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AUV 96 Video Proceedings

Autonomous Underwater Vehicles (AUV) '96

Video Proceedings

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Video Proceedings Editors	Postproduction Editing	Video Proceedings Inquiries
Don Brutzman & Mike Holden **Theme: "Fathom"** **Russell Storms** **Naval Postgraduate School**	**Greg Frederick** **BigTime Communications** **Monterey CA 93940 USA** **bigtime@redshift.com**	**Don Brutzman** **Code UW/Br** **Naval Postgraduate School** **Monterey CA 93943 USA** **brutzman@nps.navy.mil**

AUV 96 Executive Chair - Video Proceedings Welcome

	Tony Healey	start time

	Code ME/Hy Naval Postgraduate School Monterey California 93943 USA *healey@me.nps.navy.mil*	3:00 duration 1:00

Arctic Ocean Trials of the *Theseus* Autonomous Underwater Vehicle

	**Mervin R. Black** Esquimalt Defence Research Detachment Defence Research Establishment Atlantic F.M.O.Victoria, British Columbia, Canada *black@edrd.dnd.ca*	start time 4:00 duration 4:40

This video presentation shows trials of the *Theseus* autonomous underwater vehicle which was launched in Jolliffe Bay, NWT, Canada and run out into the Arctic Ocean during the month of April, 1995. *Theseus* is designed to lay up to 220 km of optical fiber cable in ice-covered waters and has an endurance of over 80 hours at four knots.

The presentation begins with scenes around the on-ice camp which was set up for launching and recovery of *Theseus*. *Theseus* was housed in a 20 m by 11 m tent which was supplied by Weatherhaven Inc. of Vancouver, BC. A 12 m by 2.5 m hole was cut through the 2 m thick using a hot water drilling system. *Theseus* pieces were flown to the ice-camp by helicopter. The vehicle was then assembled inside the tent on its track and lowered into the water via electric chain-blocks on gantries. Dry weight of *Theseus* is 8,600 kg or 19,000 lbs.

A Phantom DHD2+2 tethered underwater vehicle was used to observe *Theseus* during under-ice operations and to attach recovery lines. A launch of *Theseus* is shown with withdrawal of the launch depressor weights. Trials of all the main sub-systems of *Theseus* including ring laser gyro inertial navigation, doppler speed log, acoustic homing, acoustic communications, obstacle avoidance sonar, acoustic tracking and optical cable deployment systems were carried out. *Theseus* was designed and built by ISE Research Ltd. of Vancouver, BC under contract to the Research and Development Branch of the Canadian Department of National Defence.

ORCA: U.S. Navy's Oceanographic Survey System

	**CDR Brian Bourgeois USN** Naval Research Laboratory Stennis Space Center, Mississippi USA *bsb@catinhat.nrlssc.navy.mil*	start time 8:40 duration 9:30

The Mapping, Charting and Geodesy Branch of the Naval Research Laboratory at Stennis Space Center, Mississippi. is conducting a multi-year program for the development of unmanned, untethered sensor systems for the collection of tactical oceanographic data in littoral regions. The primary function of this program is the development of immediate survey capabilities for the collection of a variety of oceanographic data. Additional goals include the identification and demonstration of sensor systems compatible with the ORCA vessel and the guidance of future sensor development. A long term goal is to transition appropriate sensor technologies to fully submerged low-cost autonomous vessels.

The prototype platform currently in use for this project is the ORCA submersible. The ORCA is an air-breathing vessel which travels just below the waters surface. The vessel's mast and snorkel, which extends beyond the surface, allows a direct radio link for data and control communications, as well as a DGPS system for precise platform positioning. The present data telemetry system utilizes a wireless ethernet bridge providing up to a 900 kbit/s data rate, which is sufficient for real time transmission of multiple sensor data. This vessel has a diesel engine power plant which provides ample propulsion and electrical power. The vessel is 25 feet in length and it is ideally suited for present day oceanographic sensor packages whose size or power requirements would be prohibitive for use on current AUV's. Since the vessel is actively stabilized while it is submerged, it is an extremely steady platform allowing the collection of data heretofore restricted to much larger surface vessels. The present ORCA navigation system includes a gyrocompass providing a rudimentary steer-to-heading capability. Intended vessel enhancements include over-the-horizon telemetry capability, interchangeable sensor packages for different survey missions, a 3 dimensional GPS system, and a Doppler velocity log. A variety of autonomous capabilities will be added, including detection and avoidance of surface and subsurface obstacles and autonomous survey area navigation and track line generation.

