

ADVANCING HUMAN CENTERED AUGMENTED REALITY RESEARCH

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ABSTRACT

Augmented Reality (AR) is an emerging technology that offers possibilities that other technologies are not able to fulfill. AR uses a computer to add information to the real world. Future AR technology will be low cost, fieldable, usable for multiple purposes such as actual operations, and occupy a small footprint. The technology is emerging from laboratories and beginning to be evaluated for use by people in various settings. This evaluation activity meshes well with continued research and development of the technology.

1. INTRODUCTION

Augmented reality, the addition of information to the real world using computers, offers a major advancement for the military's use of simulation technology. With mobile AR, users will be able to have a personalized training experience anywhere, anytime. AR will be able to support many applications with the same hardware and a core software system. Potential application areas include training, operations, command and control, and decision support.

Traditional training systems and contemporary virtual reality are expensive, have large footprints, often require substantial infrastructures to set up and operate, and can have human performance issues related to simulator sickness. These problems need not be present in AR systems. The principal reason is that AR is based in the real world and uses the computer to add information, eliminating some causes of simulator sickness and the need for generating a complete, synthetic world structure. Mobile AR uses GPS, but is

otherwise self-contained, so the infrastructure and footprint are reduced. The real world system basis for AR comes with its own challenges such as providing displays with large dynamic brightness range, tracking over a wide area, and creating interactive effects with real world entities and events. Nevertheless, research is underway in many laboratories to mitigate these problems.

2. AUGMENTED REALITY OVERVIEW

Augmented reality (AR) has been defined by Barfield and Caudell (2001) as a system in which "a participant wears a see-through display (or views video of the real world with an opaque HMD) that allows graphics or text to be projected in the real world." Other modalities can be included in AR and information can be subtracted from the real world using augmentation.

It is useful to distinguish augmented reality from the more common virtual environments with which many are familiar. In AR, the real world is the baseline upon which information is added, as contrasted with virtual reality where the desired state is to completely immerse the user's sensory systems within a computer-created environment. Virtual reality's baseline is in a virtual or artificial environment the computer displays. As one adds more computer augmentation to the real world, the demarcation between virtual and augmented (as well as other types of realities) becomes a continuum. Rapid advances in technology have contributed to this blurring of realities. The blurring of the various realities, however, provides opportunities for some of the technologies to be easily adapted from one domain to another. This also provides an opportunity to adapt human performance studies from one domain to another in order to better

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understand human performance across different domains.

Augmented reality systems have distinctive features that characterize their functionality. Barfield and Caudell (2001) and Azuma et al. (2001) describe these functional characteristics that include blending the real and virtual in a real environment, real time interactivity, and 3D registration of information. This functional description is broad, resulting in several levels one may use to classify different types of AR systems. At one level, there are augmented reality systems that add information to a scene, have minimal levels of blending and can keep one degree of freedom of 3D registration constant (because it is not needed). An example of this type of AR is an automobile head-up display. A second level has information fused and graphically blended with the real world with the intent to make a single, visually integrated, and indistinguishable scene. The third level is where information is available in the real world, but is not viewable without augmentation. With each type of augmentation come different types of complexity. The technical approaches used to deliver augmentation through these various groupings and which specific task is best met by a specific type of augmentation has not been determined. The second level has received most of the research attention since it requires fusion between the dynamic real world and computer-generated information, and human vision is sensitive to displacement errors that would prevent this fusion.

AR systems are not new and date back to the work of Ivan Sutherland in the 1960's. Sutherland's work also fed virtual reality, where advances were made at a more rapid pace, principally due to limitations in AR technology and requirements for fielding systems. AR emerged as a separate research program in 1990 when a team from Boeing created a prototype system for supporting aircraft wiring.

Augmented reality systems, in general, and mobile augmented reality systems, in particular, offer technology for enhancing user performance in many application domains and for various user constituencies. Activities where the addition of information to the real world could be beneficial are potential applications of the technology. Example domains include maintenance, operations, training, decision support, and design. Potential user constituencies include the military,

public safety, medicine, entertainment, and education. These user constituencies often use the same application domains, but with AR implementations focused on their particular needs. Freedom of movement and interaction, information available in the form needed and delivered in real time, along with relatively unobstructed vision of the surrounds are the benefits. There are also possibilities for one application area or user group to share their AR innovations with others.

