ONR Initiatives Grant

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LONG-TERM GOAL

The ONR Initiatives Grant is aimed at supporting basic research investigations for the U. S. Navy. These initiatives encourage interaction between The Pennsylvania State University Applied Research Laboratory (ARL) researchers and Penn State faculty members, and provides opportunities for student research. During 1999, the ONR Initiatives program included four research projects and a High School Student Intern Program.

OBJECTIVES

Figure 1: Objectives of the FY 99 ONR Initiatives Projects

Project	**Focus/Objectives**	**Key Investigators**
Turbulent flows over rough walls	Continue research in modeling and experimental data collection related to fluid flow near rough surfaces	H. Gibeling
High frequency acoustics and signal processing for weapons	A new project initiated to investigate two key areas; (a) the limitations of the ocean medium for coherent signal processing, and (b) acoustic properties of inhomogeneous time varying oceanographic environments	D. L. Bradley
Coordination science	Continuation of a project to investigate technology for effective coordination of large scale endeavors such as the design of complex systems	S. Phoha E. Eberbach
Non-lethal technologies	Continuation of a project to investigate key technologies related to non-lethal defense	D. L. Hall J. H. Shelton
High school intern program	Summer enrichment program for high school students to encourage orientation for science and engineering	G. Lesieutre

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APPROACH

Turbulent flows over rough walls – Historically, computational fluid dynamics studies have focused primarily on relatively smooth surfaces. To accurately predict flow over surfaces for realistic U. S. navy underwater vehicles, this assumption needs to be relaxed. The treatment of flow over rough surfaces requires knowledge of the effects of the height of the surface roughness elements as well as the type of surface roughness. This effort has focused on both theoretical developments and experimental measurements to improve our understanding of this important problem. Some experimental studies (performed at Penn State ARL's large water tunnel) have involved flow over rough surfaces coated with sand grains. The experimental data indicates a need for a more general rough surface that accounts for the height and shape of roughness elements. The theoretical work has extended Gatski's explicit algebraic stress model (AIAA 9900157), and Menter's kappa-omega model (AIAA Journal, 1994).

High frequency acoustics and signal processing for weapons - This project is a new project initiated in FY '99. The purpose of the project is to investigate two key areas; (a) understanding the limitations of the ocean medium for coherent signal processing, and (b) understanding the acoustic properties of inhomogeneous, time-varying oceanographic environments. The approach for the first area involves exploiting broadband multiple sequential pulse techniques to measure medium stability. This area will develop and evaluate analytic modes to extend low frequency time reversal approaches, and investigate statistical-based high-frequency approaches. The approach for the second key area involves the development of analytical computational fluid dynamic (CFD) models of 2-phase flow to predict bubble distributions in a turbulent wake. In addition, analytic acoustic models of propagation will be developed for areas within and throughout a turbulent, bubbly water mass.

Coordination science - This research is developing fundamental techniques and associated computer technology to support greatly improved coordination in simulation-based design and acquisition of complex systems. A formal mode of the design network is being formulated as a finite set of interacting *automata*. Intelligent agents for design coordination and design supervision are introduced. The introduction of higher order polyadic process algebra allows the formulation of algorithms for autonomous self-adaptation of the system design network to achieve high assurance specification in dynamic and uncertain environments. A Design Coordination Network (DCN) approach is being used. An iterative refinement mechanism, for selecting component design characteristics and behavior coordination constraints, optimizes system performance.

Non-lethal technologies – One aspect of non-lethal technology is the capability for remote sensing and activation using coordinated semi-autonomous mobile devices (e.g., robots, aircraft, or underwater vehicles). Such networks allow remote monitoring of hostile environments and extension of human capabilities to support small unit operations. Examples include monitoring the dispersion of chemical and biological agents, perimeter surveillance, and mine detection. A key problem in such systems involves how to combine human-in-the-loop control, with real-time semi-autonomous behavior by the mobile network nodes. This project has focused on the development of new techniques for hierarchical control of multiple systems with adaptation for a human in the loop.

WORK COMPLETED

Turbulent flows over rough walls – Accomplishments occurred in two major areas; (1) development of an explicit algebraic stress model and (2) development of a roughness model. In the first area, Gatski's explicit algebraic stress model was implemented and tested in a serial version of UNCLE-TURBO on a flat plate. The model was transferred to the parallel code, UNCLE-REL, where it was used to solve for the flow through three-dimensional square duct geometry. The solution was compared with experimental data, showing excellent agreement. Further analysis requires receipt of experimental uncertainty analysis and may include further grid refinement. In the second area, Menter's *kappa-omega* model was implemented and tested in UNCLE-TURBO on a flat plate with a smooth wall. In this model, omega is based on the full dissipation rate, and as a result, both omega and the gradient of omega approach infinity near a smooth solid surface. For this reason, the flux jacobians for the turbulence equations needed to be derived and coded analytically, and then computed using double precision arithmetic. This is contrary to our previous experience with the Coakley q-omega model, where omega is based on only the isotropic component of the dissipation rate. There, omega has a zero slope and finite value at solid walls. Numerical flux jacobians are sufficient for the turbulence equations, even with single precision arithmetic. In subsequent research, the kappa-omega roughness model will become the underlying two-equation model for Gatski's explicit algebraic stress models. The models will be tested together on the flat-plate geometry and used for the solution of the three-dimensional square duct.

