual authenticity of binaural room simulation. An introduction to binaural technology can be found in (Blauert, 1996) and an exhaustive overview of the underlying psychophysics of human sound localization is given by Blauert (Blauert, 1997).

Binaural Room Simulation

If a subject is to be placed in a virtual auditory environment it is necessary to present signals at both eardrums that are similar to the signals that would be present in a corresponding real environment. Obviously the easiest way is to use headphones as an auditory display, because the binaural signals to be presented to the eardrums can be given directly into the headphones' transducer terminals after having adequately equalized for the headphones' transfer function. Disturbing crosstalk between the two audio channels cannot occur. The tasks to enable a virtual auditory environment to be created are as follows:

1. The virtual environment must be modeled from the acoustical point of view at the listener's location. This is called *auditory rendering* or *sound field modeling.*

2. Based on the results of this modeling process, the resulting eardrum signals have to be calculated and presented which is known as *auralization.*

Auralizing a single sound source is comparatively easy. Given the position and orientation of the sound source and of the subject's head, the distance and the direction of incidence can be calculated. Auralization is performed by convolving an anechoic sound signal with the corresponding HRIRs in real-time. The overall gain is adjusted according to the distance between the sound source and listener. Absorption of sound in the air over long distances can either be modeled by appropriate overall gain reduction or by frequency dependent gain reduction. Complex directivity characteristics of the sound source can also be implemented using appropriate pre-filtering as a function of frequency and direction of emittance. Monopole synthesis and spherical harmonic synthesis have been successfully examined for the purpose of efficiently storing directivity data (Giron, 1993).

The model as yet does not take into account any impact of the surrounding environment upon the listener's auditory perception. Many properties of the surrounding environment can be obtained solely from the auditory perception. For example, the interior of a church sounds completely different compared to a small living room. The total absence of reflections, for example in an anechoic chamber, can even be an unpleasant sensation for people who are not used to the absent auditorily perceivable environment. Furthermore, it is believed that reflection patterns are important clues to proper distance perception.

The impact of the reflective environments on the perceived sound can be modeled with the help of binaural room simulation algorithms (Lehnert, 1992). These algorithms make use of *geometric acoustics*: Provided the wavelength of the sound is short, compared to the linear geometric dimensions of the surfaces in the room, and long, compared to the roughness and curvatures of these surfaces, then sound waves propagate almost in straight lines. They can therefore be treated as sound rays that are reflected on surfaces according to the optical reflection law. Though the assumption above is not true for wavelengths of all perceivable sounds, it has been shown (Pompetzki, 1993) that reasonable results can be achieved using geometric acoustics. Of course, wave effects like diffraction and diffuse reflections cannot be exactly modeled using geometric acoustics at first hand. This would require the acoustic wave equation for the sound pressure p to be numerically solved with respect to complex boundary conditions given by the reflective surfaces. Since a great deal of computational effort would be needed, especially for high frequencies, this method is currently not suitable for real-time applications.

Based on the above simplification, two main algorithms have been developed for binaural room simulation. According to the so-called *mirror image model* (Allen and Berkley, 1979), primary sound sources have to be mirrored on all geometric surfaces of the environment to obtain virtual *secondary sound sources*. The algorithm can be applied recursively to these secondary sources to obtain results for higher orders[2]. However, not all of the secondary sound sources found with this procedure are acoustically relevant because the surfaces are generally not extended infinitely. Therefore, the great majority of the calculated reflections of higher orders are situated outside the boundaries of the corresponding walls, or the sound path is blocked by other walls. Much effort in terms of calculation power is necessary to extract the relevant sound sources by performing „visibility“ investigations.

[2] The order specifies the number of reflections needed for the sound to reach the listener.

An alternative method for finding secondary sound sources is the *Ray-Tracing algorithm*. It is comparable to corresponding rendering algorithms applied in the field of computer graphics. Rays are emitted from each sound source in different directions and their propagation inside the room is traced. Rays hitting surfaces of the environment are reflected according to the reflection law. Diffuse reflections can be modeled by adding random components to the reflection angle. All the rays that hit a detection sphere around the receiver are acoustically relevant for the simulation. The positions of secondary sound sources can easily be found by backtracking these rays. However, when putting the Ray-Tracing algorithm into practice, missing or multiple detections have to be considered due to the finite number of rays and the spatial extension of the detection sphere around the receiver. The role of the sound source and the receiver can also be reversed. This requires less effort if more than one sound source is present.

If, in theory, calculation time were unlimited, both algorithms would obtain the same distribution of virtual sound sources. The Ray-Tracing algorithm is usually more efficient for finding high order reflections while the mirror image model is preferable when only low order reflections are required. A sequence of indices is assigned to each secondary sound source specifying the walls where the sound has been reflected on its way to the listener. Optionally, reflection angles for each reflection can be stored for simulating angle dependent reflection characteristics.

The complete characteristics of the environment as a result of this *sound field modeling* process can therefore be represented by a *spatial map of secondary sound sources* (Lehnert and Blauert 1989) in a reflection-free space. Each sound source can be auralized with the help of previously measured head-related transfer functions (cf. e.g. Pösselt et al., 1986 or Hammershøi and Sandvad 1994). Directivity characteristics of the source and wall reflection characteristics can be modeled using pre-filters. Angle-independent wall reflectance data can be found in literature or obtained from direct measurements usually carried out in reverberation chambers. The result of this primary filter process is a binaural impulse response for each virtual sound source. The *binaural room impulse response* is obtained by adding together all the (appropriately delayed) binaural impulse responses from each virtual sound source. It can be interpreted as the two sound pressure signals at the eardrums that would be measured if the sound source emitted an ideal impulse. The room impulse response completely describes the transfer characteristics of the environment between a sound source and the listener. For auralization purposes, anechoic audio signals have to be convolved with the binaural room impulse response.

Real Time Auralization

Auralizing a virtual environment by convolving the audio signals assigned to the sound sources with the respective binaural room impulse responses requires an enormous amount of calculation power[3] that cannot reasonably be performed in real time, so simplifications are necessary. Exact auralization can be restricted to first and second order reflections because reflections of a higher order can hardly be perceived separately. These reflections can be modeled with conventional reverberation algorithms which only consider statistical properties of the late reflections. Direct sound and first/second order

3 For a three second impulse response at 44,1 kHz sampling frequency, nearly $6*10^9$ multiplications per second and channel must be calculated. Using the overlap-add algorithm the required number of multiplications may be significantly reduced at the cost of an unacceptable additional processing delay.

reflections can be auralized in real time by distributing the corresponding virtual sound sources among a network of several digital signal processors (DSPs) where each virtual source is auralized separately by convolving the corresponding input signal with the respective set of filters and delaying it appropriately. In the framework of SCATIS the real time auralization was realized by a network consisting of 40 Motorola DSP56002 signal processors which provide an overall peak calculation power of 800 million multiplications per second. This is sufficient for auralizing a total of 32 primary sound sources and first to second order reflections in real time at a sampling rate of 48kHz.

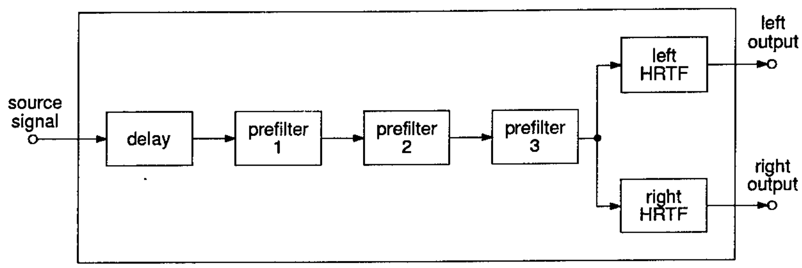

Figure 2: Sketch of an auralization unit.

The system for auralizing one virtual sound source, as depicted in Figure 2, is called an *auralization unit*. The delay is proportional to the travel distance between the source and the receiver and represents the time the sound needs to reach the listener. Pre-filter 1 models the directivity of the sound source and is selected from a catalogue according to the particular direction of emittance. The remaining two pre-filters represent the reflectional properties of the surfaces the sound wave is reflected at. These filters may not only depend on the frequency but also on the angle of incidence. Since direction dependent reflectance data is presently not available in literature and extremely difficult to obtain from measurements, a catalogue of impulse responses of a great variety of architecturally important wall materials was established. At present, it is based on directionally independent absorption data supplied by the German Standards Organization. In general, all filters are implemented as FIR filters with 20 coefficients for each pre-filter whereas the Head Related Impulse Responses (HRIRs) (Sandvad and Hammershøi, 1994) employed for the spatialization of the sound sources comprise a maximum of 80 coefficients per binaural channel (if no pre-filter is involved). However, since the convolution power of a single auralization unit is limited to 160 filter taps at a sampling frequency of 48 kHz, inserting a pre-filter causes a cut in the HRIRs by 10 coefficients per channel. This may be done since, as far as reflections of higher orders are concerned, their spectral properties proved to be more important than those referring to their spatialization (Lehnert, 1995).

The three pre-filters as employed in SCAT-Lab allow secondary sound sources to be auralized up to the second order including directivity characteristics or even up to the third order if directivity characteristics of the sound source are not simulated. 43 sets of HRTFs were measured with 38 different subjects with a resolution of 11.25° in the azimuth and 22.5° in the elevation angle, each set consisting of 195 transfer functions covering (nearly) the whole sphere from -67.25° to +90° elevation (see (Møller et al., 1995) for details of the measurement method). A suitable set of HRTFs can be chosen from this catalogue and interpolated off-line by the auralization hardware in order to increase the available resolution to up to 2°. As was previously mentioned, all the auralization units work in parallel on several signal processors, their results are added together and finally equalized for the employed headphones to obtain the complete binaural output signal.

The Demonstration Scenarios

Two scenarios were implemented to demonstrate and test the capabilities of the SCAT-Lab auditory and tactile interfaces. The geometric set-up of the scenarios, including the initial positions of the virtual objects, was defined using a C-like description language, while the protocol dynamics were coded into C++ classes derived from a generic application class.

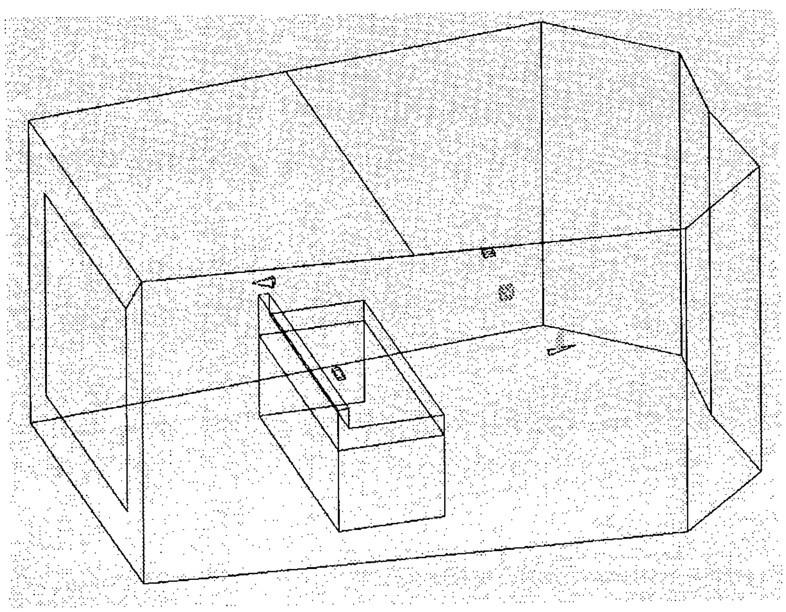

Figure 3: Sketch of the virtual studio as used in the SCATIS demonstration scenarios.

Both scenarios are located in a small to medium sized virtual studio (about 6.4 m x 5.3 m x 2.6 m, volume: 35 m^3) with a simplified mixing console inside (see Figure 3). The estimated reverberation time of this room is 0.7 sec. The walls of the room cannot be touched by the subject. Scenario 1 ("Virtual Band") comprises four virtual objects, each of them representing a virtual instrument located at one of the vertices of a horizontal square (2m*2m) at a height of 1.5m. These touchable objects with simple geometric shapes are defined as acoustically transparent. Initially, only one of them emits a sound. The task of the subject is to carry out a certain manipulative procedure on this object so that the next one starts to emit sound as well. Again, the subject's task is to manipulate the newly activated object in order to activate the next one. The task continues until all four objects have been activated and the fourth one has been treated the same way. During the operation, the time intervals between the activation of the different objects are measured. These time intervals are expected to be dependent on the number of currently active objects and also on the positions of the objects in space. The manipulative procedure the subject has to carry out on an object in order to activate the next one can be varied. In the basic scenario this manipulative procedure consists of just a grasping movement. Possible variations are to turn the object upside down, to identify a particular side of the object with differing tactile attributes or to let the subject move the activated objects away before trying to grasp the next one.

The second scenario employs virtual objects with different haptic, thermal and/or acoustic properties. The task of the subject is to auditorily localize these objects representing virtual balls, to explore their properties tactually, and to move them into special areas in the subject's workspace, which represent virtual holes, according to their shape, temperature or texture. The balls emerge one by one at different spatial positions and vanish again as soon as they have been moved to the correct holes. The balls and holes emit two different kinds of sounds and can therefore be distinguished auditorily by the subject.

Performance Measurements

Performance tests were carried out measuring the frame rate and the latent period using the test scenarios described above. To this end, the system was set up whereby all the afferent renderers were initially replaced by dummy processes. Then, all the afferent renderers were gradually inserted into the system. In principle, the frame rate was limited to 60 Hz by the maximum speed of the tracking device (Polhemus Fastrak) when operating with two receivers. The processes involved in the measurements were executed in parallel and in changing configurations on a set of 5 Silicon Graphics workstations (2 Indigo R4000 + 3 Indy R4600) connected via Ethernet, so that, in general, each process had a CPU of its own. Applying the initial concept of synchronous rendering (all processes running at the same frame rate) a frame rate of 60 Hz could be achieved in any configuration of processes as long as the tactile pathway was excluded from the simulation system. The overall latent period of the auditory pathway, describing the elapsed time between the measurement of the head position and the adequate audio signal being displayed via the headphones was measured to approx. 80ms.

As soon as the tactile subsystem (TR + TD, both running on the same host) was integrated into the SCAT-Lab the frame rate dropped drastically to about 12 Hz at maximum, although the load of none of the CPUs involved exceeded 25%. If an object was touched, the frame rate dropped even further to about 10 Hz. Since the integration of a visual renderer running on the same host together with the CC, the TR, and the TD could not even decrease the overall performance significantly, it is obvious that the tactile effector represented the limiting factor. The latent period of the tactile VE-system turned out to be within the range of 300 ms to 400 ms. However, despite the limited overall performance, the "Virtual Band" scenario could be carried out successfully in a systematic manner by several subjects.

Performance tests carried out with all the rendering processes executing asynchronously, revealed that the overall system performance can be increased significantly in the sense that the frame rate of the complete system is no longer limited by its slowest component. The performance of most of the modules is increased significantly when compared to the synchronous rendering strategy that was initially employed. Since the performance of the tactile subsystem could hardly be increased, and turned out to be independent of the workload of the computer it was executing on, it can be assumed that the bottleneck is located in the tactile effector hardware or in the serial connection to the computer hosting the tactile driver process.

Perceptual Results

Although the coherent temporal behavior of the objects in both modalities is mainly guaranteed by the synchronous rendering strategy, the experimental task appeared to be quite unnatural and even tedious, as the subject is obliged to move her/his hand very slowly in order to maintain the spatial constancy of the virtual environment. If the head is turned rapidly, the sound field moves perceivably along with the head and jumps back into its former spatial position. However, this proved less irritating than the effect caused by the tactile display. As a consequence of the low frame rate and the rather long latent period that was experienced, a subject has to approach an object very slowly in order to detect its surface with high spatial precision. Otherwise the spatial and temporal resolution of the quantization of the hand and finger positions is insufficient to gain perception of contact at the correct spatial position. The tactile feedback from a virtual object is then usually rendered only after the hand has already entered the object. In this case the tactile actuators are driven to full (vibro-tactile) output. When the hand is moved back the excitation falls back to zero again, delayed, of course, by the latent period. This kind of ‚binary‘ behavior makes it very difficult for a subject to obtain a proportional tactile feedback from a virtual object's surface.

Although it certainly leads to larger perceptible inter-modal temporal discrepancies, asynchronous rendering proved to yield a much better perception of immersion into the simulated scenario, even if the responsiveness and smoothness for one of the addressed modalities is inadequate.

Investigations into the dynamic aspects of auditory virtual environments carried by Sandvad (1996) showed that update rates below 20 Hz and latency periods of 96 ms and above have a significantly degrading effect on both time and accuracy of sound source localization under free-field conditions. These results which correspond with tests made by the authors indicate that the corresponding values achieved with the auditory component (60 Hz and 80 ms) are more than sufficient to obtain a plausible representation of an auditory virtual environment.

Conclusion

The experiments show that the main aim of the project has been reached: Subjects exposed to the auditory/tactile environment are able to perform the experimental tasks as proposed by the scenarios, most of them even when using non-individualized HRTFs. This is possible even at the very limited frame rate of 12 Hz that was obtained under the generic strategy of synchronous communication and rendering.

Since the latent periods of the auditory and the tactile VE subsystems turned out to differ within a range of 100 ms to 300 ms, even when applying the synchronous rendering strategy, temporal congruence of the two modalities cannot really be guaranteed. Applying asynchronous rendering strategies, on the one hand, certainly decreases that congruence but, on the other hand, it significantly enhances the smoothness and responsiveness of at least the auditory domain significantly and even slightly improves the tactile domain. The perceptual effects of temporal incongruent rendering for the two modalities will be the subject of future research.

Considering the problems detected and the performance figures obtained from the SCAT-Lab in its current configuration, the applicability for multi-modal research appears to be still limited. However, the auditory VE-technology has already proved its applicability for human factors research and industrial use. Convincing results in terms of plausible real-time simulations of rooms with moderately complex non-trivial geometry can be obtained, although important phenomena like the dependence of the HRTFs on distances, diffuse reflections at walls, diffraction, and Doppler-shifts were not taken into account for the present system. These effects are currently subject to investigations and will be partly implemented in the near future.

Although the tactile pathway works in principle, its performance proved to be greatly impeded by the associated display. The fast and efficient rendering algorithms which have been developed and implemented can only be partly transferred to create adequate sensations of the skin because the present capabilities of the tactile effectors are inadequate. The tactile system needs to be significantly improved especially with regard to its frame rate and latent period in order to facilitate its usage in advanced VE-systems. However, the technological approach applied appeared to be quite promising for future developments.