3. CURRENT AR TECHNICAL LIMITATIONS/RESEARCH

Mobile augmented reality has reached a state of maturity where working prototypes are available. These prototypes offer infrastructures where technological and human performance advancements and improvements can be evaluated on a system basis.

Technological advancements are proceeding on several fronts. These include tracking, computer graphics, displays, and packaging. Tracking is a major area of interest with respect to outdoor tracking methods, improvements in tracking precision, and techniques to take advantage of outdoor features. Computer graphics research generally involves rendering quality and lighting models that better match the dynamic range of the real world. Display technology programs involve packaging and accommodating variations in lighting and user needs. Packaging covers all areas of AR, but is particularly focused on computing, data transmission, and power. AR is also able to leverage technical advances in other fields, such as virtual environments. AR can also leverage methods for evaluating human performance from the human factors field.

AR technology has progressed to the point where prototypes are available that can be evaluated for their ability to enhance human performance. Most work has been oriented to perception, but recent activity has begun to look at cognitive and task performance in more realistic settings, characterized by the task and the variability that might be encountered in the real world. Properly structured AR offers the opportunity to reduce the user's cognitive load by extending the human sensory system and information processing (Neumann and Majoros, 1998).

3.1 Mobile Augmented Reality Research Facilities

Several mobile AR systems are in laboratories where technical and human performance research is on-going. All laboratories mentioned conduct some research involving human use of AR. Most of the research is supported by the Office of Naval Research.

Columbia University's Mobile Augmented Reality Systems (MARS) project is designed to take advantage of the envisioned everywhere-available information infrastructure. One of the first demonstrations for outdoor AR was a campus tour application, which could either assist the user in finding a desired location or tell the user the history of the campus, including buildings no longer in existence. Later work included an authoring tool for such information experiences and development of user interfaces for collaboration with indoor users.

The Naval Research Laboratory has lead research in a system called the Battlefield Augmented Reality System (BARS). Figure 1, provides one version of BARS. BARS are located at the NRL, USA STRICOM (an early implementation), Univ. of Central Florida (UCF) in cooperation with the Army Research Institute, Concurrent Technologies Corp., and Virginia Polytechnic Institute and State Univ. (Virginia Tech). The most current configuration of BARS uses a Quantum 3D Thermite computer as the on-board processor. The Thermite provides self-contained graphics processing, interface to BARS devices (e.g., displays), and communications with other systems. The entire BARS fits on a vest and weighs about ten pounds (Figure 1).

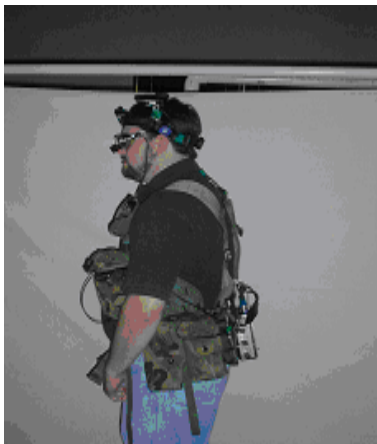


Figure 1: Side view of BARS vest.

3.2 Usability Research for AR

Usability is a measure of how easy a system is to use and how useful the system's features are (Hix, 1993). It is important because the success or failure of a system depends on how well people like the system, how easy it is to use, and the system's effectiveness. In certain situations such as medical systems, transportation systems, and military systems, usability can make the difference between life and death. If an error is committed or a system cannot be used effectively, disaster can result. A more common outcome is that if a system is not liked by users, it simply will not be used, and the money spent on its development will be wasted.

Current industry practice in both the United States and Europe is to measure the effectiveness, efficiency, and user satisfaction of a system to determine its usability. Effectiveness can be measured by determining whether or not people using the system were able to successfully complete intended tasks. Efficiency can be measured by determining how easy it is to learn to use a system and how much of the learning is remembered. User satisfaction can be measured by surveys or observational studies.

