REAL-TIME MODELING OF CROSS-BODY FLOW FOR TORPEDO TUBE RECOVERY OF THE *PHOENIX* AUTONOMOUS UNDERWATER VEHICLE (AUV)

Kevin Michael Byrne-Lieutenant, United States Navy
B.S., State University of New York Maritime College, 1991
Master of Science in Computer Science-March 1998
Advisor: Don Brutzman, Undersea Warfare Academic Group
Second Reader: Robert P. McGhee, Department of Computer Science

A virtual world provides an exceptional resource for the testing and development of an Autonomous Underwater Vehicle (AUV). The difficulties associated with the underwater environment are numerous and complex. In order to properly verify vehicle results in the laboratory such a world must accurately model the physics associated with the vehicle, its submerged hydrodynamics characteristics, and interactions with the environment. Environmental effects such as wave motion, currents, and flow forces created by bodies moving through the water can cause unpredicted performance variations and failures in the ocean environment. The current *Phoenix* AUV virtual world includes steady-state ocean currents, but does not take into account the environmental effects of waves and flow forces induced by adjacent vehicles (such as a moving submarine docking target).

This work provides a thorough real-time simulation of these complex factors using physically-based models. The problem is broken down into wave motion effects, submarine-induced flow fields, and virtual sensors to improve AUV motion control. Each set of forces is thoroughly analyzed and realistically simulated in real-time through the algorithms developed. In order to maintain real-time response, perturbations in the flow field caused by the AUV itself are assumed to be negligible. Simulated testing is performed across a range of easy to worst-case scenarios in order to justify assumptions. Extensive testing using virtual sensors is used to develop adequate control algorithms in the presence of turbulent cross-body flow.

The result of this research is an enhanced virtual world which more accurately depicts the ocean environment, along with the models and control algorithms required to design and operate an AUV during submarine launch and recovery. A platform independent approach to virtual environment simulation is presented through the use of the Virtual Reality Modeling Language (VRML) and Java. Finally, simulation test results provide strong evidence that AUV control with actual cross-body flow sensors can enable stable navigation, first through a turbulent flow field and then for subsequent docking with a moving submarine.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Surface/Under Surface Vehicles - Ships and Watercraft, Modeling and Simulation

KEYWORDS: Virtual Environment, Simulation-Based Design, Cross-Body Flow, Autonomous Underwater Vehicle (AUV), Platform-Independent Simulation

COORDINATED INLAND AREA SEARCH AND RESCUE (SAR) PLANNING AND EXECUTION TOOL

Timothy S. Castle-Lieutenant, United States Coast Guard
B.S., United States Coast Guard Academy, 1991
Master of Science in Operations Research-September 1998
Advisors: Gordon Bradley, Department of Operations Research
Alan Washburn, Department of Operations Research
Second Reader: James Eagle, Undersea Warfare Academic Group

This thesis designs and implements the Coordinated Inland Area Search and Rescue (SAR) System (COINSS). This system provides several important features not provided by current inland SAR computer systems. First is the ability to model movement of the target. Second is modeling the effect terrain has on the movement of the target. Third is the visual presentation of a probability map, a color display showing the probability that the target is located at various geographic positions. COINSS is developed in the Java programming language. It is designed to be implemented with a map-based planning system using loosely coupled components. COINSS provides the initialization, movement, and search algorithms

which are used by the planning system to support the search operation. The initialization algorithms define the search area where the SAR operation will occur. Initial areas are defined for the target. COINSS models the movement of the target as a discrete time Markov chain. Bayes theorem is used to update the probability map when negative search information is provided. This thesis will improve inland SAR operations by providing the first model with an interactive graphical user interface and a model of target movement.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Search and Rescue, Java, Loosely Coupled Components, Map Based Planning

SUBMARINE PERISCOPE DEPTH COURSE SELECTION TACTICAL DECISION AID

D.J. Danko-Lieutenant, United States Navy
B.S.E., University of Washington, 1990
Master of Science in Operations Research-December 1997
Advisor: Alan R. Washburn, Department of Operations Research
Second Reader: James N. Eagle, Undersea Warfare Academic Group

Coming to periscope depth is one of the most intensive of the routine submarine operations. Errors in fire control and sonar system information serve to produce uncertain contact solutions that complicate the decision of selecting a safe course. The model developed in this thesis simulates a specified number of trials on each possible course, with the measure of effectiveness for each course being the probability of the course being acceptable with respect to specified minimum range criteria. The model outputs a geographic display and a graph of the measures of effectiveness versus course.