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An Integrated Multimedia Concept for Distance Teaching of Engineering

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Abstract

An integrated set of courses for a track of four subsequent semesters is being developed covering computer engineering in great width and with strong links to technical applications. The courses are envisaged to become integral parts of a distance teaching university's curriculum. Combining short phases of presence with interleaved media-based self study blocks, they are also well-suited for continuing education purposes. An innovative approach is taken by integrating all course elements - acoustic and written information, diagrams and figures, animations, simulations, video clips, and laboratory exercises - in a single electronic document. Whereas up to now all this information is only accessible on different storage media, the new multimedia teaching programmes even replace printed material to a large extent.

Introduction

FernUniversität is the only German language institution of higher distance education at the university level, i.e., granting doctoral degrees and habilitations. It has students in almost all countries on earth. Engineering curricula are offered by the Faculties of Informatics and Electrical Engineering with several thousands students enrolled. After a vocational or another academic training, most of these students have a job and, in parallel, are further educating themselves by a study at FernUniversität. They are motivated by both wishing to update their knowledge and to enhance their career opportunities by obtaining a (higher) academic degree (Diplom-Ingenieur, Dr.-Ing.). To this end, they either enroll in continuing education modules consisting of a number of courses whose successful completion is certified, or by following an entire study. In the latter context the very successful supplementary curriculum in electrical engineering is to be particularly mentioned, providing engineers having graduated at Fachhochschulen (polytechnics) with the opportunity to earn an university diploma in a shortened study period.

Traditionally, the main didactical components of university curricula are lectures, exercises, laboratory practica, and seminars. In distance teaching, lecture notes and corresponding exercises are sent to the students' homes, where notes are studied and exercises elaborated before being returned for marking and correction. Hitherto, self-study course texts and exercises are shipped in form of printed material to the students, who return their feedback by mail as well.

At FernUniversität, the Faculty of Electrical Engineering is transforming all its courses to multimedia form. Thus, they can be distributed on CD-ROMs emulating traditional shipment or via communication networks leaving the initiative to obtain material to the students. Electronic mail appears to be the most appropriate means for returning exercises, and video conferencing is successfully employed to eliminate seminar travels.

In the course of fundamentally revising the contents and examination regulations of FernUniversität's electrical engineering curricula, the increased requirements of electrical engineers for computing knowledge and industry's need for demand-oriented training were particularly taken into account. According to this need, an integrated set of four subsequent single semester courses in multimedia form was defined covering computer engineering in great width and with strong links to technical applications. The courses will become integral parts of the mentioned curricula offered by FernUniversität. Combining short phases of presence (e.g., weekend seminars) with interleaved media-based self study blocks, they are also well-suited to be used in continuing education.

Project Objectives and Considerations

For the development of multimedia courses all teaching elements - acoustic and written information, diagrams and figures, animations, simulations, video clips, and laboratory exercises - are integrated on a single electronic storage medium to fully exploit the possibilities of contemporary teaching and learning technology and to lead corresponding practices far into a new area. Phases of conveying factual knowledge and of elaborating exercises are interleaved by integration into the medium computer to allow for a maximum extent of interactive exposure to the teaching material. Combined with hypermedia techniques complete integration offers hitherto unimagined possibilities to dynamically adjust teaching material to the students' progress of learning as well as to their specific ways of learning. Furthermore, multimedia enables to always transfer information in its most suitable form. This innovative approach is not without risks and, thus, has to be carefully accompanied with methods of empirical pedagogics.

The disadvantage of combined media introduced several decades ago was that their single elements could only be made accessible on different storage media (study texts, audio cassettes, movies, video tapes, video disks, diskettes) each - except the texts - requiring a special device for replay. Therefore, it was practically difficult to have the complete volume of information at one's disposal, and its manageability was particularly cumbersome. This made it advisable to keep the interleaving of the information offered on the different media rather limited. The older multimedia concepts tried to overcome this shortcoming, at least a little bit, by "programming" the linkage of the still separated media and, thus, realising an integrated sequence control.

Our approach takes a decisive step ahead: information (text, sound, picture, movie etc.) hitherto separated by different media is integrated on a single, qualitatively as well as quantitatively high performance storage medium. Complete availability of all information is always ensured, and in combination with hypermedia techniques high flexibility is given for accessing different information. Furthermore, multimedia offer a great potential for technology migration, since information can always be communicated in the most suitable form.

Certainly it makes no sense to offer large quantities of written information for perception via a computer screen. Therefore, in general FernUniversität's learning programmes do not present larger quantities of text. This is achieved by either selecting for programmes such topics which require only little text, or by letting programmes accompany printed course material, or by adding supplementary written information to programmes. Hitherto, teaching software mainly concentrated on functions which cannot or which can only inappropriately be fulfilled by written courses, such as to present and deal with processes of all kinds or to support active perception of the material. However, after it is now technically possible to integrate acoustic information including spoken texts into teaching programmes, the latter cannot only accompany and supplement printed courses but, in principle, also replace them. Thus, electronic courses become possible as integrated multimedia programmes. The most striking characteristic of our approach is to overcome combined media by integration and completely relinquishing printed media.

Teaching media designed as self-instructing materials - this is the case for all distance education materials - can, in principle, be used in three forms of teaching and study organisation: as studying materials at an institution of higher distance education, as studying materials in a single phase of distance studies organised by an institution of presence education or by a distance learning institution in co-operation with an institution of presence learning, or as self-studying materials at institutions of presence education in order to supplement or to replace lectures. The multimedia learning programme "Computer Engineering" is designed to be employed (entirely or in defined parts) in all these areas.

Didactic Features

The project's most striking characteristic is overcoming combined media by real, physical and complete integration and the total renunciation of printed media. This approach contains considerable potential for innovation. It requires to further develop didactic-methodical concepts of distance teaching, and of media-based learning in general. Thus, the main question is: with which didactic-methodical concept and with which practical implementation technique can a modern electronic course be developed that gets by without printed media and combines different information elements such as text, sound, picture, and movie, that are hitherto stored on separate media, in a single electronic document?

In particular, the didactic-methodical concept has to contain suggestions, how the different elements, mainly acoustic and written information, can be optimally co-ordinated for the presentation of the material itself and of exercises and problem sets. The concept's realisation and its validation are carried out step by step (formative evaluation). It is hoped that the optimum co-ordination will have been found by the end of the project.

The electronic courses are conceived in such a way that they may be used not only for distance learning, but also as self-studying materials. To this end, the material is structured in modules. In the course of the project it will become clear, whether this goal can be achieved.

In pursuing the objectives stated above, it is looked into the question how teaching of a quite technical subject with corresponding laboratory phases can be interleaved by integration in the medium computer. How to explain and to accustom students with the function of a physical device when there are no laboratory sessions? As now common in science, it is not dealt with the real world, but components up to computer cores are simulated. Acceptance and range of this virtual world are to be investigated in the particular subject area of computer engineering. Basic digital circuits and electronic gates, for instance, are represented graphically in diagrams - the input values can be assessed by students. Simulation programs then provide the same values at the outputs like in a real circuit.

A central item of the courses is a simulation program for an easily programmable digital computer. This hypothetical computer does not match with any really existing computer. On the one hand, it is so powerful that it possesses the most important properties of digital computers dealt with in the course. On the other hand, it is so simple that it dispenses with all further special features that might be disturbing while demonstrating the basic properties of a computer. As depicted in Figure 1, this computer shows the contents of its memory and the most important registers on its graphical user interface, and is programmable with the help of a set of 20 instructions. The execution of a program can be performed either in step mode or in free running mode, as desired.

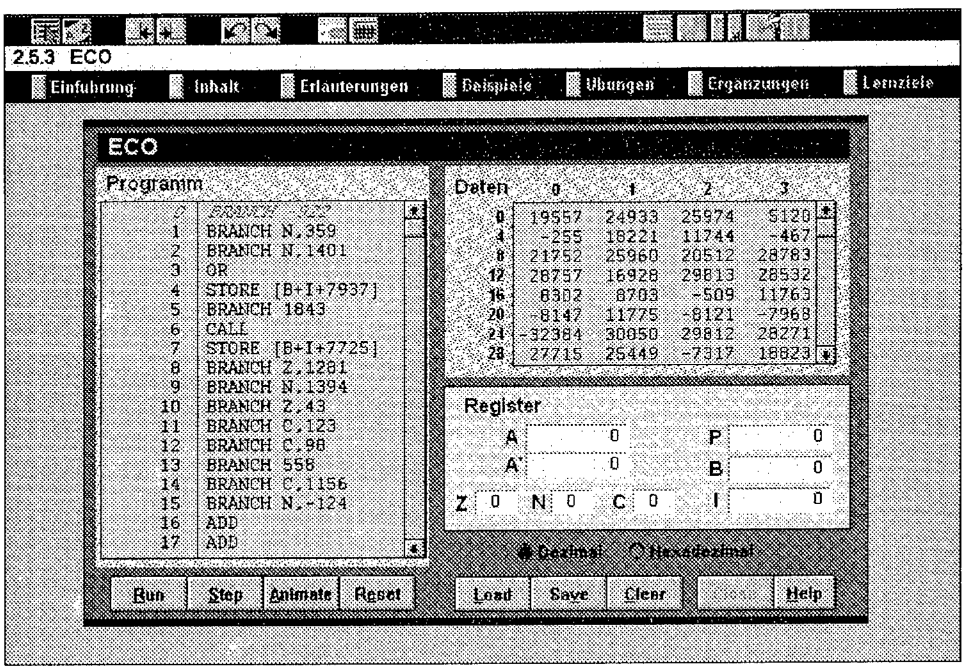

Fig. 1: Simulation of a computer core

With these simulated circuits and computers, first the mode of operation of systems can be demonstrated with examples, especially the basic working method of a digital computer and its programming. Furthermore, students are given the opportunity to work actively on the problems dealt with in the course and to develop practical experiences in the handling of systems. Finally, the simulated devices are at disposal for free experimenting, which might lead to new questions and the search for own answers.

In the project it is investigated, whether the need of practical experiences in the subject of computer engineering can be completely covered in the way described, in how far this offer is accepted, and how it is assessed.

Another question concerning the complete integration and the relinquishment of written media arises because of the commonly held estimation that it is not feasible to offer extensive written information for reading on a monitor. Admittedly, longer verbal passages usually do not take up a central position in the passing on of technical contents, but they do have their place in the field of computer engineering, e.g., in introductions into a subject, in motivations for a problem or in supplementary remarks about the reference to practice or the like. But since the integration of acoustic information is now technically realisable, it is possible - and in the sense of easing the visual channel even desirable - to offer such information as spoken texts. A typical example for this type of information in the programme "Computer Engineering" is made up by a historical look back at the development of calculators. In the style of a sound-slide-show, a detailed spoken description of the development is given together with several pictures of inventors and their historical machines.

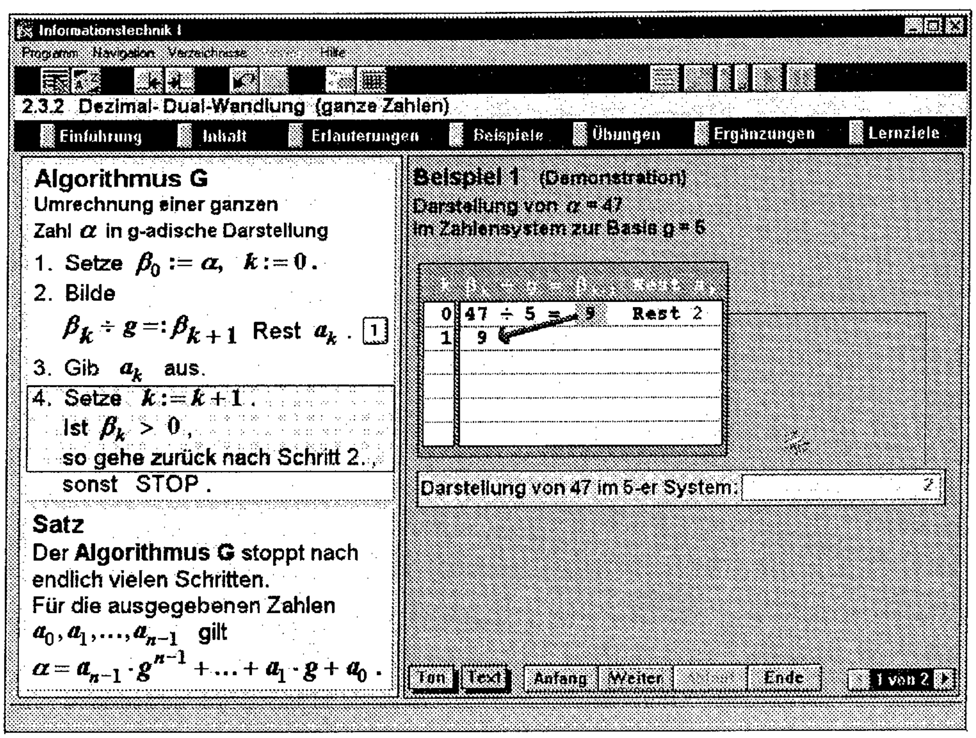

Fig. 2: Demonstration of an algorithm

The concept of the integrated information is in essential parts superior to conventional presentations in study texts, lectures or films. As there is no longer a limitation to the respectively small presentation facilities, it is now possible to present any content in its optimal form. As examples that are of special importance in the field of computer engineering the picture-sound-sequences are to be cited, well-known from educational films, i.e., sequences of diagrams, formulae etc. that are accompanied by sound commentaries. Thus, gradual developments and processes, like e.g., the construction of a complex diagram, the derivation of a mathematical formula or - especially in computer engineering - the demonstration of the operation mode of algorithms or circuits as shown in Figures 2 and 3, respectively, can be presented graphically by picture sequences, and - in contrast to written material - explained at the same time in an optimal way. Most importantly, and in contrast to educational films, the speed of the process can be determined by the user himself.

Of even greater importance as for the presentation of the subject are the aspects of new presentation and individual usage facilities in the field of the use of computer programs. With the help of simulated circuits and devices, now - conventionally only in the context of a special practical instruction - the gaining of practical experiences is possible. The passing on of the syllabus and the practical exercises can be interconnected in a way chosen by the student himself.

Completely new is also the approach to provide the student with an interactive environment of software tools. This surrounding offers the opportunity to deepen the understanding of the learned terms by means of trial and error. Thus, e.g., the working method of circuit networks, digital circuitry, finite automata, algorithms or complete computer architectures can be illustrated by animation, interaction, colour and sound accompaniment. A further feature of the software environment is the opportunity to adapt and expand the functionality of the tools in correspondence to the user's learning process.

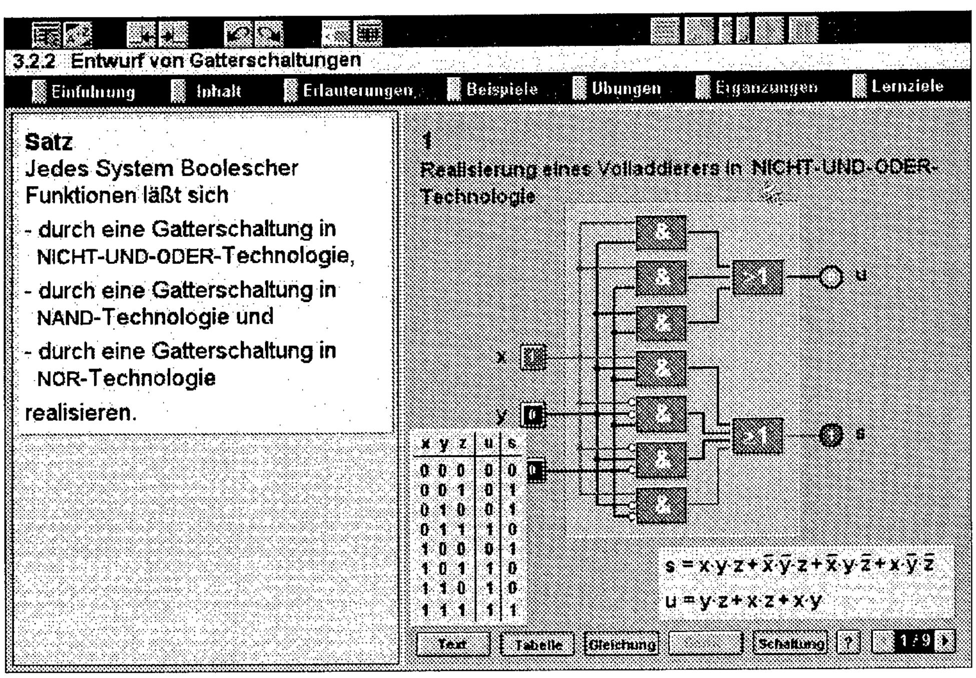

Fig. 3: Demonstration of a circuit

In addition to the advantages of the concepts of integrated information, that are to be found in representing and operating the single information elements, there is a further crucial advantage that is based on the overall structure of the teaching programme: a computer teaching programme is able to overcome the presentation that is ordered linearly and to be passed through sequentially, as it is given in books or study texts, lectures and films. With such a suitable structure, on the one hand the individual student can be provided with essentially better opportunities to go through the subject in a way that is in accordance with his individual background knowledge and learning experiences, on the other hand a large, even quite heterogeneous range of persons can be addressed.

The students that are addressed by the teaching programme "Computer Engineering" have the most different background knowledge and learning experiences. This is valid for the students of FernUniversität, among whom there are students with modest school knowledge, practitioners with the most different abilities, and university graduates of a related field, and it is even more valid, if a further range of students, e.g., at other universities or in the field of continuing education, is addressed.

The requirements for teaching material to be suitable for such a wide range of addressees and, at the same time, to be effectively manageable by the individual student are only very hard to meet by subjects presented in a linear fashion (book, lecture, video clips). This is due to the fact that clearly and stringently presented material can only be comprehended in an optimal way by learners with certain background knowledge and learning abilities. Material endowed with learning aids, however, is confusing and only ponderously manageable by the individual person.

A computer program, however, offers the chance to provide an amount of learning aids and, furthermore, to structure this offer in such a way that the learner effectively can make his choice that is in accordance with his individual needs. It is our approach to make a strict distinction between the contents to be passed on - e.g., the definitions, propositions, methods, algorithms or descriptions of devices or circuits - that are compulsory for everyone, and the didactic elements - introductions into a subject, motivations, explanations, examples, demonstrations, exercises, lists of teaching aims, provision of background knowledge from mathematics and electrical engineering - that are only offered optionally.

In the programme "Computer Engineering", the contents to be passed on are decomposed in small sections that are offered in linear order. To each of these content sections a set of didactic elements is allocated that can be chosen as required via a selection menu. Thus, e.g., a student repeating the course will mainly go through the content elements before an examination and only rarely take advantage of supplementary information, whereas a beginner in this subject possibly falls back on most of the aids. Thus, an offer arises that on the one hand copes with the diverse needs of learning support, and on the other hand is simply and clearly to handle and - especially with the help of the lists of teaching aims and self-test exercises offered in every section - enables an effective and object-oriented working on the syllabus.

