AOSN MURI: Real-Time Oceanography With Autonomous Ocean Sampling Networks: A Center for Excellence

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LONG-TERM GOALS

The long-term goals of this project are to create and demonstrate a reactive ocean survey system, capable of long-term unattended deployments in remote environments. We refer to such a system as an Autonomous Ocean Sampling Network (AOSN). The work described below is the product of a collaboration of research groups at the Massachusetts Institute of Technology, Woods Hole Oceanographic Institution, Scripps Institution of Oceanography, University of Washington, Northeastern University, and Webb Research Corporation.

OBJECTIVES

The objective of this project is to create and demonstrate the next-generation robotic oceanographic survey system. This is being accomplished by:

1) Creating small, high performance mobile platforms capable of several month deployments. Both propeller-driven, fast survey vehicles, and buoyancy-driven glider vehicles have been developed.

2) Creating an infrastructure that supports controlling, recovering data from, and managing the energy of, remotely deployed mobile platforms. Elements include moorings, docking stations, acoustic communications, two-way satellite communications, and the Internet.

3) Demonstrate these capabilities in science-driven field experiments.

4) Develop operational techniques that make most effective use of these new assets, including adaptive sampling strategies.

APPROACH

This project is coupled with a series of science-driven experiments, each chosen to focus instrumentation development and to convincingly demonstrate new capabilities. The first deployment, June-July 1996, during the Ocean Frontal Dynamics Primer Initiative in Haro Strait, focused on coordinated platform operations, adaptive sampling, and communications. The second deployment, January-April 1998, in support of the Labrador Sea Accelerated Research Initiative (ARI), was

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designed to demonstrate long-term deployment and remotely controlled capabilities. The third phase of the MURI was linked with the NOPP Littoral Ocean Observation and Prediction system (LOOPS) culimating in a cruise that demonstrated a range of extended-range AUV, acoustic communications, and radio frequency networking techniques which allowed observational assets to be coupled to shore-based modeling/prediction systems in real-time. The final phase of this project is to demonstrate a fully integrated, multi-scale ocean observation system off of Monterey Bay, and the first field experiment of this series was completed in September 1999.

Phase 1 Activities: Platform and Operations Development

The two classes of survey platforms developed in this initiative are the small, propeller-driven vehicles and buoyancy-driven gliders. The first systems, autonomous underwater vehicles (AUVs) are capable of moving at several knots for part of a day (the current vehicle can carry substantial payloads for half a day), while the second systems, gliders, operate for several months at much lower speeds. The gliders developed under this initiative are entirely new systems. In contrast, the propeller-driven vehicles (Odyssey IIb AUVs) were developed under prior ONR support and are being augmented in this activity.

AUV efforts have focused on integration of oceanographic sensors and development of new operational techniques. Acoustic communications is a key facilitating technology for AUV operations. An acoustic modem, the UAM, has been designed and demonstrated for small AUVs. Operations in Haro Strait (1996), Labrador Sea (1998), Massachusetts Bay (1998), and Monterey Bay (1999) highlighted the advantages gained from an acoustic link for both routine operations and adaptive survey strategies.

Phase 2 Activities: Unattended Deployment

An extended deployment capability for small, high performance AUVs is being created by developing a docking capability which allows vehicles to use moorings as fuel stations and communication relays. This requires the high-efficiency power transfer and high bandwidth data link between a dock and a connected vehicle developed by Electronic Design Consultants. Satellite communication to the dock via a surface buoy allows data transfer and mission programming for the docked AUV. To develop docking and acoustic communication, MIT is collaborating with the Woods Hole Oceanographic Institution. Satellite communications and mooring systems were developed at the Woods Hole Oceanographic Institution.

Phase 3 Activities: Coupled Observation/Modeling System

In the final two years of the effort the observational and communication capabilities developed will be integrated with complimentary modeling and prediction systems, to create a coupled observation/modeling system. The New England shelf, with the large variety of oceanographic processes, has been chosen as the demonstration location, and the first experiment was just completed in Massachusetts Bay.