High frequency acoustics and signal processing for weapons – This project was initiated in FY '99, in anticipation of the Office of Naval Research shift in emphasis to focus the initiatives program on ocean acoustics. Accomplishments included the following. First, ARL participated in a joint experiment in the Mediterranean with MPL/SI0 on a time reversal test at 3.5 kHz. Collected data are currently being analyzed. Second, computational fluid dynamical modeling has been initiated. The model involves hydro-dynamical source mechanisms due to a high-speed surface ship. Acoustic propagation modeling has also been started with simplified bubble distributions. This model is based on an analysis of airborne photographs of ship wakes.

Coordination science – Mathematical models and innovative analytical approaches were developed for the coordination of component behaviors to achieve high assurance of the integrated dynamical system. A survey of related research results identified software being developed at the University of Berkley for automated coordination of component behavior from graphical models of behavior interactions and constraints. The software was acquired and used to enhance ARL developments. Specific accomplishments include the following. First, a formal mathematical technique was developed for explicit coordination of component behaviors. This general $-calculus was derived to assist the representation of behavior coordination. Second, a common message parsing language was developed for behavioral coordination of system components. A basic compiler/processor was implemented to allow utilization of the parsing language. Third, syntax was created for automating computational intelligence for design refinement.

Non-lethal technologies – During this year, research focused on extending concepts of generalized controllers (e.g. for a hierarchy of semi-autonomous agents) to include human-in-the-loop decision-making. In particular, architectural extensions were developed for the ARL intelligent controller (initially developed and successfully utilized for controlling underwater vehicles). These extensions included a fractal architecture and a hierarchical approach that allows an application to be simultaneously controlled and monitored at a real-time level (e.g., milliseconds), and support for interaction at a non-real time, human decision time-scale. This formulation includes the human-in-the-loop as an integral part of the system. This architecture and approach will allow a human to interact with an intelligent controller (IC), and allow the IC to evolve to "learn from the human" (adapt to the human user's needs), and also allow a human to "learn from the controller". This research has provided concepts and architecture formulations for use in areas such as intelligent control of manufacturing processes or intelligent monitoring and control of damage control on board ships or aircraft.

RESULTS

Figure 2: Summary of Results

Project	Summary of Results
Turbulent flows over rough walls	Continuing project. Developed an explicit algebraic stress model, and a roughness model. Implemented the models and compared with experimental results on a flat plate.
High frequency acoustics and signal processing for weapons	New project initiated in FY ’99. Initial results include; (a) completion of a collaborative experiment in the Mediterranean with SPL/SI0, and (b) formulation of CFD models of 2-phase flow to predict bubble distributions in a turbulent wake
Coordination science	Created a new mathematical formulation (an $-calculus) for representing/coordinating component behaviors; implemented a parsing computer language; and created a syntax for automating computational intelligence for design refinement
Non-lethal technologies	Developed new architectures for intelligent controller systems including integration of a human-in-the-loop decision maker

IMPACT/APPLICATIONS

Figure 3: Impact and Application of FY 99 Initiatives Projects

Project	Potential Impact	Example Applications
Turbulent flows over rough walls	Improved ability to accurately model turbulent flow over rough surfaces	- Improved designs for advanced underwater vehicles - Improved understanding of system limitations and capabilities
High frequency acoustics and signal processing for weapons	Development of new acoustic inversion methods, improved signal processing algorithms, and channel conditioning techniques	- Adaptive weapons - Hard kill counter weapons - Network-centric distributed sensors/weapons/shooters
Coordination science	Major advances in the ability to coordinate designs of complex systems	- Improved capability for DoD acquisition of complex systems - Reduced costs of collaborative system design
Non-lethal technologies	New advances in intelligent controller systems involving human in the loop decision making	- Controllers for automated damage assessment and control systems - Advanced condition-based maintenance systems for aircraft, ships, and submarines

TRANSITIONS

The research performed under this project is integrated in the Pennsylvania State University Applied Research Laboratory's on-going support to the U. S. Navy. Transition potentials include support to programs such as the DD-21, the AAAV, the Joint Automated Environment Accelerated Capability Technology Demonstration (ACTD), and related programs.

RELATED PROJECTS

Figure 4: Related Projects

Related Projects	Sponsor	Leverage/Relationship
Ocean sampling mobile network (SAMON)	Office of Naval Research (ONR)	ONR Initiatives project provides the theoretical basis for practical applications of distributed design of complex systems and semi-autonomous robots
Integrated Air Defense Systems (IADS)	NAVSEA (Dahlgren)	ONR Initiatives project provides concepts of human in the loop decision support systems
DCARM	NRL	ONR Initiatives project provides new concepts and techniques for hierarchical control and human in the loop decision making

PUBLICATIONS

[1] Eberbach, E., Brooks, R., and Phoha, S., "Flexible Optimization and Evolution of Underwater Autonomous Agents," Technical Proceedings of the *Seventh International Workshop on Rough Sets, Fuzzy Sets, Data Mining and Granular-Soft Computing*, November 9-11, 1999, Ube, Yamaguchi, Japan.

[2] Eberbach, E., and Phoha, S., "SAMON: Communication, Cooperation and Learning of Mobile Autonomous Robotic Agents," Proceedings form the *11th IEEE International Conference on Tools and Artificial Intelligence*, Chicago, IL, November 9-11, 1999.

[3] Phoha, S., "Design Coordination Networks for High Assurance In Complex Dynamic System," invited presentation to *ONR PM Dr. Kam Ng at the ONR Workshop on Undersea Weapons Design & Optimization* held at ARL/PSU, State College, PA, August 3, 1999.

[4] Hall, D. L. and Garga, A. K., "New Perspectives on Level Four Processing in Data Fusion Systems", *Proceedings of the SPIE AeroSense '99 Conference: Digitization of the Battlefield IV*, April 1999, Orlando, FL