Course Development

The project work consists of development activities that are directly followed by testing activities. The former can be subdivided into teaching (selection and restriction of material, definition of pre-conditions and expected performance, standards of grading, etc.) and presentation activities (didactics of the media, design of teaching media, technology of teaching and learning, etc.). As far as the testing activities are concerned, we distinguish between (further) teaching (organisation of the situation of teaching and learning, selection of parts to be tested, assessment of the evaluation results, etc.) and research activities (formulation of hypotheses and questions, selection of testing instruments, assessment of testing results, etc.).

The sequencing of development and testing phases characterises the project's schedule:

1. development of the pilot unit,
2. testing of the pilot unit,
3. development of the first half and important parts of the second half of the course package,
4. testing of the first half of the course package and further development of the second half of the four courses,
5. testing of the second half of the course package and adding testing results, and finally
6. adding of testing results and completion of the course package.

It is estimated that some 150 "person-months" are required for the complete development of the course package.

Course Assessment

Empirical pedagogics distinguishes between formative and summative evaluation. Whereas the latter investigates the prepared course, i.e., the developed product, the former focuses on the development process. As in the present project, formative evaluation is always selected when a new type of a teaching medium is to be developed. Therefore, testing phases are scheduled within the development period as formative evaluation. This will concentrate on structure, contents, and methodics of the course package. The main questions aim at clarity and consistency of the course structure, the optimum proportion of informative, activating, and testing contents, the optimal balance of sound, text, pictures, films, and simulations, as well as whether the teaching programme is reliable and easy to handle. Needless to say, formative evaluation is to detect and remove errors.

The schedule provides three phases of formative evaluation, with the first one serving for the better formulation of hypotheses and questions, whereas the second and third phases are totally aimed to gain more knowledge. The first phase will be carried out using the pilot unit with just a few students in class at FernUniversität. Owing to the objectives and the low number of participants, in this phase it is tried to obtain first results by observations and (group) discussions. It is not sensible to use interviews and questionnaires before the second and third evaluation phase, following the first one with a distinct delay. The evaluation sites will partly move to the students' homes, in order to meet the conditions of distance learning. It is envisaged to include up to 50 participants into these tests.

They will be questioned following a structured programme.

Distance Laboratory

Whereas the utilisation of new technology for the above mentioned purposes in distance education is straightforward, it is not so obvious to find under severe cost limitations new ways of allowing students to conduct - from their homes - laboratory projects with experimental work, indispensable for the understanding of technical subjects.

Therefore, up to now, two approaches are taken. One possibility is to arrange practica in laboratories on-site a university, that require the local presence of the students. In order to save time and travel costs, it is essential to schedule these practica close together and to minimise their number. The other approach is to carry out experiments at home. To this end, FernUniversität sends out experimentation kits such as microprocessor boards. Their disadvantage is that they have to be returned together with the results obtained. This method has many drawbacks such as limited kit size, damages during shipment, and high costs for inspection, repair, replacement, and handling.

The above considerations establish the need for a new approach to conduct technical experimentation under the conditions of distance teaching. The requirements to be fulfilled by a new system are reasonable costs, no need for travel, and provision of a generic environment allowing for great flexibility in experimentation.

A solution developed to meet this need is called Distance Laboratory. Since actually all students have access to a personal computer, which can be linked to the telephone network with a modem, it does not require any new investments on the students' side. For experimentation, the students work with particular programs on their computers. In the course of this, data are generated and transmitted via a network to FernUniversität, where they are loaded into automatically operated experimental rigs. Results are returned showing the students in appropriate ways how their experiments ran and providing feedback for improvements or corrections in case of errors.

In more detail, on their personal computers at home, with tools provided by FernUniversität the students develop control software for their experiments, which are first simulated. When this step is successfully completed, the control software is transmitted via the Internet using, for instance, the electronic mail service to a host at FernUniversität. The host shown in Figure 4 queues the requests, simulates the experimental runs once more for safety purposes and, then, down-loads each control program to a corresponding rig for carrying out an experiment. During the experimental run the host samples status data, which are processed and returned to the student to provide information on the outcome of the experiment.

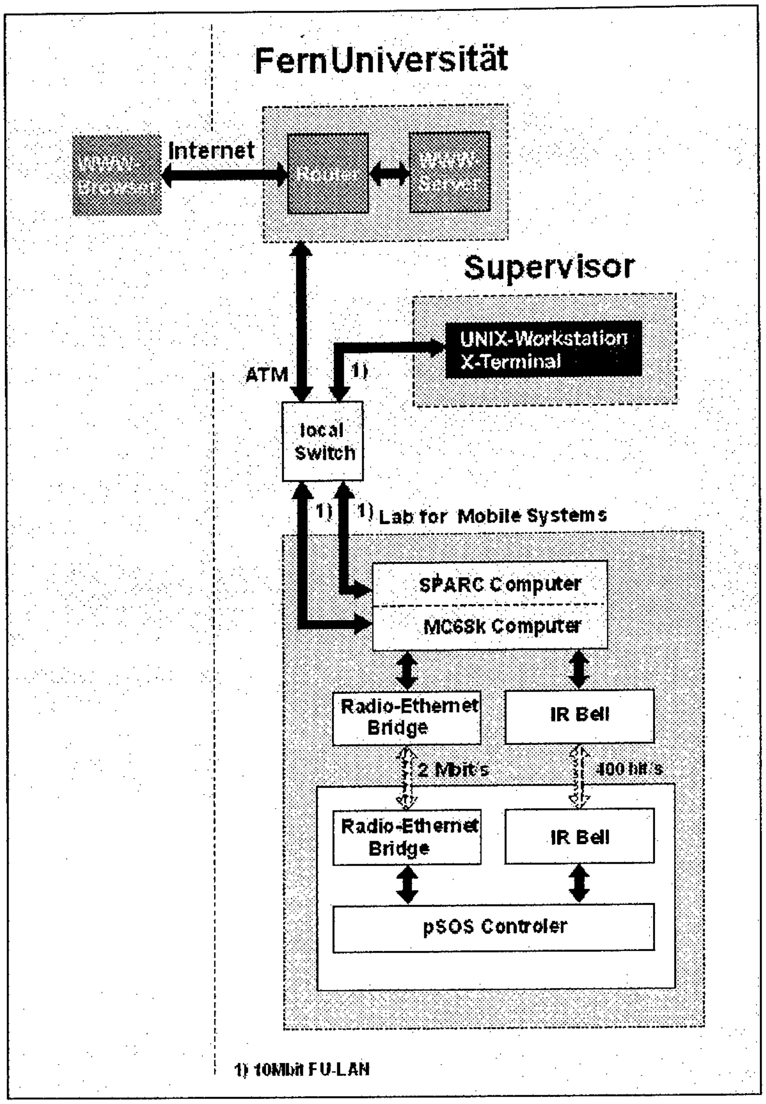

Fig. 4: Configuration of Distance Laboratory

An exercise on the design of digital circuits, for instance, can be carried out via a network in its entirety. It comprises the design of a digital circuit, its implementation using programmable logic, and also the test of configured, real hardware. There are further applications of this concept in robotics, programmable logic control, and distributed digital control.

Teaching Synthesis of Digital Systems. A Challenge for Multimedia Applications

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Abstract

Construction of electronic hardware is done by engineers which need a real good education during their studies. The approach we are describing below has proven a good means for performing this difficult task. The transfer of synthesis knowledge is a task which covers theoretical as well as practical aspects. This usually leads to courses which are split in two parts, the lecture part and the practical training part. The concept described here shows a way how to cope with this problem. In addition, the internet as information carrier opens quite new ways of interaction between the teacher and the course participant. The participant has access to all course materials and he can use the tools via the internet. The strong binding to a particular location, where the high end workstations and the commercial software are available is resolved, too. Finally, the availability on the net makes the system suited for teaching at the university as well as for training within a company.

Introduction

Teaching in areas where new technologies have a strong influence requires a steady update of the lecture contents. In addition, the tools used for the design of digital systems like processors become more and more complex and are changing continuously, which makes the update process for the course materials look like the fight of Don Quichote against the windmills. On the other hand, nobody is really able to spend all his time in the preparation of new lecture materials. This contradiction must be resolved if we want to keep pace with the technical evolution in education.

The way how we faced this challenge was to start a cooperation with the idea in mind to apply the well known concept of divide and conquer to the area of teaching synthesis of digital system. Here dividing means that each participant focuses on the area he knows best so that he does not have to cope with the complete area. Conquering means, that we share our contributions freely so that every participant can make use of all available information and tailor it to his own needs. The medium we have chosen for the implementation of the concept is the internet. The growing information pool is not printed and mailed, but it is made available as HTML[1] text which reduces the effort in maintaining the data enormously.

Finally, this approach offers new ways of cooperation between teacher and student. Previously the teacher used a set of slides and recommended one or more textbooks. Here the global availability gives much more freedom to the student to select material which

[1] HTML: Hyper Text Markup Language

may have been presented by the teacher or is part of the overall information pool. In addition, the new medium allows the integration of text, graphics, animations and real tools into one homogenous environment. In this paper we will first introduce the course structure to illustrate how we are teaching system design. In the second part we will show all the various means we are using, like www pages, animations, tool interfaces etc.

Courses on synthesis of digital systems

Digital system design today means that the behaviour of a system is described in a kind of programming language, describing the behaviour similar to a standard language, but introducting mechanisms for structured designs, too. Timing information, which usually is not part of a programming language becomes a key issue. During the synthesis process the abstract description is the mapped to real gates and cells which can finally be implemented in silicon.

Any course on digital system design has to cope with several aspects of teaching, each requiring different approaches. First, you have to teach basic technologies so that the students get an understanding about all the constraints which have to be kept in mind during the design process. Then the students need to know about the design process and design representations, beginning with simple logic gates and ending with behavioural descriptions. Topics like simulation, test and testability have to be covered, too. Finally, they have to be trained in the use of commercial design systems, because otherwise the procedure is like learning a programming language by writing code on a sheet of paper. Luckily parts of this highly complex program is taught in other courses, so we do not have to cover everything. Still, the amount of information to be transferred is very big. So the teacher has to select some parts of it and create a curriculum which fits into the overall course structure of the faculty as well as to his own ideas.

As an example we will outline the design course at Siegen University. It is called *Entwurf Integrierter Systeme* (E.I.S., pronounced ice = design of integrated systems). It covers two semesters. During the first semester the students learn about full custom design and semi custom design. The lecture part begins with all what is needed for the design of a simple cell, which is e.g. the function of a CMOS inverter, the influence of fan out and fan in and timing definitions. The model which is required for the simulation of such a cell is part of the lecture, too. Later on, the knowledge about the design of a digital logic is shortly refreshed. Test methods and approaches to design for testability are introduced. The lecture completes describing the functionality of a digital simulator, test pattern generation and fault simulation. In parallel, the students design a single cell using the Cadence system and simulate it with Hspice. Then a small standard cell design is made to practice this method and learn about the design problems an this level. Usually the students start a competition which group gets the fastest design. The teaching concept for this part is currently still conservative which means that we use conventional slides.

The second semester focuses on system level specification, using VHDL[2] as the basic hardware description language and the synthesis tools from Synopsys. The system we are describing in this paper covers the second semester of this course. The lecture part consists of teaching various system description methodologies. It starts with abstract approaches like Petri Nets and state charts. Emphasis is set on behaviour descriptions. The next step covers scheduling and allocation. The synthesis steps are explained and

[2] VHDL: Very high speed integrated circuits Hardware Description Language

FPGAs are introduced as an example technology which permits rapid prototyping and for the practical part a system can be implemented on the fly without the crucial waiting for silicon. We will not go into more detail here because courses at this level are well known. This part of the lecture is completely based on the new means we are describing below.

Web based teaching

As mentioned above, switching over to a web based environment introduces a lot of new possibilities which have not been available before. In the following we will show the various features used in the preparation of the course and their applications and implications.

The first idea when you start working with the web is to transfer your ***slides*** which you use for the lecture into HTML pages. The result is that you can your computer and an overhead display and just show the pages without producing transparencies using a standard web browser. It might give a good feeling but the information really needs not to reside on the machine you are using for the presentation. Further on, the amount of material available is usually much more than what you can present in one course. So you can select exactly that information which is relevant for you for your lecture, but still the students can if they wish, go through all available information.

The more interesting aspect is the fact that as soon as you make the web pages accessible to the students they have the opportunity to go through the pages in advance to prepare for the lecture and can trace back what has happend after the lecture. This is a real change in the style of teaching. Following the conventional approach the teacher is the owner of the slides and the students have to take a textbook for further reading. This strict flow of information does no longer exist if an linked structure with slides, explanatory text and tutorial parts is used. The resulting structure motivates to browse through the information and play around with the examples, thus making it much easier to learn than in a strictly ordered course. Playing is much more effective and by far more fun.

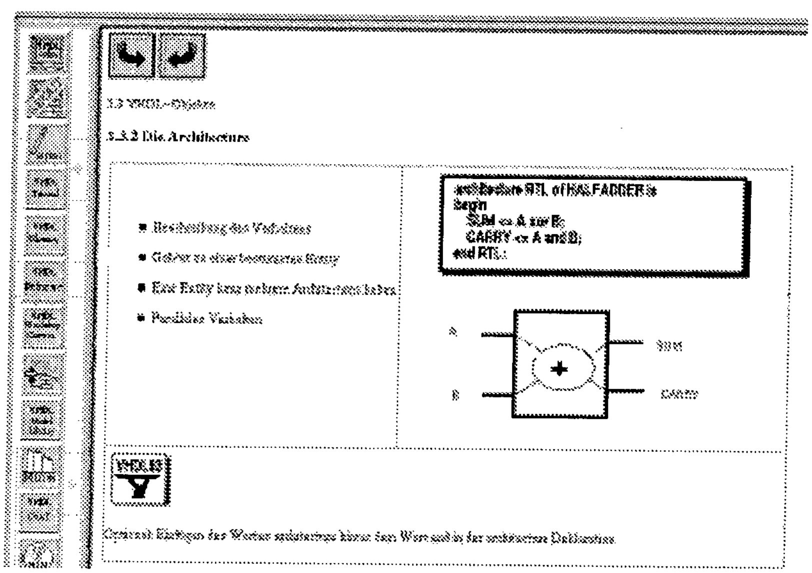

Figure 1: Example of a lecture transparency

After this initial step the contents can be expanded by **written text**. The series of sequential lecture transparencies can serve as a guide through the material, accompanied by text pages. These text pages must be associated to the transparency pages and switching between the two information types must be made easy. A structure supporting this approach is e.g. a ladder as illustrated in the next figure.

The entry point to the structure is the first lecture transparency. To make the access more convenient links from the directory to the begin of the chapters and subchapters is provided. These links are omitted in the sketch below. The text pages themselves lead to other problems which are of more technical kind: The size and the resolution of the screen. The size of a screen is usually less than a book page. To avoid that the user has to scroll up and down in addition to moving from page to page using buttons the text should be limited to the size of a screen, at least of a 17" monitor. A 21" Monitor is preferred, because the amount of text then gets similar to that what can be printed on a book page.

A book may be printed on a laser printer of 600 dpi or better, but the screen usually has only 72 dpi. This factor of (at least) 10 limits strictly the complexity of graphics. One way to work around this bottleneck is to put a thumbnail of the picture in the text and put the full screen drawing on a separate page. This methods allows to roughly figure out the contents of the drawing and, if something is not clear, to look into the detailed version of it.

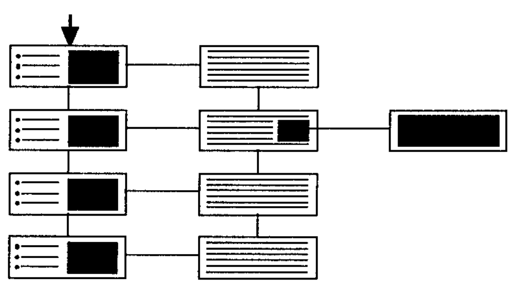

Figure 2: Ladder structure of transparencies and text pages

The next method which we are using are ***animations***. Usually you will think of comic strip figures which are animated, but we have a more technical view here. May be, in the future... In the technical domain there a many flows which have to be explained to the students. In all these cases the slide in the lecture can only show a snapshot of the flow, but never really the dynamic process itself. Usually you start with: At the initial stage ..., then: This step is shown here..., and finally: When the process is terminated, then, as you can imagine,...

This procedure requiring the imagination of the student can me really simplified. In the example shown below we have taken a Petri Net describing a simple baking process, where one worker produces the dough whereas the other one prepares the rolls and puts them in the oven. At the beginning both dishes are empty. Then we get the first dough and the second worker can start his job. To come to an end, the first worker has to stop reparing dough and, after all dough has been processed, the second one can finish work, too[3].

The animation is written as a Java applet so that every browser can display it. The flow is controlled by the two buttons `next` and `reset`. Whenever you click the next button, you go to the next state. The transitions do not follow directly the rules of the Petri Nets but require pressing the next button twice to get to the next state of the net. This was introduced to give ample time to look what is done in the next processing step. To be able to control the flow or to be more precise, to allow the two guys to go home in the evening the state of the branch points can be changed by clicking on the circles. The active state is indicated by a short thick line in the circle which shows the way the token will flow when it reaches the state next. Using this animation the teacher can illustrate the basic mechanism of a Petri Net much easier and the student can play with the animation when he is on his own machine and browsing through the lecture pages.

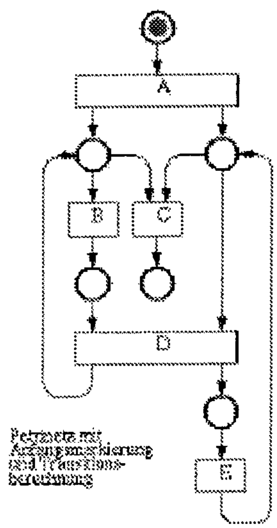

Figure 3: Petri Net animation

Speedchart Tutorial

As stated before, just a lecture is not enough to teach system synthesis. Working with the tools is absolutely necessary to get a feeling how synthesis is performed. So there is the need to introduce tools into the course. An appropriate tool for describing systems on a high level is Speedchart. This tool allows to work with state diagrams, state charts and state tables to describe a system. For those parts of a system for which one on these approaches are not appropriate VDHL or Verilog code can be included, too. For speedchart a tutorial has been prepared so that the students can work on their own after having received a short introduction. The following figure shows a bubble diagram entered using speedchart.