KEYWORDS: Submarine Periscope Depth Operations, Course Selection, Tactical Decision Aid, Simulations Using Visual Basic Programming

DoD KEY TECHNOLOGY AREA: Surface/Under Surface Vehicles-Ships and Watercraft Ground Vehicles

TESTING AND DEVELOPMENT OF A LOW COST, DIGITAL SIGNAL PROCESSOR-(DSP) BASED TORPEDO COUNTERMEASURE (U)

Mark T. Evans-Lieutenant, United States Navy
B.S., United States Naval Academy, 1992
Master of Science in Engineering Acoustics-September 1998
and
Robert J. Jezek Jr.-Lieutenant, United States Navy
B.S., United States Naval Academy, 1992
Master of Science in Engineering Acoustics-September 1998
Advisors: Donald P. Brutzman, Undersea Warfare Academic Group
Thomas G. Muir, Chair of Mine Warfare

The wide spread proliferation of modern submarines and torpedoes has significantly increased the threat to U.S. Naval Forces. Current U.S. torpedo countermeasures are not as effective against the latest generation of torpedoes. A new torpedo countermeasure is required to provide an acceptable defense against these new weapons.

The cost of any system is an important characteristic in today's restrictive fiscal policy. The use of Commercial-off-the-shelf (COTS) technology can significantly reduce development and procurement costs of any military program.

This thesis details the acoustic testing, troubleshooting, and development of a new type torpedo countermeasure. This torpedo countermeasure is based on a Digital Signal Processor that allows a computer microprocessor to analyze a torpedo's sonar signal and generate an appropriate response signal as dictated by its programming. This gives flexibility that is a significant improvement over today's dedicated hardware systems and enables the device to outperform current countermeasures. Extensive use of COTS technology has minimized the cost of a prototype device. Computer simulation has

played a large role in troubleshooting countermeasure software. Laboratory acoustic testing of the prototype hardware and software is described in detail, along with the resulting problems, proposed solutions and additional developmental steps.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Conventional Weapons

KEYWORDS: Torpedo Countermeasures, Digital Signal Processing, Acoustic Modem, Acoustic Telemetry, Acoustic Decoy, Signal Analysis

SURFACE SHIP SENSOR EMPLOYMENT AGAINST DIESEL SUBMARINES

Matthew Jordan Harrison-Lieutenant, United States Navy
B.S., United States Naval Academy, 1992
Master of Science in Operations Research-March 1998
Advisors: Wayne P. Hughes, Department of Operations Research
Don Brutzman, Undersea Warfare Academic Group
Second Reader: RADM John J. Ekelund Jr., USN (Ret)

This thesis provides tactical guidance for employment of surface ship sensors against torpedo-armed diesel submarines during littoral operations. Advantageous utilization of antisubmarine sensor systems in the littoral environment incorporates a blend of competent tactical experience and innovative thought processes and reflects environmental conditions, threat status, and mission priorities. Through extensive use of a modeling and simulation program, this thesis determines the preferred sensor employment configurations based on surface ship and submarine detection and counter-detection ranges and vulnerabilities to torpedo attack. Preference is based on a measure of effectiveness that minimizes the risk faced by surface ships from a diesel submarine threat, and provides tactical recommendations that are readily implementable as sensor employment policies.