The first major sensor installed on ORCA is the Simrad EM950 system which collects bathymetry and collocated acoustic imagery. The EM950 is a 95 kHz system capable of bathymetric surveys in water up to 300 meters deep. Supporting the EM950 is an attitude sensor system with 0.1 degree precision and a surface temperature sensor. With the real-time data telemetry to the ORCA host vessel and the NRL developed HMPS bathymetry post-processing software, the completed system is capable of same-day chart production. NRL has developed two vessels with this capability, and one of the vessels has been transitioned to the Naval Oceanographic Office. The second vessel is being retained by NRL for further sensor and vessel system development. Additional integration efforts on the NRL vessel include an acoustic doppler current profiler and an acoustic sediment classification system. Plans for future sensor integration and testing include:

- optical systems for the determination of beam attenuation, optical backscatter, up and down welling irradiance, and a bathyphotometer. These data will provide the necessary information for the rectification of satellite imagery and laser sounding systems used to determine water depth.
- magnetic sensors for measuring sediment conductivity.
- synthetic aperture sonar for ultra-high resolution acoustic imagery.
- a multiple frequency acoustic mapper

AUV Testing using Real/Virtual Synthetic World

Yoji Kuroda *, **Koji Aramaki** ** and **Tamaki Ura** **

* School of Science & Technology, Meiji University, Kawasaki, Japan

** Institute of Industrial Science, University of Tokyo, Japan

ykuroda@isc.meiji.ac.jp

start time 18:10

duration 4:40

This video shows a practical example of a method for the research of underwater robots using technique of combining virtual world with real world. The world which is virtually created using the sensory information of both the real and a virtual world is called "synthetic world." In this world, the robots behave as if they were swimming in the underwater-world even in the case they are deployed in a simple shaped testing-pool. By testing in the synthetic world, the efficiency of underwater systems' development is improved because the software can be developed directly on the embedded computer system and the hardware and software cross-checking can be easily conducted.

The synthetic world is an ideal world which consists of both the actually measured and the virtually created sensory data. Since the mobile robot moves around in its workspace by referring environmental sensory data such as visual image, range map, etc., it is possible to let the robot regard the virtually created data as those of the real world by swapping certain actual sensory data for corresponded virtually created data. Virtual agents such as underwater robots, obstacles, seabeds, etc., are deployed in the real world. Consequently, a synthetic world is created. The actual robot in the synthetic world recognizes and communicates to both actual and virtual agents without distinction. Thus, the synthetic world can realize the hardware-in-the-loop testing in the realistic undersea environment without risk of losing under-developing robots.

The synthetic world was created by using newly-developed virtual underwater-world simulator *MVS (Multi-Vehicle Simulator)*. *MVS* was designed as an integrated developing environment which can deal with the various developing stages from the very beginning of considering mission strategies of robots up to the end prior to launching them to the ocean.

Underwater robot navigation in a synthetic world was carried out in an actual testing pool with four virtual obstacles. The synthesis was carried out using the ranging sonar with which the actual and virtual underwater robots are equipped. It was demonstrated that the actual robot navigated in the synthetic world with avoiding both actual pool-walls and virtual obstacles.

Pectoral Fin Model for Maneuver of Underwater Vehicles

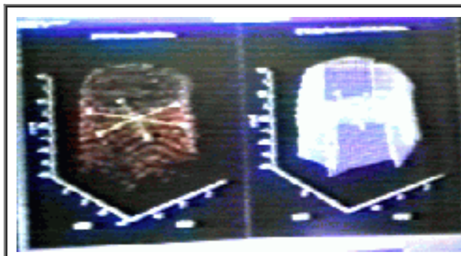
	**Naomi Kato** and **Motonori Furushima** Tokai University School of Marine Science & Technology Shimizu, Japan *nkato@simizugw.cc.u-tokai.ac.jp*	start time 22:50 duration 5:20

This video describes the observation of pectoral fin motion of a Black Bass and peformance tests of apparatus of the pectoral fin motion from the viewpoints of maneuverability of underwater vehicles.

Observation of the pectoral fin motion revealed that the combination of feathering motion and lead-lag motion dominantly generates the fish motions of advancing, retreating, hovering and turning at a low speed.

A fish model consisting of fish body model and a pair of the appartus can swim forward and backward and turn.