In system design, one must work within budgetary, design, resource, and technological constraints. Through usability analysis, an attempt can be made to make the best use of AR technologies from a human factors viewpoint. While usability is often an add-on performed at the end of a design lifecycle, it should actually be an integral part of a comprehensive view of system development. A usability analyst should be a part of a concurrent engineering team from the concept through the final design phase. Many AR technologies are in their infancy, however, and analysis of what works and what does not in technological implementation will provide valuable lessons learned for future research and systems development.

Research in AR usability can be conducted via two avenues: practical application-oriented or theoretical. The former would be for a specific system, the latter for the development of general guidelines applicable to a broad range of applications. General research in AR, without specific intent to develop usability per se, will also tend to lead to the development of guidelines for good system design. In addition, studies can

also be performed to determine whether or not AR offers benefits in certain tasks.

For example, Tang et al (2003) performed a study comparing the effectiveness of AR (via overlaid 3D instructions) to paper-based and monitor-based instructions in an object assembly task. They found that AR reduced the error rate by 82%. The authors noted several display-related usability issues and technological limitations. A Sony Glasstron display was used in their research. Issues the researchers encountered included focusing problems and the fact that supplying information outside the user's central vision area would be an improvement for some users. Attention tunneling was found to be a potentially problematic phenomenon, because with users fixating on the AR display other important visual information might be ignored.

Research in the usability of virtual environments (VEs) and in human-computer interaction and interfaces are related to AR research. Bowman et al. (2002) performed a "classification and comparison of methods" used to evaluate usability in virtual environments. Issues they noted include the system usage environment and the type of human-computer interface used, the method of evaluation of the interface, the types of users, and what measures to use for the users. The authors differentiate and compare several usability evaluation methods. As they note, traditional techniques for usability evaluation in graphical user interfaces (GUIs) may not always generalize for use in VEs. Methods need to be tailored and developed when novel interfaces and interaction techniques are used. In AR a similar situation exists, and creativity must be used to adapt and develop usability engineering techniques to help develop and evaluate new AR systems.

Usability engineering has been applied in the development of BARS (Gabbard et al., 2002). The primary arguments for involving users at every stage of the design process are (1) to enable the designers to include the most useful set of features in the user interface and system capabilities and (2) to gather data that supports the claims that those features are implemented in a way that users will be able to use them during system operation. In the case of military applications, that of course can mean under high stress conditions (emotional and time pressure).

Head-up displays (HUDs) are an example of a successful application of AR technology. From the beginning, the human factors issues of such displays were among the primary concerns. For example, HUDs in automobiles needed to be developed so that they were easy to see both at night and in glaring daylight sun. Early models were less than ideal, but newer models are greatly improved. Eventually designs became more sophisticated. Research has been conducted using a thermal imaging camera for night time vision integrated into a HUD, which could only be considered after the usability problems of early HUDs were worked out. (Department of Transportation, 2000).

3.3 Issues with Field vs. Controlled Studies

There are many considerations when conducting studies involving human users. Considerations include experimental confounds, number of participants needed, demographics of participants, and testing environment. For example, many experiments sponsored by DoD involve university laboratories using college students who are considered as novices. However, access to military users and appropriate settings are often very limited.

When conducting research using human subjects it is common to reduce the number of confounding variables so that results have statistical validity. Care must be taken, though, so that the results have some clear connection to the use and that the results duly consider the full range of operational situations that might be encountered. A hypothetical example in AR illustrates this point. If the Army's Objective Force Warrior is to use a monocular display device, AR display-related research involving human performance should consider similar types of displays. A fully-immersive video-based display might yield results that are not relevant to this program; the display likely changes performance characteristics.

The number and quantity of participants should also be a consideration in various types of studies. Small numbers of participants in each treatment of an experiment result in low statistical power or high sample variance in the results. Common practice is to have at least eight participants in each treatment for studies involving the evaluation of human performance. This low

number is sufficient for low-level perceptual tests in which each participant can do many trials. The number can quickly swell if an independent variable can not be experienced by each subject, such as gender. On the other hand, practical considerations of time, funding, and access to participants temper our ability to reach theoretical requirements.