WORK COMPLETED

Six major scientific experiments have relied on the systems and operational techniques developed under this MURI. In the Haro Strait Primer (1996) Odyssey AUVs were used for multiple AUV operations, for coordinated AUV-drifter measurements, as moving sources for tomography experiments, and were coupled with HOPS (the Harvard Ocean Prediction System) to demonstrate model driven sampling. In Kaikoura, New Zealand (1997) the AUV Lab deployed an Odyssey to search for the giant squid, together with teams from the Smithsonian Institution and National Geographic. The Labrador Sea Deep Oceanic Convection experiment (1998) saw the first use of AUVs, moorings, and docking systems to generate high spatial resolution measurements of mixing and to demonstrate important technological capabilities such as satellite and acoustic communications, rough-weather AUV operations, and deep-water homing on a dock. The GOATS experiments (1998), conducted with SACLANT in the Mediterranean, demonstrated multistatic sonar techniques and buried mine detection using an Odyssey-mounted acoustic array. Operations with LOOPS (Littoral Ocean Observation and Prediction System) in Massachusetts Bay (1998) demonstrated acoustically controlled AUV operations, long range acoustic communications, radio-frequency networks for real-time operations, model driven sampling (again with HOPS), and long endurance Odyssey performance. The most recent field experiment, the Synoptic Internal Tide Experiment (SITE 99) saw the first field use of the glider vehicles, as well as demonstration of a sophisticated network of communications buoys, allowing two-way, communication with Odysseys from shore.

The MURI has developed two gliders and a third is under development. A WHOI-Scripps collaboration demonstrated two-way satellite communications from their glider (Spray) during a ten day deployment in Monterey Bay. The University of Washington's vehicle, the Virtual Mooring, demonstrated . Both systems are battery powered, and will run for several months. Also, systems are designed to incorporate satellite communications for data recovery and controlling the vehicle's trajectory. The University of Washington team has demonstrated their vehicle with a cellular phone connection, while the WHOI-Scripps vehicle will incorporate a link to the ORBCOM satellite system. The third glider is under development by Webb Research Corporation, and uses a thermal engine to power its flight to achieve much greater endurance.

The introduction of the Utility Acoustic Modem (UAM) was a major milestone. This is an advanced modem designed for low power and small size that meets the requirements of small, high-performance AUVs. This system provided communications between the AUV and dock in the Labrador Sea, between the AUV and a relay mooring and the R/V Oceanus in coastal experiments, and between the AUV and networked moorings in Monterey Bay..

RESULTS

Survey Platforms:

1) The Odyssey AUV range has been increased to 60 km with rechargeable batteries. A range of sensor systems have been integrated into the AUVs and employed in experiments including: CTD, sidescan sonar, fluorometer, optical backscatter sensors, 300 kHz ADCP, 150 kHz phased array ADCP, eight element acoustic line array, and acoustic Doppler velocimeter. A new, modular version of Odyssey will be introduced in 2000.

2) The Odysseys have been demonstrated to be fully operable from oceanographic vessels without small boats, an extremely important capability for routine operations. Operation in conditions up to sea state 5 was demonstrated in the Labrador Sea.

3) Two battery powered glider prototypes have been developed and are in at-sea testing. The APL UW vehicle is referred to at the Virtual Mooring Glider, while the Scripps/WHOI glider is called Spray. Both vehicles have projected endurance of several months at speeds of a fraction of a knot.

4) In a highly successful first field deployment, Spray operated continuously for ten days in the Monterey Bay SITE 99 experiment. During that deployment, Spray reported measurements back and was commanded via an ORBCOM satellite link.

5) The Virtual Mooring Glider has operated fully autonomously in Monterey Bay and Puget Sound, communicating temperature and salinity profiles and vehicle commands via cellular telephone. Its longest mission to date was a 225-dive sequence over eight days in Puget Sound, where it was remotely steered between basins through a passage less than 500 m wide.

6) A complete prototype thermal glider has been successfully field tested by Webb Research Corporation, with all hydrodynamic, control and environmental propulsion systems in place.

Docking:

1) Acoustic (WHOI), optical (NRaD) and electromagnetic (EDC) homing systems have been successfully demonstrated on Odyssey AUVs. Acoustic homing systems were favored primarily for their large 'lock-on' distance (kilometers as opposed to tens of meters).

2) Cone and pole type docks were tested. While all worked, the pole approach was selected as it allows omni-directional approach.

3) An inductively coupled power transfer and 10baseT ethernet link (EDC) has been integrated into the WHOI dock and both capabilities demonstrated in water.

4) Robust homing and docking algorithms developed by WHOI and MIT have been extensively tested for docking and undocking.

5) Software to support autonomous operation of an AUV from a dock has been written and partially tested. Unattended deployment is a major objective of the coming year.

