Enhancing AUV Operational Capabilities: Hovering, Rendezvous, and Docking.

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1 LONG-TERM GOALS

This proposal describes a program of work designed to contribute to the Navy's capabilities in mastering the mine warfare problem by providing AUV hovering, rendezvous, and docking capability in modular reconfigurable AUVs. These enhanced maneuvering capabilities will extending mission durations, enable stormy weather operations, and provide station keeping abilities for imaging and intervention tasks. The significant activity associated with bottom sediment transport occurs during the energetic sea states associated with inclement weather. Furthermore to extend the duration of AUV reconnaissance missions, docking for recharge and data upload is necessary.

2 OBJECTIVES

One of the goals of the AOSN is to achieve extended duration (2 week) missions from AUVs, mine reconnaissance, rapid environmental assessment, surveillance, and adverse weather missions would all benefit greatly from multi-day capability. One way to achieve extended duration missions is to dock and recharge batteries and off-load data.

An important mission is to observe the dynamics of the ocean environment during the passage of a storm front. Because surface ships are precluded from operation during a storm passage it is difficult to make measurements of the dynamics during the fronts passage. Hence, models of sediment re-suspension and mine like object burial rates must be made on extrapolations of levels days later. This project and companion projects are developing many of the enabling technologies necessary for cold front passage measurement. Since storm front disturbances are substantially reduced below the surface, an AUV could be used to measure in-situ events during the front's passage. However, the AUV must be inserted during calm weather, sleep on the bottom, awake and sample during the storm front, and then go back to sleep until calm weather permits its recovery. This is best done if the AUV can dock and therefore be constrained until it needs to operate.

The utility of AUVs in shallow water search and survey operations is enhanced by multiple vehi-
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cle operations this enables synoptic data collection and high coverage rates. A major objective of this project is to design and build the next generation modular mini AUV with reduced cost of manufacture, maintenance, and operation at similar levels of capability to the current generation of AUVs.

3 Approach

Docking:— The modular nature of the OEX provides tremendous reductions in the time required to reconfigure the vehicle for different missions. This is accomplished by placing all the mission specific sensors in a mid and nose cone section dedicated for payloads. The components needed to operate the vehicle, such as propulsion, navigation, energy, and control are grouped in the tail section. Putting docking components in the nose violates this separation and would substantially reduce vehicle reconfigurability. Hence, our approach is to use a belly mounted stinger that couples with sea bottom dock. The docking system navigation is based on a low cost high precision commercial SBL/LBL system. The SBL is mounted on a portable collapsible rigid SBL array. This will provide a portable low-cost docking system. The docking mechanism can be described as a 4 leaf clover with a spring loaded latch at the center. The the puck catches under the edge of one of the leaves and is directed to the center where the leaves attach. Once latched, power recharge through a direct connection to the bottom of the puck and data transfer through RF antennas in the puck and clover is accomplished.

FAU has developed a full 6 DOF nonlinear simulation program for AUVs. Based on this simulation an intelligent docking controller has been developed that can dock an AUV to either a moving or stationary target. This controller uses fuzzy logic rules to determine desired direction and speed. The fuzzy rules make provision for the docking environment such as the location of nearby objects and the bottom. Comparable approaches to path planning in the presence of known obstacles such as potential fields are much more computationally expensive. Essentially, the fuzzy rules define a vector flow field for vehicle motion. Precision increases as the vehicle approaches the target.

Modular Mini AUV:— The new mini AUV design is ultra modular with easy connectable plastic molded pressure vessels and cabling systems. Innovative features of this design include exterior fared cable channels that allow reordering of pressure vessels without any interior rewiring and an octagonal cross section high strength micro fiber reinforced injection molded plastic pressure vessel that minimizes configuration and maintenance costs. Each pressure vessel acts as a fared hull section. Each section is 12” long and 8.5” from side to side.

Hover Capability:— Hover capability will be added to the new mini modular AUV by the construction of two cross body tunnel thruster sections. This will be two of the modular hull/pv sections that have been each outfitted with a vertical and horizontal thruster. This will make hovering capability a removable option for any of the new mini AUVs built in the future. The tunnel thrusters will have 3” diameter propellers. The control system is parametrized so that inclusion of thrusters can be accounted for automatically. FAU will use its simulation facilities and collaborative efforts with NPS to develop the hovering controllers.

Obstacle avoidance capability will be based on inexpensive single and multi-beam sonars.