[3] Entnommen aus: Siegfried Wendt: Informationstechnik

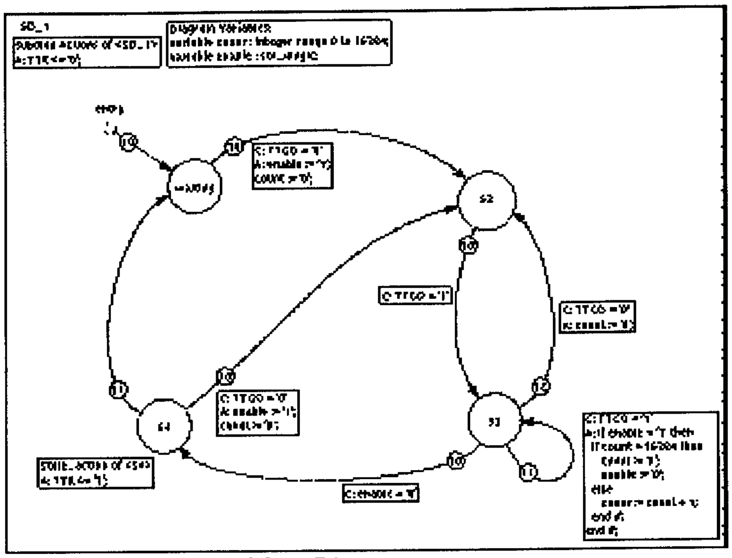

Figure 4: Typical speedchart Diagram

The **integration of tools** is always done in the same manner. All CAD tools used in this tutorial have an X-Windows GUI[4] and are running on SUN Workstation. All software is protected by licensing and can only run if the appropriate licence server is available. A direct interface usable by the web browser is not available. The way how we solved the problem is to use an X-Client on the local machine. The complete procedure for calling an external tool is:

0 • Log on with username and password. This is required because the commercial tools can be used for teaching but must of course not be made available to the public.
1 • Start your X-Client
2 • Get your IP-Address and set the display variable of the host machine running the CAD software to your IP-Address
3 • Activate the appropriate link. Doing this a cgi script is activated which provides the correct environment for the CAD tool before it starts the tool

After having performed this step he software can be used. The experience showed that if both machines are workstations the feeling is as if you were directly connected. Other X-Clients are significantly slower, even with a high speed connection. Using a slow modem turned out to be a little boring because of the communication overhead of the X protocol. Besides this it works nicely.

VHDL Online

The core part of the system is the VHDL Online module which comprises a whole set of elements: A VHDL tutorial, an annotated reference manual, a module for multiple choice tests, simple examples and a more extended example, the camera control unit.

---

[4] GUI: Graphical User Interface

The VHDL ***tutorial*** started as a conventional course. The materials developed for the course have been transferred into a sequence of HTML documents and form the basis for this part of the complete system. The amount of pages is still growing, because not only the language constructs have to be explained semantically but the examples are getting more and more and are improving in quality. When the student analyses the examples he will mention that the simulator produces error messages. This is intended, and after a correction according to the error message he will be able to analyse it.

To help the students when they are not sure how to use a construct a ***reference*** has been built up. In the reference the constructs are listed by category and each entry has an example associated to it describing the environment where it is used. The ***glossary*** contains additional information around VHDL and links to the appropriate keyword if necessary.

Finally, a ***workshop*** is provided in which the control of a camera is designed. Starting with the structure the modules are designed one by one. An example text is provided for all subtasks. Within that workshop all concepts of VHDL are used, structural as well as behavioural style descriptions. The students can work on this example really on their own. After having passed the workshop they know enough to work on a bigger VHDL model which is usually the core of the practical part of the course.

For the implementation of their big example the students can rely only on their own code, but within the project a ***library of synthesizable models*** is provided. Elements are carry look ahead adders, array dividers, fifos, a parity generator and various counters.

FPGA Online

Teaching all this theoretical contents including synthesis is good if only the principals shall be shown. For getting a better feeling a real technology has to be targeted at. In our case we have chosen Xilinx FPGAs[5]. There are several reasons for this:

0 • The FPGAs give a lot of limitations with respect of size and the number of pins. In this case it is a real advantage, because the examples which are small enough to fit into the course usually can easily be implemented in any other technology.

1 • FPGAs are really in industrial use for fast prototyping. So the constraints are not artifical but reflect the reality.

2 • The availability of FPGAs on a demo board permits to immediately check out in reality if the design is working or not. When a standard cell design is made the manufacturing cycle usually is so long that the students have finished their course month ago when the silicon is arriving.

3 • There are libraries and interfaces available to link the synthesis system and the Xilinx tools.

The FPGA Online consists of two parts, an introduction into FPGAs and an introduction to the Xilinx tools. The Tools are called in the same way as described above and the next figure shows how it looks like when you call the Xilinx tools for placement, routing and programming.

[5] FPGA: Field Programmable Gate Arrays

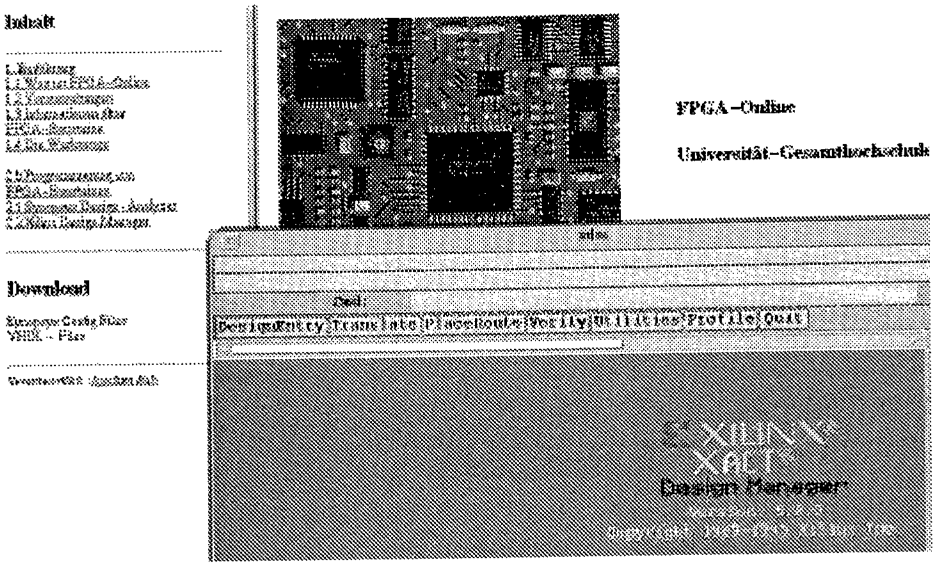

Figure 1: Example of a lecture transparency

Communication

With the internet advanced communication means come nearly for free. Within the course we are using two of them: the first one is the well known e-mail communication which allows to send information to the adviser and back without being online. This works fine but lacks the possibility of immediate response. So we have introduced a chat channel where the teachers are available at a certain time. This is not limited to one location. Having a common time for all locations where this system is in use gives the opportunity to talk to the most competent person among the instructors, thus increasing the quality of the course. The chat communication is implemented as a Java applet and thus can be used using any internet browser.

Conclusions

The system presented here has been proved workable by using it in lectures at the Universities of Bremen, Darmstadt, Erlangen, Frankfurt and Siegen. The general experience was very positive and everybody who worked with the system continue using it. In particular the ease of tailoring the system to the needs of a specific course is a big plus. The solid support of practical training for various tools helps to reduce the effort of maintaining the examples and offers a much wider variety as could be provided in a pure local version.

Nevertheless the system is by far not complete. First, there are still gaps which have to be filled. The bigger problem still is the maintenance, because there are tools missing which really support cooperative authoring and which help to maintain all the links between the various parts of the system. This is a point where many changes can be expected in the near future.

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Interface Design of a Multimedia Training Course for Electrical Engineers Including Evaluation Design

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Abstract

The discussion of the article's intention is followed by a brief summary of the status of distance learning at the FernUniversität Gesamthochschule at Hagen. Against this background the further explanations have to be seen. They want to demonstrate how a multimedia course for students of an engineering science can be developed using a systematical procedure. Regarding the various evaluation methods in detail, this article tries to emphasize the importance of this item, which has been neglected in so many other comparable projects so far.

Introduction

The systems approach is a well proved method for developing systems. Because of the fact, that the systems approach can be modeled on a high level of abstraction, it is generally useful for many disciplines. The working scope of designing educational systems does not make an exception (Issing, 1995). But the more you want to cut down wide fields of action (e.g. because of the desire of creating a single educational film or curriculum for a special subject), the more an abstractionally defined systems approach has to loose its heuristical power. Therefore it is necessary to elaborate the abstract model for the considered domain. This elaboration is as valuable as the abstract modeling of the systems approach for the wide working scope. For the task of developing a multimedia course for engineers a possible elaboration will be described in this article.

Status of Distance Learning

At the University of Hagen teaching has mainly been based on letters of studies, which are similar to books. Because electrical engineers have to get some practice, there are additionally to these so called "Studienbriefe", exercises, laboratories and seminars. Up to now, these events have taken place at Hagen. Thus we can summarize, that there is a combination of distance and presence learning at the university.Furthermore it is possible to study videos for special items (e.g. solar energy), which may partly replace excursions and practical demonstrations.To evaluate new or redesigned courses formative evaluation is realized by the so called "Lehrtextkritik", which means a questionnaire, that is not specific to a single course or discipline like engineering. The implementation of the so called "virtual university", that is internet and PC based, offers new possibilities in using multimedia aspects. Especially ET-Online, the part that has been created by the department of electrical engineering, has been working with several synchronous and asynchronous communication services. At the moment, students can discuss with the departments' collaborators by using for example electronic mail, newsgroups and chat. In addition to these kinds of online support, students partly can get the letters of studies in a multimedia version on a CD-ROM.

Theoretical approach for the design of a new multimedia course for engineers

The systems approach is a proved scientific method to structure the process of developing a system. A system consists of a number of elements interchanging information, energy and matter. The systems approach is often associated with the idea of a succession of single steps in a totally linear procedure. But in reality it is imperative to work with repetitions, branching and feedback. Otherwise one would not be able to achieve a solution in the sense of the systems' goals. The systems approach is used to be modeled by the basic model of the general system design (GSD-model).

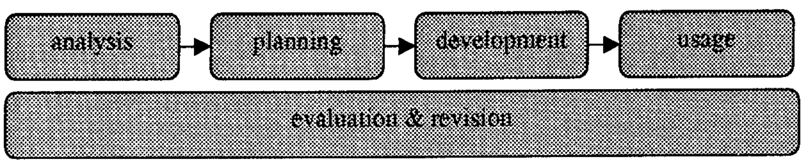

Figure 1: Basic model of the General System Design (GSD-model)

Because of the complexity of single phases like analysis, planning, development, usage and evaluation/revision it may be supposed, that the GSD-model can only be understood as a heuristical problem solving method.

The systems approach has been used for educational purposes since the end of the 50th. There have been hundreds of articles, which publish ways of putting the GSD-model into concrete terms. The result is an instructional design model (ISD-model). Gustaffson (Gustaffson, 1991) divided these ISD-models into

- ISD-models for developing systems of education
- ISD-models for lessons
- ISD-models for the development of products and media

by using the level of action criteria. Nevertheless the intention of the above mentioned groups of ISD-models is quite different, they all concur more or less in the basic steps analysis, planning, development, usage, and evaluation/revision.

Directed by a certain ISD-model, the system designers' task is to derive an appropriate instruction design. For multimedia courses, the last two groups of ISD-models are the most important ones.

Elaboration of the GSD-model for designing a new multimedia course for engineers

It was mentioned, that teaching is partly based on written letters of studies, which are dispatched each term. A few years ago some departments started to work out multimedia versions of their courses. In this paragraph we want to discuss the reflections, that are necessary for deriving an ISD-model for developing such a multimedia course for engineers. For this purpose we subdivide the phases of the GSD-model.

The exceptional position of evaluation

The term evaluation is defined in a lot of different ways, because evaluation can be connected with many totally different domains. In the context of multimedia courses, evaluation means first of all regarding the efficiency of the developing process. Additionally it deals with the criteria acceptance and effectiveness of multimedia courses. But independent of the chosen focus, evaluation is always more than only collecting data.

Will, Winteler and Knapp (Will, 1986) take this into consideration, when they talk about the four main aspects of evaluation:

- Evaluation has got a purpose or an aim.
- Evaluation is based upon a systematically captured data base.
- Evaluation always includes kind of a judgement that is result of using statistical methods on the data.
- Evaluation is not interested in the performance of a single subject (e.g. a student), but it means aggregation to judge about a special item like a multimedia course.

Regarding these four main aspects we can differentiate several kinds of evaluation. The most important and best known ones are:

- Formative Evaluation

  In an early stage of the developing process mistakes and deficiencies can be remedied with less expense. Therefore it is advisable to involve members of the user group in the developing process. The observing and interrogating of these persons helps to optimize the product or service. The risk of a total failure is minimized (Issing, 1995). Alternative to formative evaluation one can use the method of rapid prototyping, too (Tripp, 1990). The method implements system functions only (most of the time software functions) in a way, that is sufficient to optimize the interface between user and system. It is not necessary to implement the total functionality (Kraiss, 1986).

- Summative Evaluation

  This kind of evaluation is focused on the completed product or service. It is always placed at the end of the developing process. If we remind the GSD-model, we are talking about the phase of usage. In comparison with formative evaluation this one is quite more expensive and has a higher expenditure of time.

The numerous kinds of evaluation are listed in the article of Götz (Götz, 1993). At this point we can summarize, that evaluation is not only a necessity in a single phase (summative evaluation in the usage phase), but it should accompany the whole developing process, modeled by the GSD-model.

Analysis

Learning material always pursues an object. These aims are exposed by answering the question, what should be changed in the students' way of thinking, their knowledge, their skills and their mental attitudes by working with the multimedia course. Without precise definition of these teaching goals, you are not be able to find out, whether they have been attained or not.

Such a specification is not possible without having a closer look at the students' attributes. It is impossible to define any aim, especially an educational one, without reflecting their status momentarily. First of all, it is quite important to elaborate the decisive signs. Then you should be informed relative to what sign the group of students is homogeneous or heterogeneous.

For example, electrical engineers as well as students of computer science are more familiar with computers than other groups, because it is part of their courses and normally they have already some experiences before they start studying such disciplines. This effect can be used with some benefit for the introduction of a multimedia course. Furthermore it is obvious, that the goals for high motivated students, who have already got specialized knowledge, have to be different from those for students forced to participate because of the curriculum.

Additionally, the usage of multimedia technologies depends on the students' technical equipment. For example, it does not make much sense to produce expensive videos, if a high percentage of students' PCs do not allow to play them, does it? But nevertheless, it is recommended to estimate future evolutions.

In consequence, a personal data base should deliver information about demographical, socio-economical, psychographical items as well as about technical equipment. To capture these data it is common to interview the students. You have to weigh the selected number of attributes (which of course correspond with the size of your questionnaire) against the quality of your data.

At the institute of automation (LG AT) we are working with a self-designed questionnaire.

Compared with the above mentioned "Lehrtextkritik", this questionnaire is specifically designed for electrical engineers and for those, who are interested in automation technology. An extract is shown below:

- Why do you participate in this course?
  O I have to proof a certificate.
  O I have got a general interest in the subject.
  O I have to qualify myself for my job.
  O I will start a new job dealing with this subject.
  O ...

- How would you describe your specialized knowledge at the moment?
  Excellent O O O O O O Bad

- Do you cooperate with your fellow students?
  O Yes
  O No

- What kind of technical aids do you use for cooperation with your fellow students?
  O Telephone
  O Fax
  O Email
  O ....

- What do you prefer working with your fellow students?
  O Discussing the content of the letter of studies.
  O Doing exercises
  O Preparing myself for the exame
  O ....
- Would you like to get any support using the following services?
  O Email
  O FTP
  O Telnet
  O Chat
  O WWW
  O ...

Having a closer look at these examples out of our questionnaire, you can realize, that the measuring level can be quite different. That means, you have to be very careful using statistical methods. You can dismiss the result of a statistical approach, if the statistical method does not suit the measuring level.

So far, we have only discussed appropriate ways of analyzing the students' attributes. But for the phase of analysis of the GSD-model some additional work has to be done. Developing a multimedia course for electrical engineers, it is very helpful to have a closer look at the special requests of the occupational life of electrical engineers. This part of analysis we based on a working sheet, like the one you can see in figure 2.

Requirements of occupational life	**Discipline**			
	Natural science	Engineering	Economics	...
Ability to get familiar with new domains	...	*1*	...	...
Ability to abstract	...	...	...	...
Ability to communicate	...	*2*	...	...
3-D imagination	...	...	...	...
....	...	...	...	...
legend: 1 ≡ very important 2 ≡ important 3 ≡ ...				

Figure 2: Working sheet to elaborate the importance of special requests

It has to be said , that the working sheet in figure 2 is a general one, because it offers to regard other subjects than engineering as well.

In this paragraph it is shown that for a multimedia course teaching goals shall be defined against the background of reflections to students' attributes, technical equipment and special requests of the occupational live.

Planning

The phase of planning from the GSD-model focuses on achievement of the defined goals. In this context we can list four important factors (Minnesota Research Center, 1990):

- Fidelity
  Means presenting contents in a realistic and problem driven way
- Visualization
  Means presenting contents close to the students' world
- Range and depth of experience
  Means presenting contents out of different points of view.
- Mediation
  Means emphasizing essential contents

The mentioned factors' character show, that you have to consider thoroughly the courses' contents. This consideration has to define the relevant parts of the courses contents, which are to be trickily connected with didactic elements in the factors' sense. But this is a quite difficult task, because there is a great variety of these elements using multimedia (e.g. in addition to common didactic elements you have got videos, simulation, sound and so on) and there exists no detailed prescription how to do this.

Therefore, first of all we think about appropriate measures, that will qualify the students to meet the requirements. Here, we use another worksheet, shown in figure 3.

Working life requirements	**Qualification measures**			
	Natural science	Engineering	Economics	...
Ability to familiar with new domains	...	...	...	...
Ability to abstract	...	**Exercises for training model-ling**	...	...
Ability to communicate	...	...	...	...
3-D imagination	...	...	...	...
....	...	...	...	...

Figure 3: Working sheet to elaborate qualification measures

Then in a second step, we combine these founded qualification measures with the didactic elements of multimedia.

To illustrate the above mentioned, furthermore will be pointed out a global teaching goal called "Fachkompetenz". If students are able to use their work equipment properly and can control working processes based on their specialized knowledge, they will reach this goal.

An elaboration of this goal naming suitable indicators is given remembering the contents of the working sheet in figure 2. Regarding the there mentioned indicator "Ability to abstract", one appropriate qualification measure would be a couple of exercises, which train modeling (figure 3).

Which kind of didactic element trains students in modeling? A possible answer to this question is the integration of simulation environments in a multimedia course for engineers.

A simulation is a special form of an interactive program. It is based on

- a model of the viewed system and
- a number of equations that determine the dynamic features of the system.

There are several ways to elaborate the simulation environment, starting with displaying only a static model and the equations, up to graphical displaying of the dynamic behavior including a modification of the parameters by the students (remember the factors "Fidelity" and "Visualization"). Because of the fact, that the cognitive requirements of such environments can be very high it is recommended to think about a certain degree of instructional support.

Depending on the specific elaboration the students will have more or less opportunities for an active integration of the theoretical contents in their so far existing mental models. When we follow the didactic theory of constructivism, theoretical contents have to be experienced and can not only be put over to the students' minds.