Clustering and Feature Extraction in a 3D Real-Time Echo Management Framework

	**Per G. Auran** and **Kjell E. Malvig** Department of Engineering Cybernetics Norwegian Institute of Technology Trondheim Norway *pga@itk.unit.no*	start time 28:10 duration 5:20

The video shows the experimental background of the AUV 96 paper "Experiments with 3D Sonar" showing in sequence:

- Laboratory equipment (Signal generators / Sampling circuit / PC host and sampling program)

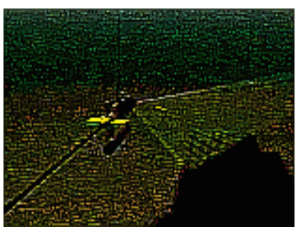
- Experiments at sea (Inside "Balchazar" / The Hopla object / The muruvik cylinders)
- 3D echo sampling (WesMar SS150 sonar / Cylinder + Bottom / Pier rocks)
- Surface modeling (Profiles / Sweep models / Surface and echo point merging)

The basic idea for this sonar algorithm is to maintain a local map of sonar returns filtered in strength, space and time, i.e. the map should be a dynamical view of the more likely echoes within sensor range. Special attention is given to realtime implementation of the map as it must continously be updated to reflect the AUV's current field of view. A spherically organized map is proposed to keep track of the 3D spatial relationships in real time. In addition to be a tool for 3D image formation the map will be directly usable for lower level processes like collision avoidance, the basic idea being that AUV perception must be seen in a broader perspective. The underlying echo representation need to support several processes onboard the AUV. In this presentation focus is on clustering and feature extraction within the spherical 3D map, i.e. extraction of information needed for object classification and recognition purposes. Important issues include:

- Clustering and connectivity: The spatial separation of objects, size (volume), location and centroid calculation.
- Local features: Planar or curved reflection surfaces, corners.
- Acoustical Shadow Detection.
- Events: Whereas each sonar return is unreliable in nature, the appearance or disapperance of whole clusters or features are events providing useful geometry information (for example an AUV passing the corner of a concrete wall of a harbour being surveyed).

Multi-Sensor Data Fusion for Bottom Mapping and Ordnance Location

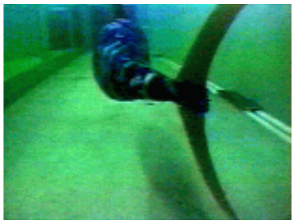
Mobile Underwater Debris Survey System (*MUDSS*) Project

	**John Wright**, **Ken Scott**, **Tien-Hsin Chao** and **Brian Lau** Jet Propulsion Laboratory California Institute of Technology Pasadena California USA *john@cassis.jpl.nasa.gov* **John Lathrop** and **John McCormick** NAVSURFWARCEN COASTSYSTA - DAHLGREN DIV	start time 33:30 duration 6:10

This video accompanies the associated paper of the same name in the conference. The paper presents results of ongoing work supporting the Mobile Underwater Debris Survey System (*MUDSS*) project. The project seeks to develop a system for locating and identifying unexploded ordnance on the seafloor. The results of the project are highly applicable to Autonomous Underwater Vehicle operation. The video begins with a 3.5 minute animation describing the Phase I *MUDSS* system, a 1.5 minute video showing the next generation upgrades, two minutes on the Site Survey Tool, then shorter sections on Automatic Target Recognition Processing (ATRP), 2D data visualization, chemical sensing, and 3D data visualization. Slates and credits are included.

MIT *RoboTuna*

	David S. Barrett and **Michael S. Triantafyllou** Department of Ocean Engineering	start time 39:40

	Massachusetts Institute of Technology (MIT) 77 Mass Avenue, Room 48-015 Cambridge, Massachusetts 02139 USA *dsb@athena.mit.edu*	duration 5:40

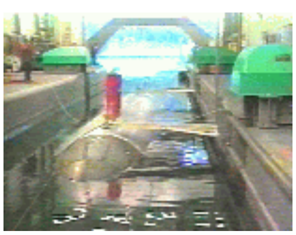
Existing AUVs are small robotic submarines powered by rotary propellers driven by electric motors. The low efficiency of the small diameter propellers coupled with the large fraction of the hull volume required to hold the motor's batteries leads to short mission times, restricted payloads and control problems.

