

# **Sensing and Navigation System for a Multiple-AUV Testbed**

Naomi Leonard  
Department of Mechanical & Aerospace Engineering  
Princeton University  
Princeton, NJ 08544  
phone: (609) 258-5129 fax: (609) 258-6109 email: [naomi@princeton.edu](mailto:naomi@princeton.edu)

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<http://www.princeton.edu/~naomi>

## **LONG-TERM GOALS**

The long-term goal is to enable the creation of a multiple-AUV testbed in which control strategies for network coordination can be studied in three-dimensional space.

## **OBJECTIVES**

The objective of this project is to provide a sensing and navigation system that will support the coordination of multiple underwater vehicles in a freshwater, laboratory test tank. At Princeton University, an investigation into coordinating control strategies is already underway and an indoor multiple AUV experimental testbed is under development. The indoor, freshwater experiment will allow for comprehensive testing of control architectures, low-level control laws and dynamics of a fleet of AUVs in an environment that can be controlled and manipulated as desired. A key challenge to operating a group of AUVs in an indoor tank or pool is the development of a sensing and navigation system that provides to each vehicle not only its own position and attitude but also the relative position and attitude of at least its nearest neighbors. The aim of the sensing and navigation system is to provide for this critical capability for a group of AUVs.

## **APPROACH**

In order to create a testbed for experimenting with network control laws, it is necessary that each AUV not only navigates individually but also senses the relative position and attitude of its nearest neighbors. The sensing and navigation instrumentation is intended to address these needs using acoustic and optical solutions. To sense the absolute position of each vehicle we consider using acoustics at appropriate frequencies to minimize the reverberations from the walls. Three baseline stations are placed at the circumference inside the tank. Those three base stations will send out synchronized acoustic pings. Each AUV in the network will receive these acoustic signals as well as an RF-synchronization pulse. This allows for the on-board computation of each vehicle's global position, based on the known synchronization time and the known location of the base stations. The approach has the advantage to allow for additional vehicles in the tank without requiring additional acoustic energy in the tank that would lead to a deterioration of the position accuracy (scalability and multi-path reduction). Attitude will be measured using a fiber optic gyro because of interference problems of the earth magnetic field with the tank's steel hull. Relative position and attitude measurements will be determined two ways, and the two will be fused to get the best kind of information for feedback control. The first method will be to use radio-frequency (RF) communication via a central computer

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such that each vehicle can be provided with the absolute positions of its nearest neighbors. Each vehicle can then calculate the relative positions of its neighbors by subtracting its own position from its neighbors. The second method will use optics to determine directly the relative position and attitude of a vehicle's nearest neighbors. This includes the use of position sensitive devices (PSDs) and stereo computer vision. The PSDs also have the potential to be used for basic communication directly between vehicles (e.g., by means of sensing and then decoding light pulses). The stereovision system will also be used for sensing objects in the environment, for example, in the context of a search task or an obstacle avoidance task.

Ralf Bachmayer (Research Staff) and Naomi Leonard (PI) lead this effort. Robert Sorenson (Technical Staff) and Edward Fiorelli (Graduate student) as well as a number of undergraduate students support this effort on a part-time basis.

## **WORK COMPLETED**

As part of the larger testbed development, we have designed and constructed three “grouper” vehicles. The design of the second and third generation was slightly altered based on the experience of the former generations. This development has significantly improved the manageability of the platforms. Only minor changes to the propulsors were necessary. The controller, motor and propeller characteristics for the initial set of thrusters were successfully matched, and this allowed for a quick reproduction. We have developed a smart interface for our sensors and actuators using a common communication bus and a standardized protocol. In addition to the motor controller, the interface has been implemented on the depth sensor, temperature sensor, fiber optic gyro, inclinometer and on a battery monitor. The smart motor controller boards were developed into a robust subsystem, that allows for easy reconfiguration of the overall propulsion system with interchangeable components. A large number of computer boards was prepared for out-of-house production.

Further, towards the sensing and navigation system, we have performed testing of an RF-modem for underwater communication in the test tank. A highly accurate temperature sensor with a smart interface was developed as part of an undergraduate student project. We have acquired several fiber optic gyros as a heading reference for the individual vehicles. The interface and a data-buffer board were designed and tested and await implementation. We have made significant progress on the development of a vision-based heading module using position sensitive devices (PSDs). Two student projects contributed to this effort. The PSD work is in progress as we aim to use the technology for relative position/heading measurements of neighboring vehicles. We are currently implementing two vision systems into a grouper vehicle to perform sensing and tracking experiments. A global (tank-fixed) vision system with an appropriate frame grabber was installed in the tank allowing for real-time vehicle monitoring and recording as well as providing the framework for future computer vision experiments. The acoustic navigation system has been installed in the tank and we are currently working on the ping synchronization. An acoustic doppler velocity meter was installed and tested on a grouper vehicle and is expected to considerably improve the positioning system. In an effort to facilitate controller development and implementation we just have concluded the initial test phase of a single board computer (PC104) with newly available software tools (Matlab XPC-target). These tools allow us to download controllers into the vehicle's main computer without cumbersome coding and enable us to implement controllers designed by project collaborators. This approach heavily benefits from the communication architecture and the smart interfaces of sensors and actuators implemented on the vehicles.