Finally, you can see an example of a simulation environment in figure 4.

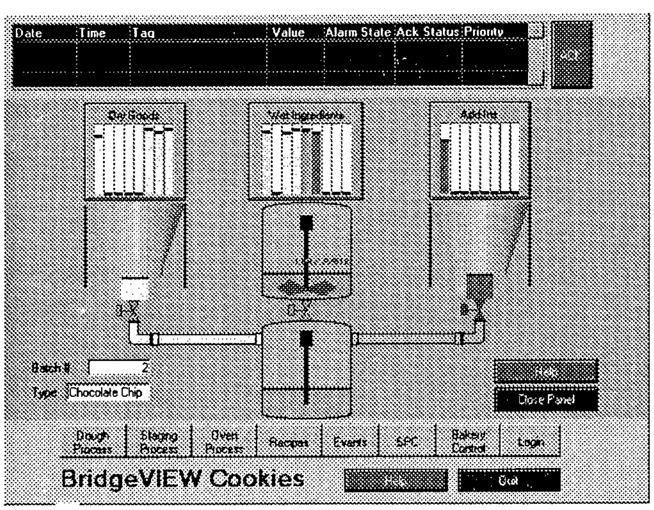

Figure 4: Simulation environment for the new multimedia course

Human-machine interaction is an important part of automation technology today. Therefore it is necessary to learn, how human-machine interfaces are designed and integrated in the automation system. Using a well known HMI-tool, the student has to design a HMI for a specific example. The shown panel consists of the typical elements, e.g. function keys (bottom) to switch from one panel to another, a scheme of the plant (background , which has to be designed in a graphic editor), and the dynamic values shown as bar graphs (wet ingredients), and the status of a mixer (indicated by color) as well as alarms (upper part) and acknowledgement. Additionally, the produced batch "Chocolate Chip" is shown.

We will integrate such an simulation environment into our new multimedia course for electrical engineers.

Development

In the developing phase of the GSD-model, the systems approach gets into a more operative character. The teaching goals (analysis phase) combined with the theoretical reflections how to achieve them (planning phase) have to be integrated in a concrete instruction design. Considering the intention of working out a multimedia course this means to determine the look of the user interface.

For this purpose we will use the method of rapid prototyping which was already mentioned in the paragraph about evaluation work. We decided to use the tool MS-Powerpoint©, which allows not only to create panels but also to simulate the dialogue between the user and the system. Unfortunately, there are again only heuristic hinds of disciplines like software-ergonomics (e.g. DIN 66234) and psychology, so that an iterative design process is unavoidable; which means having repetitions, branching and feedback.

A part of the new interface design out of an early step of iteration is displayed in figure 5.

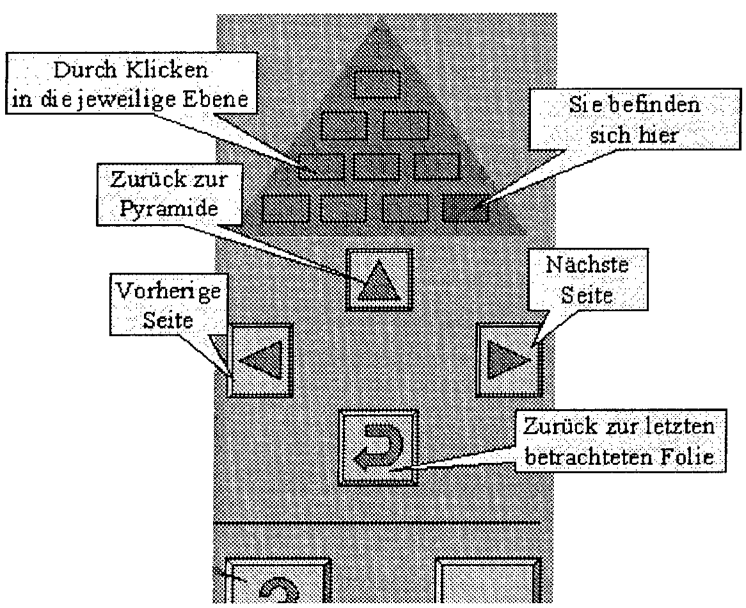

Figure 5: User -system interface (early step of iteration)

Each version of the user interface will be formative evaluated using the following methods of test:

- Inspection by a team of experts
  A team consisting of didactic experts, screen designer and subject experts evaluate the user interface considering transparency and consistency. Additionally it is important to know whether it is self-explaining.

- Observing the behavior of students' representatives
  Only students' representatives can give a feedback about the acceptance of the user interface. Therefore student co-workers of the institute of automation will participate in small test designs where they will have to solve small problems. During the test their navigation activities will be recorded. Finally in an open interview they can give impressions, criticism and recommendations.

The so optimized instruction design will be written down in a scenario. This scenario is thought to be handed over to the producer of the new multimedia course. Therefore it has to specify the following aspects in detail:

- Structure of dialogue
  The structure of dialogue can be reported by determining a network of navigation possibilities between the user interface elements.

- User interface
  Each panel of the user interface has to be described including the use of buttons, frames, pull downs and so on

- Media production
  Listing of the desired production of videos, photos, sound, computer graphics and simulations

At this point we do not conceal, that the production of these media has a strong influence on the expenses for a multimedia course on a high degree. On the other hand, even media like video sequences and simulation support the integration into the students' mental models (Kozma, 1991).

In additon to our example simulation environment think of a video sequence showing plant facilities, including the integration of elements like PLC (Programmable Logic Controller), actuators and sensors.

Usage including summative evaluation

After finishing the new multimedia course for electrical engineers it will be provided at the beginning of the half year term WS 98/99. At the end of the term the students will be requested to answer a questionnaire. We think, that it will be better to start evaluation work at a time, students will have got familiar with the new course. Otherwise the evaluation data are influenced on a high degree on emotional or start-up aspects. This questionnaire will deal with the following domains:

- Expectations of the students

  What do you expect from a multimedia course?

- Acceptance of the course

  Regarding your expectations, how do you judge this multimedia course?

- Success

  Did you think it is more efficient to work with this new multimedia course compared with the paper course?

When we decided to work with a questionnaire including open questions we kept in mind, what Schulmeister says about this method of evaluation. He thinks, that it is very critical to base an evaluation mainly on students' statements because of their insufficient to express themselves (Schulmeister, 1995). But with a questionnaire, combining both kinds of questions and the possibility to inquiry, we are convinced to get a usable data base.

Conclusions

This article demonstrates the advantages of the general systems approach, modeled by the GSD-model, developing a new multimedia course for electrical engineers. Following the phases of analysis, planning, development, usage and evaluation/revision we developed an instructional design system model (ISD-model). Our ISD-model fits very well in the context of developing multimedia courses for electrical engineers. Partly we pointed out, how to use this ISD-model by the aid of working sheets. The further elaboration of the phases by specifying tasks and working sheets will be part of our future work. Finally we do not want to conceal, that our ISD-model can not be more than a heuristic aid, although we will put it in concrete terms on a high degree. Following Issing, who talks about the science of learning and the art of teaching (Issing, 1995) we are convinced, that the instruction design developing process cannot be totally automated.

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Fixation Disparity under Vergence Load: Clinical Optometric Procedures and Ergonomic Applications

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Abstract

Binocular vision requires that the vergence angle φ between the visual axes of the two eyes (Figure 1a) is adjusted by the extraocular muscles in order to fuse the two retinal images. Even when fixating a target binocularly, errors in vergence angle (referred to as fixation disparity) may occur in individuals and can be associated with visual strain. We extended clinical optometric procedures by measuring fixation disparity with dichoptically presented nonius lines at viewing distances of 20 to 100 cm, so that both vergence and accommodation were stimulated adequately as in normal vision at the workplace. As the viewing distance was shortened, mean fixation disparity in 34 subjects changed monotonically from 1 minute of arc eso (i.e., the eyes converged in front of the target) to - 3 min arc exo (i.e. convergence behind the target). Fixation disparity was also measured at a constant viewing distance of 40 cm, while varying the power of prisms in front of the eyes to change the vergence angle. Fixation disparity was more strongerly affected by prisms than by viewing distances that induced the same vergence angles (which can be explained by accommodative vergence), however the slopes of these two types of fixation disparity curves were correlated.

The change of fixation disparity with distance differed reliably among subjects with normal binocular vision. Those subjects with a large exo disparity at near fixation adopted longer viewing distances in the course of a laboratory near-vision task. These results suggest that near vision problems can be caused by a fixation disparity at near distances; in such cases, visual displays should be used at longer viewing distances.

Introduction

Observing visual displays at man-machine interfaces is in no way a process of passive intake of information. Rather, the eye muscles continuously have to adjust the eyes so that the point of regard is projected onto the fovea of each eye, i.e. the center region of the retina with the best spatial resolution. The present paper deals with the vergence function of the eyes: the horizontal external eye muscles have to turn the visual axes relative to each other, depending on the actual viewing distance (Figure 1a). If we look at infinity our visual axes are parallel. The resting position of vergence varies among individuals with an average of about 3.5 deg, corresponding to a distance of 1 m. The closer the target the stronger the force that the extraocular muscles have to exert in order to turn the eyeballs towards each other. If you move this piece of text continuously closer to your eyes, you immediately feel the increasing effort that is needed until, at a certain point, double vision occurs, thus the ocular muscles are no longer able to superimpose the images of the two eyes.

The aim of the present study was to measure the effect of viewing distance on the vergence function of the two eyes and to investigate implications for the choice of a comfortable viewing distance for working at visual displays.

- In a first experiment, it was shown that the viewing distance has an effect on how precisely the external eye muscles are able to converge the two visual axes to the actual fixation point. This error in vergence angle (i.e. fixation disparity) as a function of viewing distance is compared with similar measurements as a function of prisms in front of the eyes, as used in conventional optometric test procedures.
- A second experiment investigated whether fixation disparity as a function of viewing distance can predict the viewing distance that subjects find comfortable during a laboratory near-vision task.

Fixation disparity as a function of viewing distance and prism load

As described before and illustrated in Figure 1a, the viewing distance d and the resulting vergence angle φ determine the load (or stress) on the vergence eye muscles, in a similar way to, e.g. a weight lifted by the arms in the case of skeletal muscles. However, in clinical optometry (e.g. Sheedy and Saladin, 1993), a different concept of testing vergence under load is used which is illustrated in Figure 1b. Instead of changing the viewing distance, one uses a fixed viewing distance d_0 and varies the power and orientation of prisms that are placed in front of the eyes. A comparison of Figure 1 a and b shows that the same vergence angle φ_1 is adjusted by the eyes by either having a short viewing distance d_1 or by having an intermediate viewing distance d_0, but with an appropriate prism in front of the eyes which - in case of the prism bases oriented outward, i.e. "base-out" - turn the visual axes inward and increase the vergence angle from φ_0 to φ_1. Reversed prisms ("base-in") induce a smaller vergence angle.

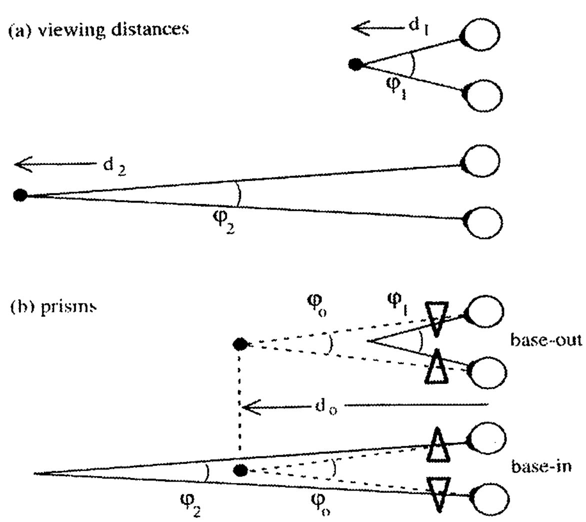

Figure 1: Vergence angles induced by viewing distances (a) and prisms in front of the eyes (b).

This prism technique of testing the vergence system under load is known in optometry as "forced vergence" (e.g., Sheedy and Saladin, 1983). A possible drawback of this procedure is that the viewing distance is kept constant, thus the stimulus for accommodation (the focus mechanism of the eye) is also constant. This differs from the natural way of seeing where a change in vergence always coincides with a change in accommodation. Therefore, it was the aim of the first experiment to compare how the vergence system responds when the load is varied by changing the viewing distance (as shown in Figure 1a), or by changing the prism power (and orientation) at a constant viewing distance (as in Figure 1b). Table 1 describes the viewing distances and prisms that where chosen to have the same vergence angles in the two experimental conditions (for a subject with an interpupillary distance of 60 mm).

Viewing distance D	Vergence angle φ	Prism power at 40 cm
20 cm	17.1 deg	15 prism dioptre (base-out)
30 cm	11.4 deg	5 prism dioptre (base-out)
40 cm	8.6 deg	0
60 cm	5.7 deg	- 5 prism dioptre (base-in)
100 cm	3.4 deg	- 9 prism dioptre (base-in)

Table 1: Viewing distances and corresponding prism powers used in the experiment.

The dependent variable that was measured to describe the vergence function at different viewing distances and prism powers was the fixation disparity, i.e. the error in vergence angle that may occur when a fusion stimulus is fixated. Only in subjects with optimal binocular vision is the fixated target imaged onto the center of the fovea in each eye, so that the principle visual directions of both eyes intersect at the fixation point (Figure 2, left). Many subjects with normal binocular vision (indicated by good stereoscopic acuity) may have slight deviations from this optimal state. These small errors in vergence typically amount to a few minutes of arc; they are smaller than the Panum areas and, therefore, do not lead to double vision. Fixation disparity is called "eso" or "exo" depending on whether the eyes converge slightly in front of or behind the fixation point, respectively, as illustrated in Figure 2. Subjects with large fixation disparities tend to have more eyestrain and asthenopic complaints, but this need not be true in all individuals (Sheedy and Saladin, 1983; Pickwell, 1989).

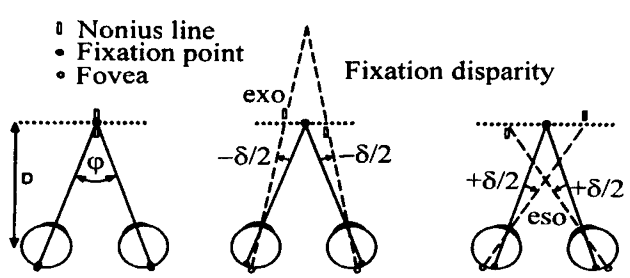

Figure 2: Possible conditions of fixation disparity δ; exo is defined as negative (see text).

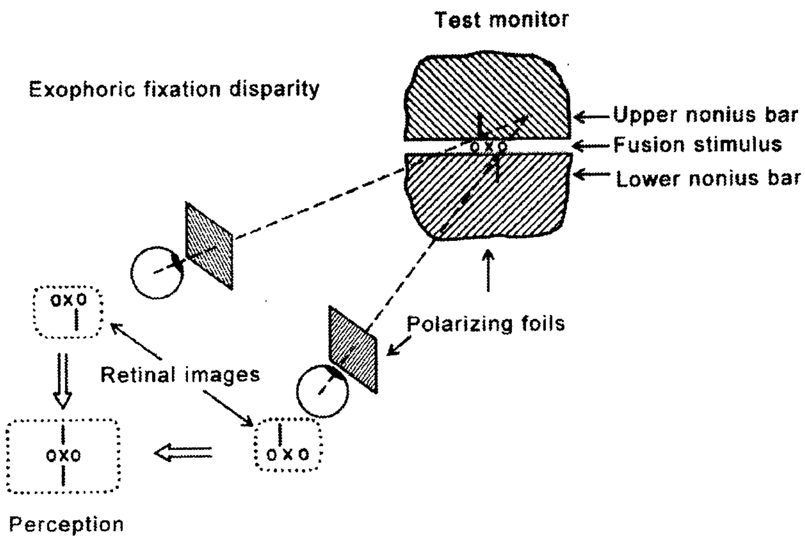

Figure 3: Method for measuring fixation disparity [from Bonacker et al. (1994)].

As shown in Figures 2 and 3 we measure fixation disparity psychophysically by presenting both the fusion stimulus (OXO, visible for both eyes) and two dichoptic nonius lines (made visible separately one to each eye by means of polarizing filters) on a monochrome cathode ray tube of a personal computer (Bonacker et al., 1994). If a fixation disparity is present the nonius lines must have a physically horizontal offset in order to coincide with the principle visual directions, to be imaged onto the center of the fovea and to be perceived in line. This physical offset between the nonius lines is determined with an adaptive psychometric procedure by presenting the nonius lines in a series of short tests of 100 ms duration, varying the amount of horizontal offset and having the subjects say whether the upper line is perceived to the right or to the left of the lower line.

Measurements in a group of 34 young adult subjects with good monocular and binocular vision revealed the following results (Jaschinski, 1997). As the viewing distance was shortened from 100 to 20 cm, mean fixation disparity changed from 1 min arc eso to - 3 min arc exo. Figure 4 shows three individual examples of fixation disparity curves describing the extent of change in fixation disparity with vergence angle, approximated by regression lines separately for the distance and the prism condition. Both the prism curve and the distance curve were rather flat in Subject JK and much steeper in Subject KM; Subject MU is an intermediate case. The slope of the prism curves and the distance curves were correlated across subjects ($r=0.39$; $p=0.024$; $n=25$). However, the prism curves were significantly steeper than the distance curves ($t=6.63$; $p<0.001$). Thus, using base-in and base-out prisms induced larger amounts of eso and exo fixation disparity, respectively, than when the same vergence angles were induced by viewing distances. This can be explained by the different way of stimulating accommodation.

Repeated measurements in the same subjects showed that the slope of the distance-dependent fixation disparity curves differed reliably among individuals, as shown by a significant test-retest correlation of r = 0.65 ($p < 0.0001$; n = 34). Thus, some subjects (e.g. JK in Figure 4) had a small fixation disparity irrespective of viewing distance, while others showed a marked shift of fixation disparity in the exo direction, if the viewing distance was shortened (e.g. KM).

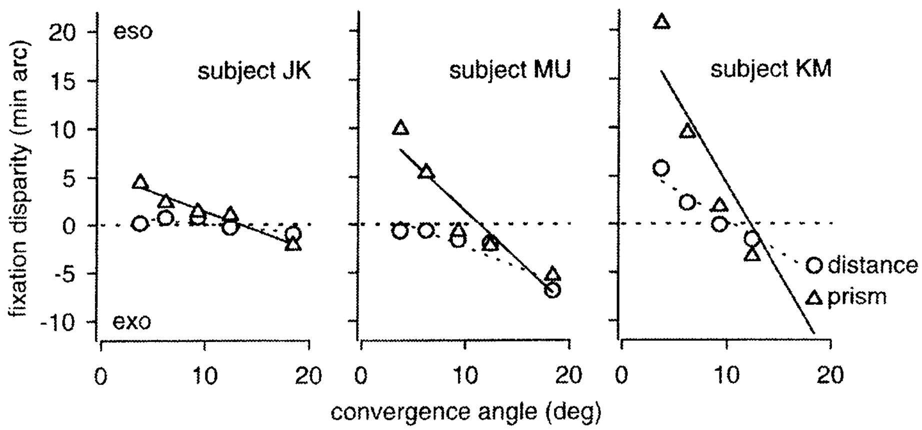

Figure 4: Three individual cases of fixation disparity as a function of vergence angle (Circels: varying viewing distance; triangles: varying prism power).