In order to overcome these shortcomings better propeller or battery technology could be developed. However at the current state of the art, both only offer the hope of modest gains. To explore the possibility of substantial gains we have turned to the design of comparably sized biological systems for inspiration. There is a large body of experimental data that suggest biological systems achieve tremendous propulsive efficiencies. They do so using a flexible hydrodynamic body propelled by an oscillating tail foil. In order to determine if a man-made system can successfully exploit these same basic elements, we have build and are currently testing a complex robot fish (*RoboTuna*) in the MIT Ocean Engineering Towing Tank.

Determining the optimal swimming motion for the *RoboTuna* is an acutely complex problem involving the tuna's body kinematics and the hydrodynamics of the surrounding water. The overall intractability of the hydrodynamics of a flexible body precludes a purely analytic solution. The immense size of the experimental variable space prevents a purely empirical one. In order to overcome both difficulties, we have developed a self-optimizing motion controller based on a genetic algorithm. This controller effectively uses evolutionary principles to exponentially optimize swimming performance.

We briefly describe the design and construction of MIT's *RoboTuna*, the theoretical basis for its self optimizing genetic controller, and the experimental implementation of said controller under real "wet" conditions in the Towing Tank. In short: how the *RoboTuna* employs a Genetic Algorithm to experimentally "learn" to swim efficiently. We also present an extensive summary of the promising experimental efficiencies achieved to date as well as a projection of the impact of this technology on the range and duration of conventional AUVs.

Large Scale Vehicle (LSV) *KOKANEE*

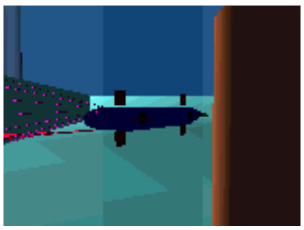
	**John R. Spina** Carderock Division Naval Surface Warfare Center Bethesda Maryland 20084 USA Naval Sea Systems Command, Code 92RT *spina@code70.dt.navy.mil*	start time 45:20 duration 11:30

The Large Scale Vehicle (LSV) *KOKANEE* is an unmanned, autonomously controlled, free-running submarine model, with external features modeled to SEAWOLF (SSN-21) at a scale factor of 0.25. The vehicle displaces 155 long tons, and is powered by a 3000HP DC motor and 480 lead-acid battery cells. *KOKANEE* is used by the Naval Surface Warfare Center (NSWC), under the sponsorship of the Naval Sea Systems Command, for advanced submarine propulsor development, test and evaluation.

Operations are conducted at the NSWC Acoustic Research Detachment (ARD) located on Lake Pend Oreille at Bayview ID. The lake, which covers 92,000 acres, is more than 1100 feet deep; a very low ambient noise level is achievable much of the time. A resident team of engineers, technicians, and skilled trades operates the vehicle and support facilities, supplemented by visiting scientists and engineers from navy laboratories, universities, and private industry.

KOKANEE has proved to be an extremely valuable tool in the development and evaluation of advanced submarine signature reduction technologies, providing a capability unmatched by other facilities. Saving many times its cost compared to the same evaluations at full scale, *KOKANEE* will continue to be a critical asset for evaluation of technologies for the next attack submarine (NSSN) and future classes.

Phoenix AUV In-Water Tests with Virtual World Design

	**Tony Healey**, **Dave Marco**, **Don Brutzman** and **Duane Davis** Center for AUV Research Code UW/Br Naval Postgraduate School Monterey California 93943 USA *auvrg@cs.nps.navy.mil*	start time 56:50 --- duration 11:10

The NPS *Phoenix* Autonomous Underwater Vehicle (AUV) is a student research testbed for shallow-water minefield mapping missions. We discuss implementation of the Execution, Tactical and Strategic levels of the Rational Behavior Model (RBM) robot architecture. Simulation-based design using an underwater virtual world has been a crucial advantage permitting rapid development of disparate software and hardware modules. Details are provided on process coordination, navigation, real-time sonar classification, path replanning around detected obstacles, networking, sonar and hydrodynamics modeling, and distributable computer graphics rendering. In-water experimental results are presented and evaluated.

World Submarine Invitational Human-Powered Submarine Races

	**Kevin Hardy** Scripps Institution of Oceanography University of California San Diego La Jolla California 92093-0210 USA *kevin_hardy@igppqm.ucsd.edu*	start time 1:08:00 --- duration 29:10

Scripps Institution's World Submarine Invitational'96 was a stunning success featuring 21 teams from around the U.S. and Canada. This fourth in a series Scripps event ran March 30 through April 4, 1996 in the clear, warm water of the Offshore Model Basin, San Diego County, CA. Previous Scripps events were held in August 1992, October 1992, and March 1994.