The environment for testing AR is limited for several reasons. One reason is the limited access and availability of military bases or other appropriate settings. The other is the nature of the AR equipment, such as BARS. This equipment is typically prototypical in nature and fragile, both of which limit its functionality in operational settings.

3.4 Current Human Centered Mobile Augmented Reality Research

Evaluations of AR's benefits on human performance are not easy to obtain for several reasons. First, the equipment is at a prototypical stage and therefore fragile and sometimes with limited or variable performance characteristics. This results in experimental designs that must consider the performance, planned enhancements, and reliability of equipment being used. Secondly, evaluation of AR can consider evaluation methods of related systems, such as virtual environments, but the methodologies used must have a clear linkage to their heritage and sound basis for extension into AR. Third, identification and involvement of appropriate user groups in the evaluation process is difficult. For example, it is often difficult to get access to military users in sufficient numbers to support experimentation. Fourth, relevant study methods must consider the operational realism with the accompanying experimental confounds an operational environment introduces. On the other hand, overly simplified experiments in controlled environments are difficult to extend to a real life setting.

Although AR systems are just emerging and evaluations are difficult, progress is being made in evaluating human performance in augmented reality. Currently, experiments are being conducted using AR in several areas such as distance estimation, occlusion layers, navigation for search and rescue, and decision making.

Regarding distance estimation, Ellis and Menges (1998) found that the presence of a visible (real) surface near a virtual object significantly influences the user's perception of the depth of the virtual object. For most users, the virtual object appeared to be nearer than it really was. This varied widely with the user's age and ability to use accommodation, even to the point of some users being influenced to think that the virtual object was further away than it really was. Adding virtual backgrounds with texture reduced the errors, as did the introduction of virtual holes, similar to those described above. Rolland (2000) found that occlusion of the real object by the virtual object gave the incorrect impression that the virtual object was in front, despite the object being located behind the real object and other perceptual cues denoting this relationship. Further studies showed that users performed better when allowed to adjust the depth of virtual objects than when making forced-choice decisions about the objects' locations.

Furmanski et al. (2002) conducted a pilot experiment on medium-field depth perception. Using video AR, they showed users a stimulus which was either behind or at the same distance as an obstructing surface. They then asked users to identify whether the stimulus was behind, at the same distance as, or closer than the obstruction. The performance metric here is thus an ordinal depth measure. Only a single occluded object was present in the test. The parameters in the pilot test were the presence of a cutaway in the obstruction and motion parallax. The presence of the cutaway significantly improved users' perceptions of the correct location when the stimulus was behind the obstruction. The authors offered three possible locations to the users, even though only two locations were used. Users consistently believed that the stimulus was in front of the obstruction, despite the fact that it never was.

Livingston et al. (2003) gives insight into how users perceive data presented in the system. It is well-known that a consistent ground plane (a perspective constraint) is a powerful depth cue. However, graphical parameters can also provide strong depth cues, albeit not physically realistic cues. An experiment on conveying ordinal depth position found that, with the ground plane constraint apparent, the average error was 0.144 ordinal positions, whereas with the ground plane not depicted and the following settings:

- drawing style: "wire+fill"
- opacity: decreasing with distance
- intensity: decreasing with distance

the average error was 0.111 positions. The data thus suggest that the authors did find a set of graphical parameters as powerful as the presence of the ground plane constraint. This would indeed be a powerful statement, but requires further testing. As a secondary result, the fact that there was a main effect of repetition on response time but not on accuracy indicates that the subjects could quickly understand the semantic meaning of the encodings. This validates that BARS is performing at a level that is sufficient for users to consistently (but not always) identify the ordinal depth among three occluded objects.

Navigation is a particularly good area for VE's and AR because many areas cannot be fully explored for training or operational purposes. AR offers the possibility to support navigational tasks in training or operational settings.

Studies involving AR approaches to enhance human performance are underway by researchers at the University of Central Florida's Institute for Simulation and Training (IST). A special case of navigation, called search and rescue navigation is being investigated. Search and rescue navigation involves the user seeking an objective (such as a hostage), completely traversing the area (to neutralize hostile situations), and traversing a space with which he or she is not familiar.