The prism curves in Figure 4 represent examples of what is termed in optometry "forced-vergence fixation disparity curves". From clinical experience and research (e.g. Sheedy and Saladin, 1983) it is known that those subjects with steeper and more a symmetrical prism-dependent fixation disparity curves are more likely to suffer from eyestrain during visual work. Since the slopes of the prism curves and the distance curves were correlated, the following experiment was designed to investigate possible ergonomic implications of the distance-dependent fixations disparity on working at a near visual display unit (Jaschinski, in press).

Fixation disparity and the preferred viewing distance in a near-vision task

We measured fixation disparity at viewing distances of 30, 40, and 60 cm in a group of 33 young adult subjects with normal vision. The group was divided in 3 subgroups depending on the extent to which fixation disparity changed with viewing distance. In the 11 subjects of Subgroup A (closed symbols in Figure 5a) the exo change was more than 3 min arc when the viewing distance was shortened from 60 to 30 cm; in the 11 subjects of Subgroup B this change was less than 1.1 min arc (open symbols in Figure 5b). The remaining 11 subjects had intermediate values. We had the subjects perform a task of 60 minutes duration at a visual display unit and let them start with an initial viewing distance of about 40 cm (which is appropriate to the chosen character height of 2.4 mm). But during the course of the task subjects were free to adopt any comfortable viewing distance, which was measured continuously with a video system. Figure 5c shows mean values of viewing distance for each 5-minutes interval. Most of the subjects in Subgroup A (those who had a larger exo fixation disparity at shorter viewing distances) moved further away from the screen and adopted longer viewing distances compared to the subjects of Subgroup B, whose fixation disparity remained smaller when changing the viewing distance. An analysis of variance with repeated measures revealed that the time course of viewing distance was significantly different in the two subgroups; $F(11,220) = 2.94$; $p = 0.027$ with Greenhouse-Geisser correction. The tendency of the subjects in Subgroup A to adopt longer viewing distances is interpreted as a way to avoid larger fixation disparities. Most users with large exo fixation disparity at near did not accept a short viewing distances.

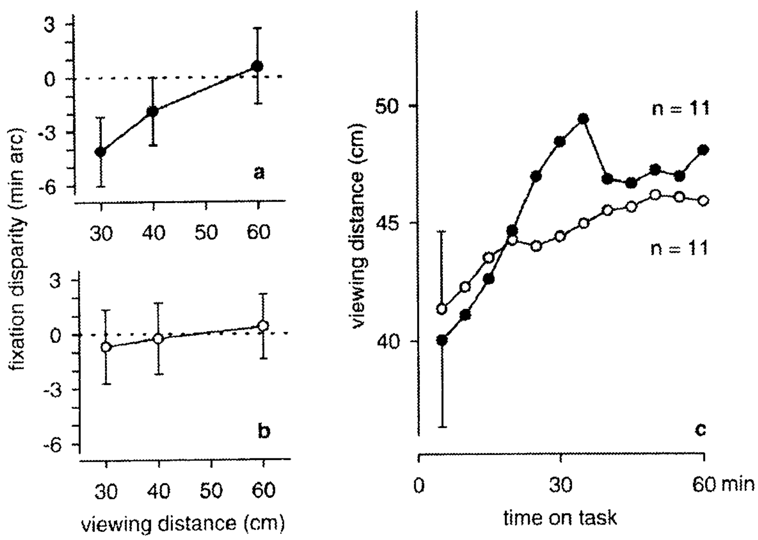

Figure 5: Fixation disparity as a function of viewing distance in two subgroups (a and b) and time course of viewing distance during a near-vision task in these groups (c).

Conclusions

Inappropriate stress on the vergence system of the eyes must be avoided, in order to reduce visual discomfort and fatigue in demanding visual tasks at human-machine interfaces. While clinical optometric methods test the vergence system under load by measuring the fixation disparity as a function of prisms in front of the eyes and keeping the viewing distance constant, the present research introduces the measurement of fixation disparity as a function of viewing distance which is directly related to the vergence angle.

The rate of change in fixation disparity with vergence angle was analysed by calculating the slope of fixation disparity as a function of prism power and viewing distance. Both types of slopes were moderately correlated; however, the slopes were smaller in the distance condition as compared to the prism condition, which can be explained by the mechanism of accommodative vergence. Measuring fixation disparity as a function of viewing distance has the advantage of preserving the natural interaction between accommodation and vergence, and thus better reflects the viewing conditions in everyday vision and at the workplace. The procedure of testing the vergence system as a function of prism load at a constant viewing distance resembles the condition at stereoscopic displays where vergence is changed by varying the disparity of stimuli presented separately to the two eyes at a constant viewing distance. Thus, the resulting fixation disparity may be comparable in these two conditions (Duwaer, 1983).

It was found that subjects with normal binocular vision differ reliably in the rate of change in fixation disparity with viewing distance, i.e. the slope of the distance-dependent fixation disparity curves. In a laboratory near-vision task, subjects with steeper slopes, thus larger exo fixation disparity at near tended to increase the viewing distance during a near vision task more than other subjects with smaller slopes. This is interpreted as a strategy to avoid a condition that causes a large fixation disparity.

This results can be compared with research on the resting position of vergence, usually called dark vergence since it is measured in darkness in order to exclude any fusional and accommodative stimulus. Heuer et al. (1989) reported that those subjects who had a more distant dark vergence adopted longer viewing distances while working at a visual display, presumably in order to reduce the discrepancy between the viewing distance and their distant dark vergence. Subjects with a distant dark vergence typically have a larger exo fixation disparity in near-vision (Jaschinski-Kruza, 1994).

Thus, the exo fixation disparity induced by near visual targets and dark vergence are idiosyncratic optometric properties that may have implications for the ergonomic design of workstations with near visual displays. Individual differences in the vergence system could be considered when adapting the workstation design to the individual user.

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A new strategy for incorporating health and safety relevant factors into planning

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Abstract

Simulation studies are successfully used as assisting tools in the field of operation scheduling and work planning. Work plans generally supply the most important input data for simulation studies in this field. They determine the combination of the technical components of a work system and the order of manufacturing steps towards a product. Simulation studies support the labor organization of a work system from the view of high effectiveness and economic efficiency in a given time period. Missing information about strains and risks a person, which is the worker, might be exposed to leads to a loss of quality of the used models. Health risks can jeopardize the economy of production systems, too, if the person is considered as a subsystem.

On the one hand, the simulation of operations in production and logistics requires human related input data. On the other hand, the danger exists that the demand for even more input data causes an increase in time and energy for the creation of simulation models. This paper presents a model for the integration of manpower-related information into production planning. The paper deals with the question to what extent expanded planning data can reduce the time and energy for collecting data and how simulation models can thus be prepared more quickly and more efficiently.

Introduction

It is common knowledge that simulation cannot replace planning. But, simulation is based on planning results as well as on the establishment of the necessary technical components for a production process and their cooperation. Simulation itself is not usable for optimization, but it can help to achieve an optimal output of the system with regard to one or several goals. Planning and simulation must work together within iterative steps for that purpose.

Simulation and planning tools in work planning support the high resolution modeling of technical systems and its control. Systems and processes in scheduling and work planning make use of the available resources of a system with high economy and minimal costs to manufacturing of products. The use of simulation in planning and logistics aims basically at the planning stage and the possibilities to changes in it. Presently, manufacturing simulation and planning tools allow primarily statements about the economy and effectiveness of the considered systems.

Besides, processes in production and logistics are at this time characterized by changed work tasks the workers face in the course of increasing automation, and changed structures in labor organization. Workers more and more assume monitoring, checking and controlling tasks by virtue of the increasing automation. Changed structures in labor organization require the workers to assume tasks which have predominantly planning and organizing character.

In the field of scheduling and work planning, manpower is often only modeled as a resource, like machines or other equipment components. In planning and simulation, manpower is available/not available and suitable for a certain task or not. In fact, man, with its creativity and flexibility, is one of the most important elements of production systems. And thus health risks can jeopardize the economy of production systems, if man is considered as a subsystem. Because of missing manpower-related information in the planning process, it is not possible in an existing manufacturing system to avoid dangers which are caused by current equipment. Especially dangers to the workers, caused by the use of dangerous materials or manufacturing methods as well as dangers by the combination of material, machine, manufacturing methods and work place, cannot be removed. In the end of work planning the operationally available resources are tied efficiently. Also the room to maneuver in making a decision is limited from the view of manpower studies. So it would be better to evaluate processes in their planning state. At a later stage such room to maneuver will be very restricted. Based on this knowledge, manpower- related information should be included into the processes and systems of production planning.

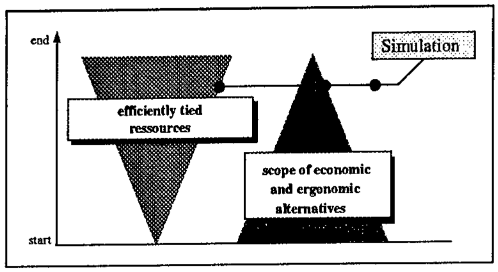

Figure 1: Scopes in the operation scheduling

Background

For the economic scheduling of work and, at the same time, preventive minimization of strains and dangers workers could be exposed to, it is not only useful but necessary to integrate safety aspects into the planning process. The following extracts from the German Industrial Safety Act, of August 21, 1996, underline this fact. They read:

> **... §3 Basic duties of the employer:**
>
> (1) The employer shall be obligated to take measures for industrial safety, always taking into account those circumstances which have an impact on the workers' safety and health ...
>
> **... §4 General rules:**
>
> (1) Work has to be planned so as to best possibly avoid any dangers to life and health and minimize any remaining risks ...
>
> **... §5 Assessment of working conditions**
>
> (1) By *assessing* the risks connected with the employees' work, the employer is to determine which labor protection measures are required.
>
> (3) A risk can particularly be caused by
>
> ... the design, the choice and the use of working tools, in particular of materials, machines, equipment and devices and the utilization thereof,

... the scheduling of work and production procedures, work sequences...

Figure 2: Extracts from the German Industrial Safety Act, of August 21, 1996

The preparation of any factory work is particularly influential in the scheduling of work and production processes. Here the integration of any information on risks and strains is to contribute to an increased planning safety regarding aspects of operational economy and labor protection. The analysis, assessment and planning mechanisms at an early stage of the planning process shall constitute a considerable contribution in order to put the often demanded condition to "take prospective, instead of corrective measures" [7] into operational practice when planning products and work processes.

The action

Within the framework of the government funded GIPS project [German abbreviation for: Integration of Information on Strains into Planning Systems], carried out by the University of Magdeburg together with the Dresden University of Technology, an approach was brought into being for the integration of manpower-related information into the work planning. As criteria for the selection of manpower-related information to be integrated into the work planning served the labor-scientific evaluation procedures BAB - [German abbreviation for: Evaluation of Workloads] [3] and SIA - Security Analysis according to NOHL [4]. Starting point of the efforts was the systemization of the data and information, collected and archived in the computer-aided process of production preparation, pertaining to the system components Technology - Organization - Personnel (T-O-P) and the selection of operationally relevant structures. On the basis of such systemization, the planning stage of the process of work preparation was modeled with the help of computer technology. This model is based upon simplified and mostly generally applicable planning data and data structures. The model serves as basis for the gradual linking of information on risks and strains with the classical data structures from the planning section, and their assignment to the diverse planning stages. In the following we want to describe our approach for the integration of manpower-related information into the work planning. This approach will show the possibilities which are brought about for the depiction of risks to safety, on the one hand, the workers are exposed to and, on the other hand, for the description, in planning and simulation, of organizational sequences.

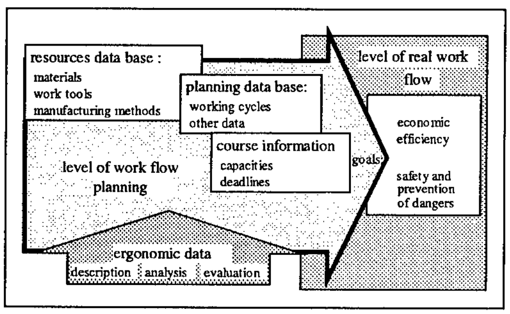

Figure 3: Scheme for the expansion of work planning

The starting points

Data relating to the technical components which are archived in the planning form the basis for modeling and shaping of the production processes. The joint action of the technical components and the sequence of steps of production are established in work plans. The work plans, prepared independently on any incoming order volume, determine a production task with regard to the required technical resources and the technological course of actions. Work plans, order and variable control strategies do, as ever, deliver the most important input data for the planning and shaping of production processes, on the one hand, and for simulation studies, on the other hand. And, work plans determine indirectly the actions to be taken by the workers. The collection and sorting of manpower-related data on the basis of work plans is therefore regarded a good possibility for the integration into the planning process. A schematic depiction of strain characteristics allows to compare diverse work traces under aspects of strains. On the other hand, the data pertaining to defined periods of planning will provide recommendations and requirements for the production planning and work control.

Departing from an investigation of cause-and-effect-relationships of selected safety-relevant factors, a database-aided model was developed which assigns information about strains and risks to the conventional planning information and, furthermore, uses existing data structures in the planning, modifying them so that it is possible to describe human actions and the effects thereof. Figure 4 shows the elaborated scheme regarding the integration of safety-relevant information on the basis of those decisions which are taken within work planning, and of the potential influences which arise for the layout of planned work traces.

Planning levels			
Archiving of basic data	Preparation of work plans	Preparation of production plans	Work control
Information conventionally archived in the planning levels:			
- Work tools - Objects to be worked on - Production techniques	*Partial work processes, work processes, work plans* - product-related, independent on orders *with decisions regarding* work tools, production techniques, objects to be worked on	*Production plans* - dependent on orders, related to structures *with decisions regarding* orders, deadlines, and capacities	*Trace plans* dependent on order, related to manpower *with decisions regarding* distribution of work and production sequences
Expansion by action-related structures and data:			
- Workplaces - Staff	*Partial work processes* manpower-related; *work processes and work plans* technical-organi-zational, and organizational level	*Work tasks* dependent on orders, related to structures	*Work tasks* dependent on orders, related to manpower
Expansion by safety-relevant data (on the basis of analyses of strains and risks according to BAB and SIA)			
- Surrounding influences - Materials and limits - Laws and regulations	- Standards as to strains and risks, planning recommendations, safety recommendations		manpower-related standards as to strains and risks as decision-making aid

Figure 4: Scheme showing the integration of safety-relevant aspects into work preparation

Analysis and Evaluation of Strains and Risks

As mentioned before, the manpower-related information to be integrated is selected in the GIPS project following the evaluation procedures BAB [3] and SIA [4]. These procedures are based on the analysis of a number of single characteristics that are collected within a work system by measurements, descriptions, analyses, and similar.

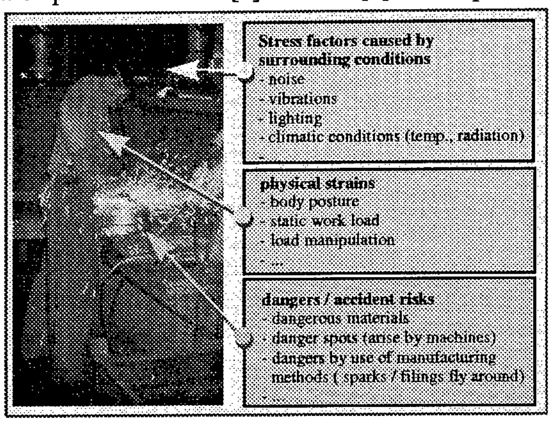

Figure 5: Selected factors of the BAB and SIA procedures

The two procedures examine and assess factors that are brought about by the co-acting T-O-P components of a given work system and that have an impact on the worker. The emphasis of the two procedures is put on the safe shaping of both sequence-dependent, ergonomic characteristics (BAB) and sequence-dependent, technical characteristics (SIA) of any studied work system.

For a model to include such manpower-related information in the planning process, like shown in, different levels are considered:

1 the **description level**, which consists of the expansion of the operational database,
2 the **analysis level** and the **assessment level,** which constitute an expansion of the planning methods. There must be integrated mechanisms for analysis and assessment of expanded planning data. These mechanisms must correspond to already existing planning mechanisms.
3 the **modification level** to produce examples of planning alternatives.

In order to fully exploit the possibilities and alternatives arising therefrom, the levels must be integrated step by step into each single phase of the work planning process.

On the basis of the described BAB and SIA approaches, individual factors of risks and strains were selected and integrated into the planning process. In the following we describe the approach for the gradual integration of safety-relevant information into the planning process, making use of the planning levels described in Figure 4.

The approach

Conventional computer-aided planning systems, the functional scope of which we leaned on when preparing the model, provide functions for the compilation and archiving of *basic data* of a given work system, such as production procedures, objects to be worked on and work tools. Procedures like those of BAB or SIA are based upon the analysis and assessment of factors which are collected in real *traces*. Thus the data collected in such procedures characterize and assess a situation arising from the co-action of all components in any studied work system. However, in order to convey the manpower-related information obtained into expanded work planning systems and processes, it is necessary to classify the cause-and-effect-relations pertaining thereto. Then the results obtained from human work analyses can be assigned to the corresponding planning data. A measured intensity of light is an example of an attribute of the workplace. Information concerning the dangers of toxic or corrosive substances are assigned to the respective materials. Machines may have corresponding information which refers to danger spots. The description level integrates the experience of manpower studies into planning systems. Apart from the so-called "measured data", also the "required data" resulting from laws, regulations and guidelines for the use of the resources, must be capable of being assigned to the corresponding planning data. So guidelines, instructions and maximum/minimum values for harmful substances were prepared, as an example. The prepared model provides the user with description aids, so-called bridge examples, for the described assignment.

Computer-aided instruments, such as CAP systems, accompany the phase of *work plan preparation*. They contain functions for the compilation and archiving of work plans. Work plans which describe the production steps towards a given product have so far been conventionally prepared through step-by-step assembling of

- partial work processes, through the assembling of production techniques, work tools, and the object to be worked on;
- work processes, as the result of 1-n partial work processes; and
- work plans, as the result of 1-n work processes.

In the phase of work plan preparation, thus the safety-relevant values which are specific for the work system, and the required values meet which have been assigned to the level of base data collection and archiving. Since the *entering into effectiveness* of strains and risks, however, prerequisites human actions, the depiction of human activities within the stage of work plan preparation is necessary. Only on that basis is it possible to integrate adequate analysis and assessment mechanisms into the individual planning steps. The mechanisms must correspond to already existing planning mechanisms. It was necessary to identify planning steps with the utmost decision room, and so safety and stress intensity data could be coupled efficiently with traditional planning data.