On the first day of the event, March 30, William Nicoloff of Northridge, Calif., set a new Guinness world speed record and a one-person, propeller-driven International Human Powered Vehicle Association (IHPVA) record with a speed of 6.696 knots in his submarine, SubStandard. Nicoloff and his brother, Robert, designed and built their submarine, which was reconfigured to also race in the two-person category. The team from Ecole de Technology Superieure (Montreal, Quebec, Canada), with their submarine Omer II, set a two-person, propeller-driven IHPVA record at 6.5 knots.

The world speed records for human-powered submarines has been steadily climbing, 4.72 Kts in 1992, 5.94 kts in 1994, and now 6.69 kts in 1996. These results validate the approach Scripps has taken in creating an event that challenges teams to push the engineering limits while at the same time removing as many constraints as possible to their success. The event follows an engineering performance evaluation format where teams are encouraged to try different configurations of their submarine in a controlled environment. In the course of their allotted time, submarine pit crews try different combinations of thrusters, control surfaces, bow domes, gear ratios, on their hull. The affect on speed and maneuverability can be accurately measured, and real world lessons of applied science and technology can be learned.

Teams were given priority access to the timing course on an assigned day. Each team had the chance to propel their submarine through the speed trap and establish their peak speed. Teams were encouraged to make modifications to their submarine to try to improve speed. Submarines that experienced component failures were pulled from the water, repaired or modified and return for further runs.

Scripps Institution's World Submarine Invitational is an important first step in the development of AUV technologies and the training of new engineers and scientists to the field. Human powered boats demonstrate vehicle, control and propulsion design. The battery powered boats remove the athlete and install power drive technology. The final step removes the pilot and places navigation sensors, computer control and a work package. This year's event successfully added new design challenges which include battery powered submarines, Diver Propulsion Vehicles, and a horizontal slalom maneuverability test for the Human-powered subs. Organizers believe they are watching the beginning of a new industry. Participants of this event will go on to create practical underwater utility vehicles for recreation, commercial and research activities, as well as develop new diving technologies to assist man-in-the-sea.

Human strength has provided the power to drive submarines since Leonardo DaVinci. In 1776, a brilliant young student from Yale College, David Bushnell, designed, built and operated a human powered submarine in support of America's quest for independence, bravely attacking the flagship of the British fleet occupying New York Harbor. The "Turtle" is now depicted in the crest of Scripps Institution's World Submarine Invitational. This event's participants are the intellectual descendants of submariners such as DaVinci, Bushnell, Robert Fulton, Simon Lake, and John Holland, applying modern knowledge, materials and fabrication techniques to the same problems of submarine design.

Modern submarine races began in 1989 with an open ocean, single elimination competition off the east coast of Florida. That event was organized through the Florida Atlantic University's Ocean Engineering Department in cooperation with the former H.A. Perry Foundation. That event repeated in 1991, and a final time in 1993. Today, Florida Atlantic University's Ocean Engineering Department helps sponsor Scripps Institution's World Submarine Invitational'96 (WSI'96).

In 1991, discussions began in California centered on creating an accurate, repeatable and verifiable timing system. In summer 1992, Guinness Publishing sanctioned the timing method. In August 1992, in the open Pacific, Scripps Institution's non-propeller submarine "SubDUDE" became the first human powered submarine to establish a Guinness World Record. In October 1992, in the first in-basin event, "Sub-Human II" established a second Guinness World Record for propeller submarines. In 1994, the International Human Powered Vehicle Association (IHPVA) sanctioned the event. In March 1994, both Guinness and IHPVA World Records were open to challenge at the West Coast Submarine Invitational'94 (WCSI'94). The Scripps sponsored 1994 event originated the multiple divisions of Open, Collegiate, High School, each with multiple categories of 1 and 2 person, prop and non-prop submarines. This expanded format provides teams with numerous possible achievement awards.

Scripps Institution extends its profound thanks to the many individuals who volunteered their time and talent to bring this event together. Scripps Institution is deeply grateful to the corporate sponsors whose generous material and financial support has made the World Submarine Invitational possible. Lastly, Scripps Institution honors the individual participants and their teams, whose hard work and uncommon persistence provides the real substance of this event.

Total tape time 1:40:00

The Uniform Resource Locator (URL) for this home page is **http://www.stl.nps.navy.mil/~auv/auv96_video.html**

AUV 96 Video Proceedings contact information: Don Brutzman (brutzman@nps.navy.mil)

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