DoD KEY TECHNOLOGY AREA: Electronic Warfare, Sensors, Surface/Under Surface Vehicles – Ships and Watercraft, Modeling and Simulation

KEYWORDS: Antisubmarine Tactics, Simulation, Sensor Employment, Antisubmarine Warfare

REAL-TIME 3D SONAR MODELING AND VISUALIZATION

Timothy M. Holliday-Lieutenant, United States Navy
B.S., University of New Mexico, 1990
Master of Science in Applied Physics-June 1998
Advisors: Kevin B. Smith, Department of Physics
Don Brutzman, Undersea Warfare Academic Group

Virtual world simulations are realistic when each individual component is simulated in a manner that reflects reality. For an underwater virtual world that simulates acoustic detection, a physically based sonar propagation model is required if ranges in excess of tens of meters are expected.

This thesis creates an application programming interface (API) for realtime 3D computation and visualization of acoustic energy propagation. The API provides features for generating complex physically based sonar information at interaction rates, and then visualizing that acoustic information. The simulation is programmed in Java and runs either as a stand-alone program or as a script in a web browser. This program generates Virtual Reality Modeling Language (VRML 97) compliant code that can be viewed from any VRML-capable browser. This approach allows the characteristics of the energy propagation to be calculated with high precision and observed in 3D.

As sonar system information bandwidth becomes larger, more intuitive ways of presenting information to a user will be required. Higher information density in a more intuitive format can free the user from integrating the data himself and allow quicker reaction times. This thesis and the API provide the foundation for fundamental advances in sonar modeling and visualization.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Modeling, Simulation, Sonar, Ray Tracing, Visualization, VRML

VRML TERRAIN MODELING FOR THE MONTEREY BAY NATIONAL MARINE SANCTUARY (MBNMS)

R. Greg Leaver-Lieutenant, United States Navy
B.S., Oklahoma State University, 1987
Master of Science in Information Technology Management-September 1998
Advisor: Don Brutzman, Undersea Warfare Academic Group
Rex Buddenberg, Information Systems Academic Group

This thesis develops an online model of the topographic terrain of Monterey Bay National Marine Sanctuary (MBNMS) seafloor. Written in the Virtual Reality Modeling Language (VRML), the model is an interactive 3D application composed of hundreds of topographic tiles linked together to form a mosaic of the bay. Low-resolution tiles are traded for higher resolution tiles as the viewer gets closer to the terrain.

Important contributions include a naming convention for autogeneration of interlinked files, test usage of proposed metadata conventions linking VRML and the eXtensible Markup Language (XML), demonstrated use of the GeoVRML Working Groups proposed QuadLOD node, and a preliminary 3D navigation icon for terrain interrogation and wayfinding. Terrain data was produced from registered, smoothed and subsampled bathymetric sonarscan results. Because the model is geo-referenced with the Universal Transverse Mercator (UTM) coordinate system, a user can easily add scientific content or data to a selected location of the MBNMS in a manner analogous to adding 2D content to an HTML page. Thus, the user can place 3D content anywhere in the MBNMS in geographic context merely by specifying the geographic coordinates and depth of the content in standard VRML syntax.

Future work includes improvement of metadata interoperability, navigation icon user testing, and autogeneration of image-based texture tiles for scientific visualization.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Computing and Software, Environmental Quality, Human Systems Interface, Sensors, Modeling and Simulation

KEYWORDS: World Wide Web, Virtual Reality Modeling Language (VRML), Large-Scale Virtual Environments (LSVEs), Monterey Bay, 3D Graphics Modeling

SIMULATION OF THE AUTONOMOUS COMBAT SYSTEMS ROBOT OPTICAL DETECTION SYSTEM

William B. McNeal-Lieutenant, United States Navy
B.S., Southern University, 1991
M.P.A, Troy State University, 1995
Master of Science in Applied Physics-December 1997
Advisors: Gordon E. Schacher, Department of Physics
Donald Brutzman, Undersea Warfare Academic Group

NPS Combat Systems students learn systems engineering through a series of courses in design, development, implementation, and testing and evaluation. In the last of this series of courses, students design an autonomous robot capable of searching, acquiring, and tracking another autonomous robot having similar capabilities. The project culminates in the Robot Wars Competition, where groups of students have their robots battle each other.