The studies involve the BARS system with a 16°x20° monocular display which contains a map of an area. This area is a small maze that is modeled in BARS and in a physical maze. This level of AR represents augmentation that is not present, but added to the real world. It is similar to a HUD.

The studies involved egocentric moving and exocentric fixed maps as well as user control on when the display is active. These studies used 120 novices, balanced for gender. Data is being analyzed, but preliminary results show some advantages to AR when compared to paper maps. Full details are expected to be completed and published by the end of 2004.

4. FUTURE AR RESEARCH

Future AR research needs to be conducted in many areas, such as outdoor navigation, variation in visibility, reducing data complexity, and the introduction of other interface modalities. The use of outdoor navigational aids will be an essential part of the toolkit for soldiers, policemen, and perhaps firemen in smoky buildings. How best to present the information and how best to design the human-computer interface are of paramount importance. With the ability to employ vision enhancement technologies such as night-vision and seeing through fog and smoke, the usability of the type and design of the display are important. The display modes (colors, see through versus opaque, exocentric versus egocentric, on-demand versus continuous) need to be optimized not just for the design but for each user's preferences. The introduction of modalities other than vision is imperative. For example, voice interfaces, both for computer output and input, will become an essential part of many AR systems and much research remains to be done in audio interfaces. In addition to voice technology, other types of sound, such as 3D or surround sound data display may prove useful in AR systems.

5. CONCLUSIONS

AR's applicability to problems in the military domain has been demonstrated by a variety of research prototype systems. The ability to have information about the surrounding environment integrated into the user's view of that environment can aid situational awareness. The potential to mitigate difficult aspects of urban operations such as location of friendly forces argues for the continued research and development of AR systems. Sensors and systems that attempt to locate enemy forces via weapons or radio signals provide yet more information about the battlespace that can be displayed in an AR system. AR provides a natural interface to view any information about the environment, gathered from any source. Embedded sensors promise to provide vast data about an environment; however, without a usable interface for such data, the individual will simply be overwhelmed by data and be unable to gather any information from it.

BARS is also being adapted to training environments, in which virtual forces can provide a realistic and rich scenario. A single controller could interactively operate a computer-generated enemy force of thousands rather than instruct a sparse human resistance force. Moving targets and varying scenarios are difficult to present with current training systems, but AR offers the potential to extend training to include these useful features. Remote operation of robotic systems currently use primitive interfaces for direct control. The ability to see the environment could make such control tasks easier.

Military designers are confronted with ever-increasing complexity and technological sophistication in their systems. While the application of more powerful technology can allow for more productive and better-equipped soldiers, the handling of computer interface complexity is challenging. Soldiers must be able to use the technology easily, and it must be mobile when needed. AR can offer computing power to the mobile soldier, while allowing for new modes of operation. For instance, via AR displays, soldiers in the field could receive updated maps in real time with critical information essential to success and survival, which, properly deployed, would be a strategic advantage on the battlefield. In addition, future training systems may depend heavily on AR. Concepts for future applications of AR need to be developed in order to take advantage of increasingly powerful technology.

Military organizations can help by partnering with academia and industry in supporting and reviewing AR research to help develop the practical and theoretical basis for AR applications. The research being conducted today is refining our AR knowledgebase, and what works and what does not work for users is being determined. It is best that this knowledge be developed in laboratories and field trials rather than in the battlefield, in order to avoid costly errors.

Usability analysis and testing, when an inherent part of the design cycle rather than an afterthought, makes the difference between success and failure in system design and deployment. Data gathered from user tests and user comments about prototypical AR systems offer good feedback on how to design them better and also about what features are needed. This, coupled with the analysis of usability experts, will

ensure successful system development and deployment.

Participation by the ultimate user or user's representative is needed in AR research for several reasons. First, technically oriented research activities involving the user can help ensure that the highest priority needs are being addressed. Second, involving users in human factors evaluations takes much of the guesswork from trying to extend the relevance of evaluations involving novices. Finally, user involvement in a systems oriented AR research program will hasten the introduction of useful technology into the military's inventory.

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