6) Docking systems have been completely integrated onto stand-alone moorings complete with two-way satellite, RF, and acoustic communication for both shallow and deep water (WHOI).

7) The deep-water mooring was deployed in Labrador Sea and the shallow-water mooring in MA Bay.

Communications:

1) The UAM has been employed for two-way communication between the AUV and ship, AUV and mooring, and AUV and dock (WHOI). In a shallow (40 m) downwards refracting environment, communications were demonstrated to a range of 10 km.

2) Supervisory control of AUVs has been demonstrated via the acoustic link out to a range of 5 km.

3) Two-way INMARSAT C satellite communications were demonstrated from a mooring in the Labrador Sea during January and February of 1998 (WHOI).

4) Networked RF communications have been employed both in the Labrador Sea and in the coastal environment (WHOI).

Survey capabilities demonstrated:

1) Coupled AUV/drifter operations were demonstrated in Haro Strait in which an Odyssey AUV maneuvered relative to the IOS Seascan sonar platform.

2) Multiple AUV operations have been demonstrated. In one demonstration one vehicle was equipped with a USBL and followed the other (WHOI/MIT). In a second demonstration, both vehicles were acoustically controlled from the surface.

3) Multi-static sonar sensing has been demonstrated during the GOATS 98 deployment.

4) Model-driven sampling has been demonstrated both in the Haro Strait experiment and in the recent Massachusetts Bay experiment with the LOOPS program (Harvard/MIT).

5) An analytical formalism for evaluating survey technologies by predicting their effectiveness at capturing oceanographic fields has been developed. The technique takes into account both spatial and temporal variability of oceanographic processes.

IMPACT/APPLICATIONS

Individual components of the system, such as the AUVs and gliders, provide unique measurement capabilities for ongoing oceanographic field programs. The use of multiple vehicles allows synoptic surveys that would otherwise be prohibitively expensive. Perhaps most important, the work creates mobile platforms and supporting systems for extended deployment in remote (and not so remote) locations. Many Navy missions, including tactical oceanography, mine countermeasures, covert surveillance, and anti-submarine warfare will benefit from the developed technology.

TRANSITIONS

Two AUVs, derivatives of the Odyssey design, are being built under ONR sponsorship to provide a wide-area covert survey capability in support of mine detection and clearance.

Demonstration cruises for NAVOCEANO are beginning the transition of small, high performance AUVs to operational Navy assets. NAVOCEANO has created a center of excellence for AUV technology providing an entry point for ONR funded work.

Lockheed-Martin funded MIT to develop a vehicle for mine-countermeasures applications, CETUS, employing Odyssey design and construction techniques. This system was delivered to Lockheed-Martin and is being used for Navy funded research. Lockheed-Martin is obtaining an Odyssey to compliment CETUS in mine-countermeasure activities.

The Utility Acoustic Modem (UAM) is being made available to the research community through a modem pool established at WHOI under separate ONR funding.

While AOSN development presently focuses on oceanographic applications, the fundamental concepts apply to military missions including mine countermeasures and clandestine surveillance.

RELATED PROJECTS

This program is the lead element of the Multidisciplinary University Research Initiative collaboratively linked with the following ONR funded efforts:

1) The Ocean Frontal Dynamics experiment, supported under the ONR Vertically Integrated Research Initiative: AUVs were used extensively in field program to demonstrate various sampling strategies.

2) The Oceanic Deep Convection Accelerated Research Initiative: AUV and mooring operations in the Labrador Sea obtained high resolution measurement of ocean mixing processes and demonstrated long-term deployment capabilities.

3) The Littoral Ocean Observation and Prediction System (LOOPS), funded under the National Ocean Partnership Program: a complimentary effort developing real-time modeling and forecasting capabilities that compliment real-time observational capabilities developed under the AOSN project.

4) The Japan East Sea Initiative: Virtual Mooring gliders are to be used to observe temperature and salinity structure of the subpolar front over several months. This work will be carried out when suitable satellite communications become available.

5) The Atlantic Layer Tracking Experiment (ALTEX), funded under the National Ocean Partnership Program: a long range (1000 km) AUV is being developed using the technology developed in the AOSN project as a foundation.

6) The Battlespace Preparation AUV program, funded under the ONR Innovative Technologies for Organic Mine Countermeasure, is employing a number of the technologies and systems developed under this program.

7) The NOPP ICON project coordinated observations with the AOSN project during the SITE 99 field experiment.

8) Several STTR and SBIR efforts are coordinated with this program.

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