As mentioned above, the preparation of work plans brings about indirectly the determination of those actions the workers are required to carry out. In the prepared model the human actions are integrated into the level of preparation of work plans, starting from the description of the *partial steps of production.* Apart from the usual production-oriented partial processes which describe the single production steps towards a product, so-called-manpower-related partial steps of production are integrated into planning. Manpower-related partial steps of production describe a worker's partial activities which do not modify the product as such. With regard to their functions we distinguish between transportation and load manipulation activities, such as delivery of parts and relocation, and activities of examination, measuring, etc. Information on strains and risks which result directly from the partial activity, such as physical strain factors, may be directly assigned to partial processes. The strains and risks resulting from partial work processes in which manpower is involved are equal, unless they refer to the situation in a special work system. The carrying of a box of 40 pounds over a certain distance will be, as an example, as much burdensome for a worker of firm A, as it will be for a worker of firm B. Departing from this knowledge, a database of ergonomically compiled manpower-related activities can be prepared. The GIPS project is about to create first bases therefor.

A connection between the product-related trace steps and the manpower-related activities can be found with the preparation of *work processes*, where manpower-related activities are assigned to the several production steps leading to a certain product. Within one production step, we distinguish between

- *main activities* which describe the processing of a product and which bind manpower up to 100%, dependent on the level of automation;
- *preparing and follow-up activities* which are necessary to prepare, or assess or treat afterwards the main activity, binding manpower up to 100%; and
- *accompanying activities* which a worker has to carry out parallel to the main activity.

The introduction of manpower-related activities in the *work process* and its time share allows here a first assessment, with the BAB and SIA approaches, of strain and risk factors workers are exposed to. For the description of manpower-related work courses within the planning process, the *work processes* in the model are classified into technical and organizational processes. While *technical work processes* subsume all necessary partial processes relating to a specific production step toward a product, the class of the *organizational work processes* serves the description of actions which, for their part, serve to implement the production process. Processes of this class are, for example, processes of changing tools and of transportation, as well as planning and organizational processes. They serve to define organizational actions both with regard to time and to the demands posed to the workers. Organizational work processes are of special interest, as an example, for the contemplation of psychological strains. Nature and number of the actions to be carried out can be used, among others, for examining responsibilities and demands on quality and concentration.

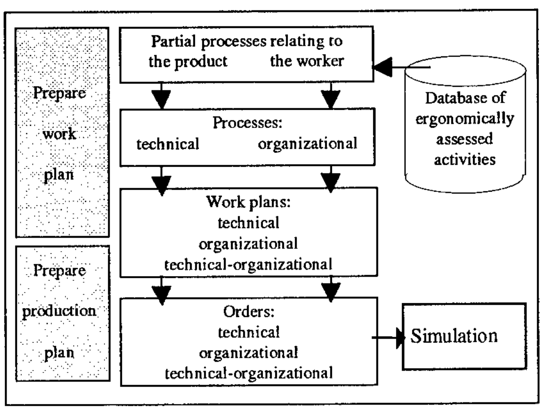

Figure 6: Extended data structures in work plan-

In strict observance of the above approach we can distinguish three types of *work plans*:

- *technical work plans* - describe the course of production towards a specific part;
- *technical -organizational work plans* - describe recurring organizational, however, technically determined courses within the work process, such as maintenance cycles, changing of the tools and transportation processes. Such

processes are required for maintaining the technical process;

- *organizational work plans* - describe recurring, and purely organizationally determined processes within the whole work process, e.g. planning cycles and, possibly, rules providing for intervals and shifts. They allow the description of sequences which are of informative, planning and controlling character.

Like at every planning stage of the developed model, relevant risk and strain factors are also assessed when preparing the work plans.

By that stage of the work preparation process, the most important *bases for a detailed description* of human work within the framework of work planning have been established. Apart from the activities related to the fabrication of a product, in particular the monitoring, controlling and similar activities are described which are common in highly automated production processes. The thus established link-up of technical work plans with activity sequences create multiple possibilities both in the next steps of the planning process and in simulation.

During the phase of preparation of production plans the incoming orders are inserted ficticiously into a system. With the help of the expanded work plan data it will be possible to depict not only technical work plans in connection with orders at a time axis scheme, but also the work courses which maintain and control the production process. If such technical-organizational and organizational courses of work are understood as orders for a given system, it will also be possible to depict the sequence of necessary actions to be taken by the workers, in order to make it possible not only to check the technical "feasibility" and "economic efficiency", but to see strains and risks which result, as

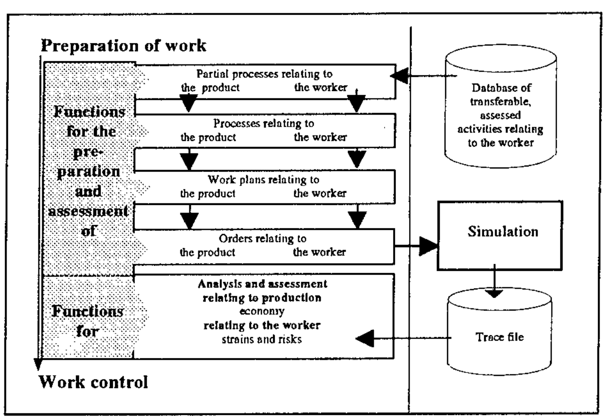

Figure 7: Expanded functions in work planning

an example, from simultaneously running production and work courses.

The level of work control serves the scheduling of a given work process for a given section and within a defined time period. In doing so, the tasks being at the agenda are assigned to the worker or the course is organized with regard to the workers. In this situation, concrete characteristics of persons, like qualifications, age and sex, etc. meet with the requirements of the work tasks. Herein, the model gives corresponding assistance in the assessment of strains and risks and also in the decision-finding. If safety risks become visible within the course of planning, planning alternatives have to be searched for. For the elimination of insufficiencies, the reiteration of planning steps will be required in the first place.

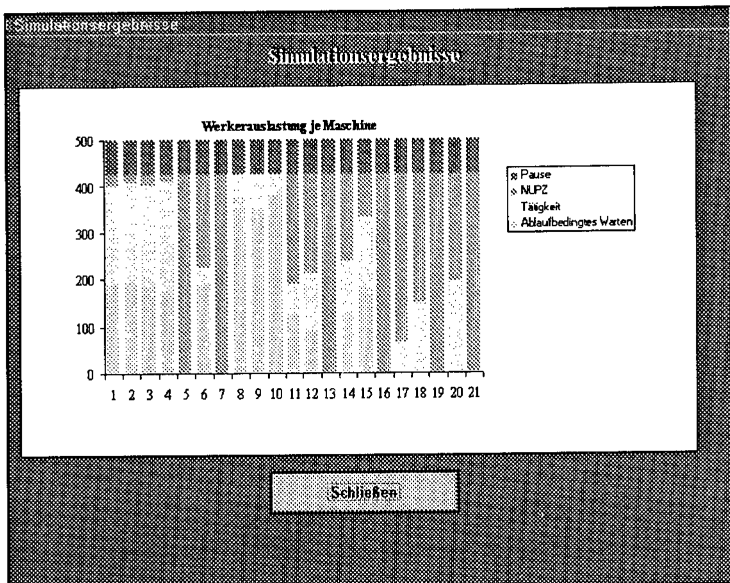

Figure 8: Depiction of the capacity utilization of workers at workplaces (screen shot)

It occurs often within the course of work planning that strains and risks cannot be excluded or can be excluded only under considerable economic losses. In such case, the model can supply information regarding the necessary protection measures which are based on the working documents. Safety and danger prevention recommendations are added to the operational instructions for the worker (wearing of ear protectors required, etc.).

Perspectives for simulation

The preparation of simulation models means in general a lot of time and energy spent on the gathering of the required information regarding the courses to be controlled and organized. This becomes all the more obvious as the workers assume more and more monitoring and controlling work tasks due to the increasing automation. And, if changed working structures bring about additional work tasks which are of predominantly planning and organizing character, in particular in complicated, partially or fully automated processes in production and logistics the human behavior frequently becomes the critical point, a "bottleneck".

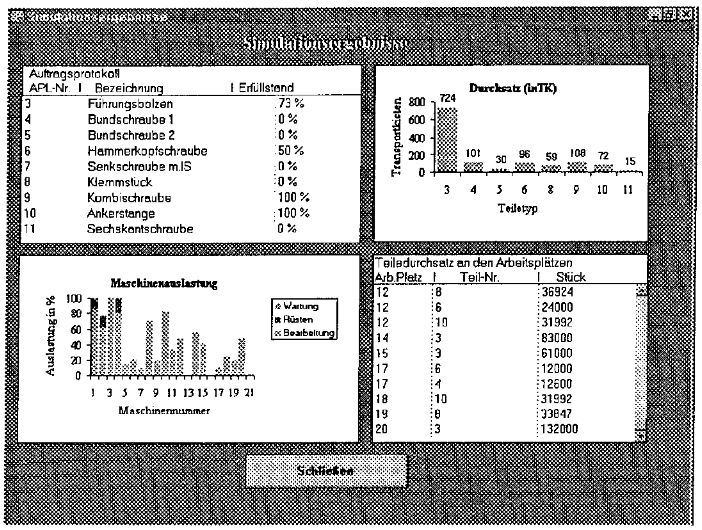

Figure 9: Selected results of an investigation concerning economic efficiency (screen shot)

The developed, computer-aided model, with the help of the combined technical and manpower-related processes in the planning, establishes the basis for a new quality of the input data for simulation directly from the planning stage. From the described extensions of the work planning data and work planning processes result new approaches for the description of human behavior in connection with the simulation of production processes. Integrated analysis and assessment algorithms assist the planning process, and expanded

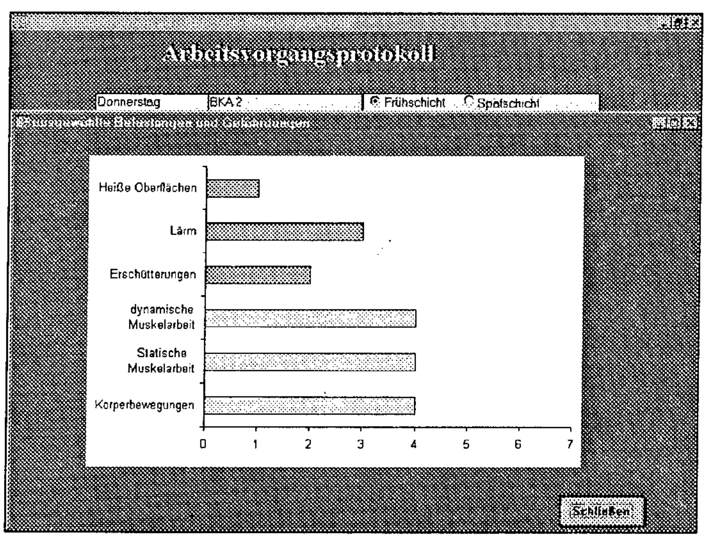

Figure 10: Extract from a risk and strain scheme (screen shot)

and additional work plans and work plan data allow the consideration of manpower-related effects in simulation. The developed model uses a simulation model for the analysis and assessment of simultaneously running processes. The simulation generates a trace file which serves to investigate economic questions and manpower-related effects. In the metal-processing industry, first successful results have been achieved with an application under the GIPS project. Further applications, such as in the glass and ceramics industry, serve to examine their acceptability among industrial users.

Conclusions

In summary the described approach seems to have succeeded, always taking into account action-related information regarding work planning, in developing a basis for the description, modeling and simulation of workers, their activities and manpower-related interactions with technology and organization in connection with the production processes. As before, work planning data are being used as input data in simulation studies. In the planning process, the developed model provides a comprehensive description of the workers' activities in connection with the fabrication of the products, on the one hand, and the maintenance of the course of production, on the other hand. Statutory regulations in Germany concerning the observance of industrial safety and health protection force already today to integrate manpower-related data into the planning process. In light of the broad scope of application of the method presented in this paper concerning the depiction of manpower-related factors in the planning process and a comprehensive database of assessed activities (Figure 7), it is likely that the time and energy spent on the collection of data for the simulation can be minimized.

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Simulation of different peripheral blood flow patterns for educational purposes

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Abstract

The simulation of physiological processes will most be done on computers. For some different purposes it is ingenious to have also (hydro-) mechanic (inter-) actions. Two of these fundamental ideas are the roots of our computercontrolled electrohydraulic phantom. This phantom can be used for quality assurance and -control of ultrasound diagnostic equipment but for the education of medical practitioners on such equipment too. An in vitro Doppler ultrasound phantom has been invented to simulate physiological and non-physiological blood flow waveforms (in the sense of peripheral hemodynamics). The teacher may manipulate the flow waveforms and practice exams to his students working on the phantom. For calibrating and testing Doppler-Ultrasound-Equipment it is not necessary to generate physiological waveforms but a reproducible continuous bloodflow.

Introduction

The Doppler ultrasound diagnosis is of highly diagnostic importance for medical investigators because of its nonivasive measurements of intracorporal bloodflow parameters. The investigator can see the acoustic (ultrasound) picture of the tissue in the region of interest and at the same time he can see the speed and flowdirection of the blood visualized by colorcoding. These flowpatterns are typical for every part of a human blood vessel, so they are called „fingerprints". There are two fundamental sources of errors:

- The system error of the equipment (up to the power of 10!).
- The errors caused by the operator by using the applicator or the settings of the equipment in a deficient way.

The errors wouldn't be detected by the untrained medicine wo/man. Putting the applicator in a „wrong" angel on the skin is very simple and will cause erroneous speed displays due to the Doppler-formula. The angel between blood vessel and the sound wave influences the result by the cosine. Also the region of interest (ROI) may not be in the center of the blood vessel. Due to the parabolic flow profile there are the next errors possible.

The hardware

The phantom-equipment (see fig. 1) consists of a PC, a steppermotor-unit mounted to a mohnopump (wormpump) and a cardiac rubber tissue phantom (ATS Model #523A with 4 different tube (vessel) diameters). The pump doesn´t need self-lubricant fluid nor damages the particles of the blood (or it´s blood-mimicking substitute) like gear pumps do. In our circuit made of rigid tubing (PVC, to avoid the Windkesseleffect), a blood mimicking fluid from ATS (Doppler Test Fluid #707-2G) is pumped either producing a continuous flow or showing a physiological or non physiological pulsflow, even with any kind of reflow. The physiological Windkesseleffect will be simulated by the (fuzzy-) controlling computer (PC).

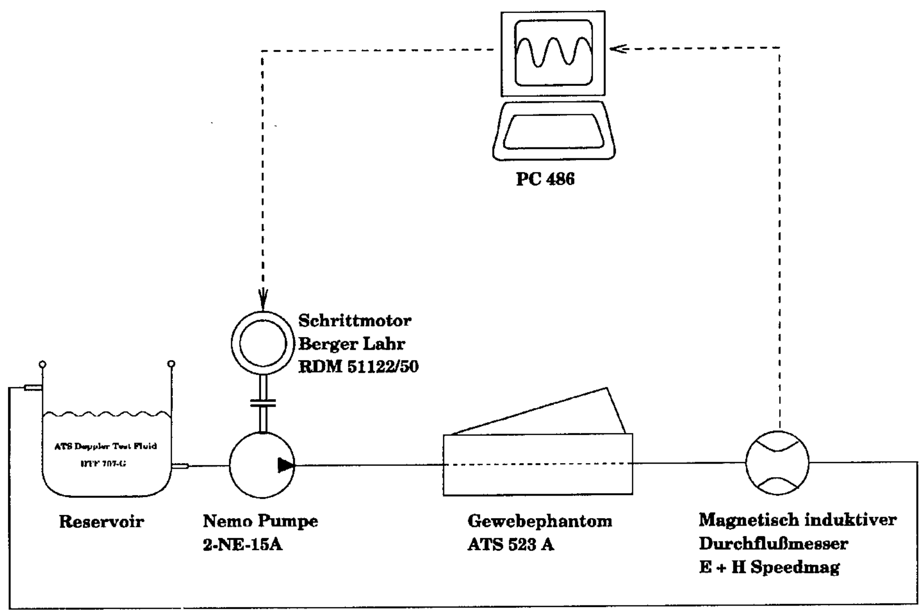

Figure 1: The hardware-circuit

How to work with the phantom

The velocity-flow-curve is to be chosen during a graphic oriented dialogue on the PC under MS-Windows. Typical "fingerprints" (see fig 2) are stored in a database on the PC-harddisk. They are „calibrated“ for one complete cycle of the heart. The user will be able to construct own flow-curves or edit one from the database by using the system's mouse in a simple graphic-editor. It is no problem for the user constructing non-physiological flow-profiles too for checking the maximum rates of the diagnostic-system, for example.

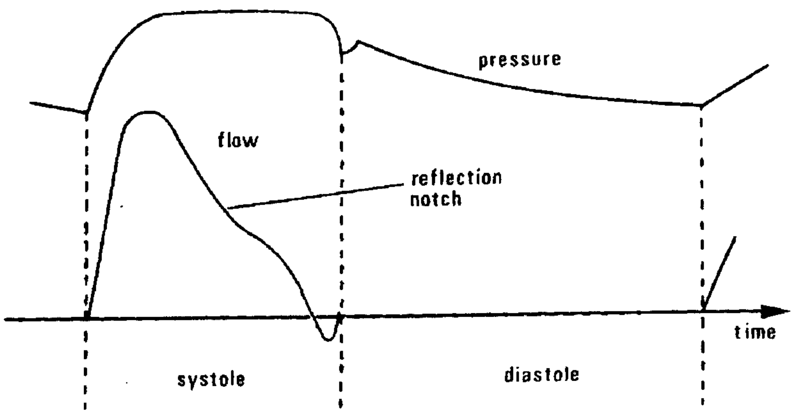

Figure 2: Fingerprint - ascending aorta

Parameters like heartfrequency, tubediameter and flowvolume are introduced by editing the predefined values in a pull down menu (see fig 3).

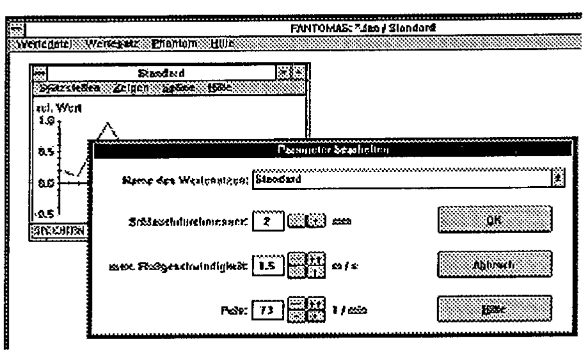

Figure 3: Pull down menu for Parameters

The parameters for constant flow are typed in using the pulldown menus only, because a graphic interface makes no sense therefor. When editing is already done, the „trainer" should use a special menu-entry for the degassing of the system. When the circuit has been unused for some days or the tube diameter has been changed, there are possibly air-bubbles in the tubesystem. The airbubbles can be removed by pumping the blood mimicking fluid for some minutes in alternating directions through the circuit, leaving the bubbles in the fluid reservoir. Than, when the system is ready and running its programmed flowsimulation through the tubes, the „student" should hold the applicator onto the tissue-mimicking part of the phantom. On his diagnostic equipment monitor he can see the influence of the angle he holds the applicator or of the different machine settings. It is the way the „teacher" checks what the students diagnose - without bothering real patients.