This thesis is the second in a series designed to realistically simulate the robot wars battles. The end-to-end functionality of the optical detection system is modeled, and the necessary physics are implemented for effective simulation and depiction. The model uses a transfer function approach and includes all physical processes, from initial optical beacon emission

to final digital control signal. Exercising the model over time using realistic robot inputs yields a simulation that closely replicates real behavior. A Virtual Reality Modeling Language (VRML) program uses data files of each Simbot's movement to generate a 3-dimensional animated scene of the detection sequence. This implemented optical model effectively simulates the SE 3015 robot optical detection system and can reproduce an actual detection and tracking sequence between two robots.

KEYWORDS: Optics, Models, Simulation, Robots

DoD KEY TECHNOLOGY AREAS: Computing and Software, Electronics, Modeling and Simulation

REMOTE NETWORK ADMINISTRATION OF THE SEANET COMMUNICATION NODE SYSTEM

Don C. Murray-Lieutenant, United States Navy
B.S., University of Oklahoma, 1991
Master of Science in Information Technology Management-September 1998
and
Christopher L. Pratt-Lieutenant, United States Navy
B.S., Virginia Military Institute, 1990
Master of Science in Information Technology Management-September 1998
Advisor: Rex Buddenberg, Information Systems Academic Group
Second Reader: Don Brutzman, Undersea Warfare Academic Group

Maritime data communications are expensive and of limited capacity. Currently there is no established infrastructure to support Internet connectivity for sea-going vessels. The SeaNet program is investigating maritime networking solutions. One aspect of the SeaNet program is promoting remote network management. Remote network management will provide the maritime research community with a flexible and cost-effective tool for monitoring sea based assets. The objective of this thesis is to investigate remote network management over a satellite connection in support of the SeaNet programs goals.

To research the potential for remote network management, the Naval Postgraduate School has developed its own SeaNet laboratory. This laboratory simulates both the shipboard and shore-based infrastructure of the SeaNet program and conducts remote network management on these components. This thesis discusses the SeaNet program, network management concepts, the NPS SeaNet laboratory, research findings, and recommendations for future research. Remote Network Management of the SeaNet Control Node system is possible, however, continued research in this area is needed.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Network Management, Internet-to-Sea, SeaNet

COMPARISON OF THE UNDERWATER AMBIENT NOISE MEASURED IN THREE LARGE EXHIBITS AT THE MONTEREY BAY AQUARIUM AND IN THE INNER MONTEREY BAY

Daniel Matthew O'Neal-Lieutenant, United States Navy
B.A., The Citadel, 1992
Master of Science in Applied Physics-June 1998
Advisor: Steven R. Baker, Department of Physics
Second Reader: Thomas G. Muir, Chair of Mine Warfare

Ambient underwater acoustic noise recordings were made in three large exhibits at the Monterey Bay Aquarium and the inner Monterey Bay, with the results reported here. Observed broadband (0-6.4 kHz) acoustic noise levels ranged from 112-125 dB re 1 μP for the aquarium exhibits under normal operating conditions. Broadband acoustic noise levels of 113 dB and 116 dB re 1 μPa were observed for the nearshore and offshore bay locations, respectively.

A comparison of the noise spectrum in the aquarium's largest exhibit to that of the environment which it attempts to simulate, the offshore bay, revealed a higher noise level of approximately 15-25 dB in the exhibit for frequencies between 20 Hz and 6.4 kHz. A similar comparison of the noise spectra of the two smaller exhibits and the nearshore bay location revealed a difference of approximately 5-10 dB across the entire frequency range of 0-6.4 kHz.

Aquarium measurements with various mechanical equipment (motors, fans, pumps, sprinklers, wave machine) turned on and off highlighted some of the prominent ambient noise contributors. It was concluded that the pump machinery is the greatest contributor to ambient noise, with the strength directly related to the exhibits' proximity to the machinery room.