## **RESULTS**

Early closed-loop control of the grouper prototype showed the feasibility of hardware-in-the-loop development by using standard software tools to design and tune the vehicle controllers on-line. We established that a controller update rate of 10Hz is sufficient for our system. Early progress on sensing and navigation using PSDs shows promise for their use in heading and position measurement both with respect to a fixed reference as well as a moving reference (neighboring vehicle). As expected, the acoustic system's performance is highly dependent on the echo level present in the tank. Sound-absorbent coating of the wall behind a base stations proved to be one key factor towards obtaining accurate measurements. The distributed communication architecture and the smart interfaces of sensors and actuators implemented on the vehicles provide an easily reconfigured and adaptable testbed. The overall system showed its potential in educating and inspiring students and researchers in various related science and engineering projects. Multiple independent student project and senior theses were performed in the framework of this development.

## **IMPACT/APPLICATIONS**

The sensing and navigation system will make it possible to create a multiple-AUV testbed in which control strategies for group coordination can be studied in three-dimensional space. Existing testbeds for group coordination are typically confined to two dimensions; for example, robotics researchers use mobile robots on the ground to investigate coordinating controllers. Furthermore, fluid dynamic effects between vehicles can be examined in the multiple-AUV testbed. While coordinating strategies for multiple vehicles should be tested at sea, a laboratory testbed makes it possible to develop and test these strategies beforehand (and afterwards) in a readily accessible environment that can be controlled and manipulated as desired. That is, the multiple-AUV testbed can be used as a proving ground to prepare for the at-sea trials. In our other underwater vehicle research projects, e.g., the underwater gliding project, we have found such laboratory testbeds invaluable both for research and education.

Research in coordination of a fleet of AUVs has the potential for significant impact since it is expected to be useful for effective and efficient adaptive ocean sampling that would not otherwise be possible with individual vehicles.

## **TRANSITIONS**

This work is in progress and so no transitions have been made.

## **RELATED PROJECTS**

This DURIP project is closely related to my ONR projects on Underwater Glider Dynamics and Control and Underwater Glider Networks for Adaptive Ocean Sampling. The advantages associated with underwater gliders are expected to be greatest when multiple gliders are operated cooperatively in a network. These two ONR projects are part of the Autonomous Ocean Sampling Network (AOSN-II) project and the Monterey Bay Predictive Skills Experiment 2003. A central part of this project and upcoming experiment is to provide adaptive sampling using a group of underwater gliders for the purpose of ocean prediction. See <http://graham.princeton.edu/~auvlab/>

I participate in an NSF/KDI funded project joint with A.S. Morse (Yale), P. Belhumeur (Yale), R. Brockett (Harvard), D. Grunbaum (U. Washington) and J. Parrish (U. Washington) on coordination of

natural and man-made groups. We are studying schooling of fish and “schooling” of autonomous underwater vehicles. Development of the Princeton multi-vehicle testbed was initiated as part of this project. See <http://www.eng.yale.edu/grouper/>

I also have an AFOSR funded project on Coordinated Control of Groups of Vehicles. This is a joint project with V. Kumar and J. Ostrowski at the University of Pennsylvania. A focus of the project is understanding cooperation in the context of coordinated control of distributed, autonomous agents, and the collection and fusion of the sensor information that they retrieve. The testbed would be ideal for testing in this context.

With my colleague Edward Belbruno, I have worked on a project for Global Aerospace Corporation (funded by NASA) on low-energy trajectory control of a stratospheric balloon network. The objective is to manage the geometry of the constellation of balloons for science and communication applications in the presence of a non-uniform flow field at 35 km altitude. The balloons can be controlled in a limited way with sails. This project is related to the problem of coordination of groups of underwater vehicles in a non-uniform flow field.

## **PUBLICATIONS**

R. Bachmayer and N.E. Leonard, “Experimental Test-bed for Multi-Vehicle Control, Navigation and Communication”, *Proceedings 12th International Symposium on Unmanned Untethered Submersible Technology*, Durham NH, 2001.

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