Other simulations

By the way: we also programmed a simple simulator on a PC for CBT (computer based training). Alike the above shown electrohydraulic phantom the medical wo/man will be introduced and trained using Doppler-Ultrasound-Diagnosis-Equipment. We took a data-glove as a three-dimensional input device. On the graphic output device (video-monitor) a laying body is shown for the investigation. The medical practitioner is able to work with a simulated ultrasound device (like a mousepointer) on this represented virtual body. The trainee can see the actual bloodflow pattern (in a window) of the region he is positioning his virtual device on. When he dives the virtual applicator into the body instead of gliding on the surface (skin of the body) a voice from the PC-speaker is protesting. The typical sound generation of the diagnostic equipment is not yet implemented due to a shortage of interest of the medical wo/men.

Outlook

Another computercontrolled electrohydraulic project is under process in cooperation with the university hospital of Hamburg. The bloodflow of the leftventricular heart will be simulated for the validation of 3-dimensional intraoesophagial ultrasound scanners. Also possible are examinations of artificial heartvalves.

Conclusions

This blood flow phantom would be valuable during the education of ultrasound Doppler diagnosis for physicists. The student puts the applicator of the ultrasound diagnostic equipment on the tissue-phantom an will be trained by a teacher to achieve and identify the simulated flow patterns and conclude a diagnosis. The teacher is able to chose the flow-patterns from a database or to generate special patterns in a graphic-oriented dialog on the PC.

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Perception-action compatibility and eye-hand dominance in using visually-displayed information*

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Abstract

The efficient use of visually-displayed information depends largely on the principle of *perception-action compatibility* which predicts that the way in which information is perceptually provided predetermines the accuracy and speed of the operations required. This principle was studied in connection with the respective *eye-hand dominance* of the operator. Subjects with pronounced dominances of their eye and hand were selected according to a test of ocular dominance and two laterality questionnaires. Their task was to react to horizontal visual motion which started at the left or right side of a computer screen by use of a static or a dynamic *response tool* (key *vs.* joystick). Static or dynamic *stimulus cues* (onset position *vs.* motion direction) were assigned to static or dynamic responses in a *compatible* (e.g., left or leftward responses to left or leftward stimuli), or *incompatible* (left or leftward responses to right or rightward stimuli) way. Overall, right-handers responded faster than left-handers and right-eyed persons tended to be faster than left-eyed persons. *Cue-tool compatibility* and spatial compatibility effects interacted with handedness, but not with eye dominance, in that the *difference* between left- and right-handers *increased* under *incompatible* conditions; in other words, the disadvantage of left-handers is significantly *reduced* under *compatible* conditions. Thus, an ergonomic design that improves the workplace design just on the base of the compatibility principle alone might help to ease the situation of left-handed persons who seem to depend above all on compatibility conditions.

Introduction

Efficient ways of displaying information have been a major concern of the human factors approach since its early days. The increased complexity of today's dynamic systems entails the presentation of a wealth of information to the human operator. At the same time, rapid advances in computer and display technology have increased both the capability of displaying multi-element, complex information and the freedom to select the aspect and mode of presentation. General guidelines for the design of complex visual displays should include the following items (Gopher & Kimchi, 1989): *1.* Aspects of the represented world (e.g., a complex dynamic system) should be selectively captured within the representing world (i.e., the visual display); *2.* The selected aspects should be represented in an optimal way; and *3.* One should recognize that items 1 and 2 depend critically upon task domain, and thus require a coherent analysis of *demanded actions in relation to perceptual information.*

* Dedicated to Professor *Hans Gerd Wenzel* on occasion of his 75th birthday.

The principle of compatibility

Even in relatively simple tasks, like that of pressing a key in response to a light flashed at a certain location, the time and accuracy of the operation are influenced by *perception-action (stimulus-response) compatibility*, i.e., by the relationship between the specific stimulus and response sets that are used and the way in which the members of the stimulus set are assigned to the responses (Proctor & Dutta, 1995). Performance tends to be faster and more accurate when the signal and an operator's response to it are perceptually related, e.g., when both are located in the same part of the operator's visual (left or right) hemifield. The *principle of compatibility* which emerged in the field of human factors in the early 1950s (e.g., Fitts and Seeger, 1953) has been applied since then to many areas such as spatial coding, man-machine interactions, and optimal design of displays or keyboards (see Wickens, 1992; Proctor & Van Zandt, 1994, for reviews). The principle predicts in general terms that the way in which information is presented predetermines the accuracy and speed of the operations required.

Static and dynamic stimulus-response pairings

Up to the 1990s, *static* stimuli and response tools have almost exclusively dominated the research of perception-action compatibility (Proctor & Reeve, 1990). With the advent of high-powered computer graphics and real-time recording of responses, *moving stimuli* and/or *dynamic response tools* have been increasingly employed (e.g., Ehrenstein, 1994; Arnold-Schulz-Gahmen & Ehrenstein, 1995, 1996; Arnold-Schulz-Gahmen et al., 1996; Cavonius et al., 1996; Ehrenstein et al., 1996), and dynamic accounts (e.g., Grassberger-Procaccia algorithms) applied to the field of compatibility research (Ganz et al., 1996; Ehrenstein, 1997). In the present study, dynamic visual stimuli were chosen, to which subjects reacted by means of static or dynamic response tools (keypress or deflection of a joystick).

Eye-Hand Dominance

Any ergonomic application of perception-action compatibility would be incomplete if it ignored the *laterality* or *dominance,* both of eye and hand, of a given operator. About one in three people is left-eyed, about one in ten is left-handed (Nachson et al., 1983; Bourassa et al., 1996). As there are 3 times more left-eyed than left-handed persons, it follows that a substantial percentage in a population has a crossed eye-hand dominance, e.g., is right-handed, but left-eyed. In their monograph on handedness and manipulation of work tools, Schmauder and Solf (1992) state *a lack of verified insights* concerning the effects and requirements of handedness in human ergonomics. Even less is known about the influence of eyedness and the putative interactive influences of eyedness and handedness in the use of visually displayed information, especially with respect to spatial compatibility. This means that the present study is entering a rather new field of research and is hence of a rather exploratory nature.

Aims of the Present Study

In the present study we asked whether the speed of action or response time (RT) depends on the respective (i) compatible relationship between (static or dynamic) stimulus cues and response tools, (ii) the compatible spatial assignment of responses to stimuli (left or right), and (iii) eye-hand dominance of the operator (in the sense that it would interact with the two above compatibility effects).

Method

Subjects

The pointing test by Walls (1951) and the laterality questionnaires by Oldfield (1971) and Coren (1993), in their German adaptations (Ehrenstein & Arnold-Schulz-Gahmen, 1997) were used to select subjects with pronounced dominances (lateralization) of their eyes and hands from a larger sample. Four subjects, matched in age and gender, formed one of four dominance subgroups: left-eyed, left-handed (LE-LH), left-eyed, right-handed (LE-RH), right-eyed, left-handed (RE-LH), and right-eyed, right-handed (RE-RH).

Task

These four groups of subjects were tested in a choice-reaction task in which a static or dynamic response was assigned compatibly or incompatibly to either the onset position or motion direction of a moving visual stimulus (see Fig. 1). The stimulus was a bright dot that appeared suddenly (after a randomly selected interval of 600 - 900 ms following a warning 'beep') at 5 deg left or right of fixation, moving leftward or rightward at 2 deg/s for 1 s.

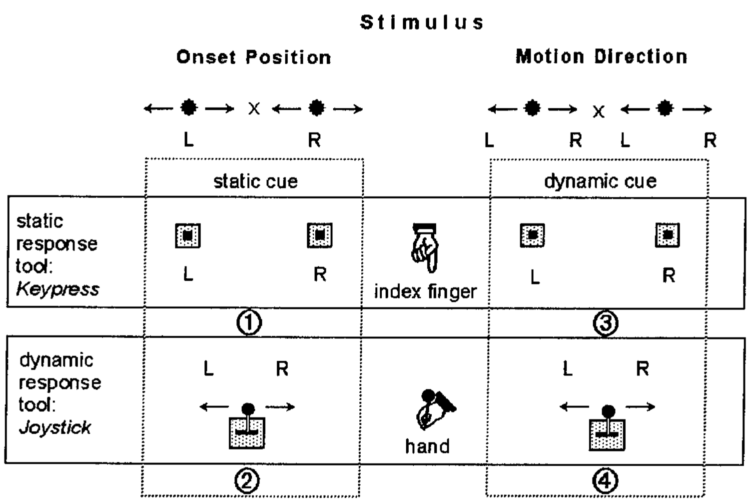

Figure 1: Experimental set-up: Each subject participated two times in four conditions (presented in separate blocks) in which either stimulus onset position (irrespective of direction, Conditions 1 and 2) or motion direction (irrespective of onset position, Conditions 3 and 4) was the relevant cue. The response was given by static (keypress) or dynamic (joystick) tools. Keypress location or joystick direction was assigned compatibly (e.g., left keypress to left stimulus onset) or incompatibly (e.g., right keypress to left onset stimulus) in all four conditions.

Each subject participated in eight conditions (presented in separate blocks of trials) in which either the *position of motion-onset* (irrespective of direction, see Fig.1, conditions 1 and 2), or the direction of movement (irrespective of position, Fig. 1, conditions 3 and 4) was the relevant stimulus cue. The response was static (keypress) or dynamic (joystick deflection). Key location or response direction by joystick deflection was assigned compatibly (e.g., the right key was pressed or the joystick was moved to the right when the stimulus occurred on the right) or incompatibly (e.g., the left key was pressed or the joystick was deflected to the left when the stimulus occurred on the right).

In the static response tool condition keys at the left and right positions were pressed with the left or right index finger, respectively. In the dynamic response tool condition the joystick was held with the whole (preferred or nonpreferred) hand (alternating in successive blocks of trials).

Results

Mean RTs were analyzed by ANOVA with *eyedness* and *handedness* as *between*-subjects factors and *stimulus cue* (onset position or motion direction), *response tool* (key or joystick), and *compatibility* (compatible or incompatible assignment of stimuli to responses) as *within*-subjects factors.

Eye-hand dominance

Overall, right-handed subjects were significantly faster than left-handed subjects by 41.2 ms [$F(1,12) = 5.57$, $p = .036$]. Right-eyed subjects responded, on average, 15.2 ms faster than left-eyed individuals, but this difference was not significant [$F(1,12) = 0.83$, $p = .38$], and eyedness did not interact with any other factor. In other words, we found no effect of eyedness and no benefit for shared eye-hand dominance (e.g., both right-eyed and right-handed subjects) over crossed eye-hand dominance (e.g., right-eyed, but left-handed subjects).

Cue-Tool Compatibility and Handedness

Responses to onset position were, on average, faster than responses to motion direction (351.9 *vs.* 442.7 ms, respectively). Interestingly, stimulus cue interacted with both response tool and handedness. The *stimulus cue x response tool* interaction [$F(1,12) = 15.03$, $p = .0022$] refers to the fact that the speed of reaction to motion onset depended on the response mode, i.e. reactions were much faster with keypress (334.1 ms) than joystick (369.9 ms) responses, whereas mean RT. to motion direction did not depend on the response mode (442.2 *vs.* 443.3 ms for keypress *vs.* joystick responses).

The 3-way interaction (*stimulus cue x response tool x handedness* [$F(1,12) = 5.19$, $p = .042$] reflects the fact that right-handers were 52.6 ms faster than left-handers when the relevant stimulus cue and response tool were incongruent (i.e., static, motion onset cue paired with dynamic response tool or the dynamic, motion direction cue paired with the static response tool) and only 32.2 ms faster when the stimulus cue and response tool were congruent (i.e., both static or both dynamic); see *Figure 2*.

Spatial Compatibility and Handedness

Overall, spatially compatible responses were significantly faster than incompatible responses [374.7 *vs.* 420.0 ms; $F(1,12) = 243.7$, $p = .0001$]. Compatibility interacted with handedness [$F(1,12) = 7.81$, $p = .016$]; see *Figure 3*. This interaction means that left-handed subjects showed a larger compatibility effect (incompatible - compatible RT = 53.4 ms) than right-handed subjects (incompatible - compatible RT = 37.3 ms).

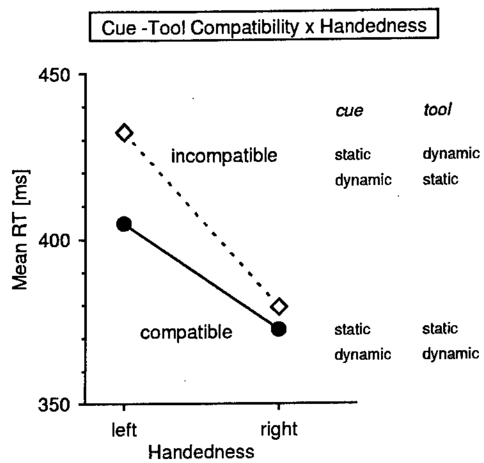

Figure 2: Mean response times of matched groups of left-handed and right-handed subjects for compatible and incompatible cue-tool conditions. Both groups of subjects show shorter RTs for the compatible condition, the decrease in RT, however, is much more pronounced for left-handers.

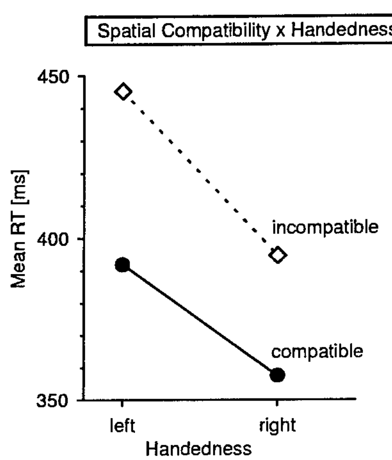

Figure 3: Mean response times of matched groups of left-handed and right-handed subjects for compatible or incompatible assignment of stimuli to responses. As in Fig. 2 left-handers show a larger drop in RT with compatible conditions than right-handers.

Discussion

The present study shows that performance depends on the compatibility between stimulus cue and response tool and on the spatial compatibility of assignment between the locations/directions of stimuli and responses[1]. Moreover, these two compatibility effects interact with handedness.

Compatibility

We have restricted the application of the compatibility principle to rather simple situations to maintain experimental clarity. While the effect of compatible or incompatible assignment of spatial dimensions (location or directions) of stimuli to responses has been studied before (see Proctor and Reeve, 1990, for a general review; and Ehrenstein, 1994, for a distinction between location and direction compatibility) the cue-tool compatibility is a new effect which deserves further investigation. This new compatibility effect adds to various further applications of the compatibility principle which comprise problems such as cursor control on a computer screen (Gude, 1993), control of manual tracking (Cavonius et al., 1996), spatial compatibility in various orientations, including orthogonal stimulus-response relationships (Ehrenstein et al., 1989; 1996), or proximity compatibility (Wickens & Carswell, 1995). Despite the reasonable assumption that all of these compatibility effects interact with (or are at least modified by) the respective eye-dominance relationships of the operator, this issue has scarcely been addressed to date. Conversely, the vast literature on handedness and on laterality of sensory or motor functions in general (e.g., Schmauder & Solf, 1992; Peters, 1995; Bourassa et al., 1996) has not yet tapped the issue of compatibility and its possible implications for the performance of lateralized functions.

Eye-Dominance

Although we obtained no significant effects of eye-dominance there was, on average, a tendency for right-eyed persons to show a response-time advantage over left-eyed persons. One reason for statistical insignificance is the obviously small sample of subjects examined. In fact in a further study (Arnold-Schulz-Gahmen et al., 1997) ocular dominance was found to affect suprathreshold motion sensitivity. Another reason for the absence of an eye-dominance effect in the present study may be due to the fact that observation was always binocular: differences between eyes can be expected to show up more clearly in monocular tasks, i.e., if the performance is tested for both eyes separately. Interestingly, preliminary results suggest that the difference between monocular and binocular performance is much more pronounced in right-eyed then left-eyed subjects (Arnold-Schulz-Gahmen et al., 1997).

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1) The cue-tool correspondence can be considered as a special case of compatibility, that of *set-level compatibility*: for a natural correspondence between stimulus sets and response sets, as opposed to element-level compatibility between arbitrarily defined pairings of indvidual stimuli and responses (Fitts and Seeger, 1953; see also Proctor and Dutta, 1995). In the present case, set-level compatibility occurs between (static/dynamic) stimulus cues and (static/dynamic) response tools. Thus, one may distinguish here a *cue-tool* compatibility from a *spatial* compatibility which occurs between spatial dimensions or directions of stimuli and responses (left/right, leftward/rightward).

Handedness

Left-handers were slower than right-handers, especially with *incongruent* cue-tool relationship and incompatible assignment between stimuli and responses. This means that their disadvantage was less if conditions for perception-action compatibility were optimal. In other words, an ergonomic design that improves the workplace design on the basis of the compatibility principle alone would already improve the situation for both right-handed and left-handed persons. Certainly, for left-handed subjects the workplace design can be further improved if it specifically addresses the issue of left-handedness (see Schmauder & Solf, 1992, for a review).

Outlook

The present study provides exploratory rather than definite evidence. As mentioned before, further research should be conducted to determine whether eye-dominance effects influence performance if, instead of binocular vision, monocular vision were required, so that the dominant eye and the non-dominant eye were employed selectively. The same holds for the effect of handedness. Our study suggests that the RT advantage for the dominant hand was stronger when the task engaged both hands (key response) than when only one hand was used (joystick response). It needs to be shown in separate experiments, which compare bimanual with unimanual tasks using the same rather than different response tools, to what extent hand-dominance effects depend on this factor. In addition, the aspect of genuine bimanual coordination (e.g., Heuer, 1990; Heuer et al., 1997; Spijkers & Heuer, 1995) and hand-dominance should be specifically addressed by future research. Thus, the present study just opens the door to a rich field of research questions that links issues of compatibility to that of dominance of eye and hand with the aim to optimize the design of an individual's workplace. In addition this future research would help greatly to become aware of the fact of dominance, especially of eye-dominance. Many of our subjects were puzzled in that they did not know what was their dominant eye or even had never heard that something like eye-dominance exists. Thus, a routine screening of eyedness and handedness by a short questionnaire (e.g., Coren 1993; German adaptation by Ehrenstein & Arnold-Schulz-Gahmen, 1997) is recommended for each employee.

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