DoD KEY TECHNOLOGY AREA: Other (Underwater Acoustic Ambient Noise)

KEYWORDS: Ambient Noise, Noise Measurements, Aquarium, Monterey Bay

AUDITORY-VISUAL CROSS-MODAL PERCEPTION PHENOMENA

Russell L. Storms-Major, United States Army
B.S., United States Military Academy, 1986
M.S., Naval Postgraduate School, 1995
Doctor of Philosophy in Computer Science-September 1998
Advisor: Michael J. Zyda, Department of Computer Science
Committee: Robert B. McGhee, Department of Computer Science
Rudolph P. Darken, Department of Computer Science
Donald P. Brutzman, Undersea Warfare Academic Group
Lawrence J. Ziomek, Department of Electrical and Computer Engineering
Durand R. Begault, NASA Ames Research Center
Elizabeth M. Wenze, NASA Ames Research Center

The quality of realism in virtual environments is typically considered to be a function of visual and audio fidelity mutually exclusive of each other. However, the virtual environment participant, being human, is multi-modal by nature. Therefore, in order to more accurately validate the levels of auditory and visual fidelity required in a virtual environment, a better understanding is needed of the intersensory or cross-modal effects between the auditory and visual sense modalities.

To identify whether any pertinent auditory-visual cross-modal perception phenomena exist, 108 subjects participated in three main experiments which were completely automated using HTML, Java, and JavaScript computer programming languages. Visual and auditory display quality perception were measured intramodally and intermodally by manipulating visual display pixel resolution and Gaussian white noise level and by manipulating auditory display sampling frequency and Gaussian white noise level.

Statistically significant results indicate that 1) medium or high-quality auditory displays coupled with high-quality visual displays increase the quality perception of the visual displays relative to the evaluation of the visual display alone, and 2) low-quality auditory displays coupled with high-quality visual displays decrease the quality perception of the auditory displays relative to the evaluation of the auditory display alone. These findings strongly suggest that the quality of realism in virtual environments must be a function of both auditory and visual display fidelities inclusive of each other.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Human Systems Interface, Modeling and Simulation

KEYWORDS: Virtual Environment, Auditory Display, Visual Display, Perception, Cross Modal, Fidelity, Experimental Design

PHOENIX AUTONOMOUS UNDERWATER VEHICLE (AUV):NETWORKED CONTROL OF MULTIPLE ANALOG AND DIGITAL DEVICES USING LONTALK

Forrest C. Young-Lieutenant, United States Navy
B.S., University of California at Berkeley, 1990
Master of Science in Electrical Engineering-December 1997
Advisors: Xiaoping Yun, Department of Electrical and Computer Engineering
Donald Brutzman, Undersea Warfare Academic Group

The purpose of this thesis is to simplify analog and digital device control inside the *Phoenix* autonomous underwater vehicle (AUV). *Phoenix* is required to process many data information streams associated with a variety of different sensors. Real-time processing is required both for input sensing and for output directing. As presently configured, hardware devices aboard the *Phoenix* are manually connected and configured using parallel ports, serial ports, analog-to-digital (A/D) and digital-to-analog (D/A) controller hardware. Current hardware control within *Phoenix* connects all devices individually to a single computer. This approach is cumbersome, error-prone and does not scale.

This project investigates the feasibility of using Echelon LonWorks hardware and LonTalk protocol as a faster and scalable networked robot control system. LonWorks/LonTalk is a flexible A/D D/A hardware networking technology that provides reliable communication, decentralized topology with no single point of failure, easy extensibility, excellent throughput, and interoperability for a wide variety of hardware.

This project builds and tests a prototype LonTalk network that connects all *Phoenix* devices. This network demonstrates the capability of using LonWorks to control various types of hardware and support rapid component integration onboard the *Phoenix*. Successful demonstration of a LonTalk solution eliminates a critical barrier to *Phoenix* progress and makes robot execution much more robust.

KEYWORDS: Autonomous Underwater Vehicle, AUV, Networked Control, LonWorks Technology, LonTalk, LonBuilder

DoD KEY TECHNOLOGY AREAS: Computing and Software, Surface/Under Surface Vehicles-Ships and Watercraf