4 Work Completed

The "Divetracker" SBL system has been acquired and integrated into the vehicle. The portable
dock has been built. It is easy to deploy taking only a few minutes. Extensive at sea tests of the SBL system have been conducted both stationery and with a free swimming AUV. The SBL have some manufacturing flaws that caused crosstalk on the receive channels. Diagnosing and correcting this problem took several weeks.

A prototype docking “cloverleaf” has been built and pool tests have been conducted with an AUV body and stinger. The pool tests tested a full range of approach angles and speeds. The basic concept was proven but did not always capture for off center approach angles. Based on the results of these tests a new redesigned version of the docking mechanism is under construction. The redesign addresses the problems in the prototype and will be used for at sea trials. A stinger retraction mechanism has been designed that is based on the same mechanism used for the pop up DGPS antennae but turned upside down.

A transformer coupled power transfer mechanism was researched but discarded because the size of transformers required would make the puck and stinger too large. Instead a simpler power transfer mechanism was designed and successfully tested. This method uses a spring loaded button on the dock that plunges into the bottom of the puck. A rubber sheath insulates the end of the button from the seawater and the exposed current return path on the top of the puck. Tests were conducted to determine the life span of the electrode should the sheath fail.

Data transfer tests were conducted in saltwater between two loop antennae to determine the maximum separation distance for reliable communications. Simulations of the docking controller were conducted using 6 DOF coefficients obtained from VCT.

The pressure vessel for the new mini modular AUV has been designed and the mold has been ordered. A consultant engineer who specializes in injection molding was contracted to help with the design. Also designed for molding is the nose cone. The tail section will be machined and will use a similar design to the redesign of the OEX gear box. Those two systems are being co-designed for the sake of economy. The sensor systems are being specified and acquired. The computer control system on the new mini-aув will be based on LonWorks for the low level system. The VME system used in the Ocean Explorer will not be used in the new vehicle. Heavy computation functions such as navigation and logging will be done with PC-104+ or Compact PCI computers. We have acquired a PC-104+ based computer and have begun the process of familiarization of porting of our code.

The small size of the thrusters required for the mini AUV meant that we could not obtain commercial off the shelf units. We had to design our own. Several different small size thrusters concept prototypes were built and tested in our tank with a load cell. These include chain driven, direct drive, and right angle gear. We found the right angle gear approach to be the best combination of efficiency and size. Two sizes (4” and 3”) were tested at Johns Hopkins University with the aid of John Witcomb. Each size was tested with both single and double propeller versions. Several hundred megabytes of test data were generated to quantify the performance. This data will be the basis of a master’s thesis. Based on the results of these tests a thruster configuration is currently being designed.

A pencil beam sonar and the Interphase phased array sonar have been acquired and tested. The pencil beam sonar has been integrated into the vehicle. Extensive hardware in the loop simulation tests of the obstacle avoidance controller have been conducted and are the basis of a master’s thesis. The system will be tested at sea at the next reasonable opportunity. Modifications to the Interphase phased array “fish finder” sonar have been specified and ordered. These will provide an RS-
232 output of range and bearing. Once the modified units are delivered they will be integrated into the AUVs and used for either obstacle avoidance or a multi-beam bathymetric sonars.

5 RESULTS

The at sea test of the dive tracker confirm that it measures vehicle position when stationary to less than +/- 6 inches rms. However this accuracy degrades rapidly when the vehicle is moving faster than 0.3 knots. This is generated by the particular pinging protocol. A modified version of the SBL with an LBL pinging protocol has been ordered to address this problem. It is expected that the new system will measure position to within +/- 3 rms for stationary vehicles. With the vehicle computing its position between fixes with its on board DVL and compass the new system should calculate position to within +/- 6” rms for motion up to 3 knots. Successful pool tests of an AUV body with stinger attached being successfully captured by the dock. Once the final version of the dock is completed at sea AUV trials will commence.

Test show the copper electrodes will survive over 9 hours of exposed operation for power transfer. Fully sheathed electrodes show no perceptible corrosion. Gold plated titanium electrodes should have several times the life of the copper. But even copper will allow multiple failure attempts at power transfer initiation. Test showed that a 900 mHz carrier would reliably transmit data as far as 9 inches in saltwater. The separation between the stinger and dock antennas is less than half that distance.

The thruster tests show that reasonably efficient thrusters can be built for small diameter tunnels.

An outlier filter was developed and tested to suppress erroneous ranges from the obstacle avoidance sonar. The filter used past returns and vehicle motion estimates to calculate a window of acceptable values. The obstacle avoidance controller simulation is able to avoid bottom, midwater column, and surface obstacles. The controller acts as a behavior that is smoothly combined with the heading and depth controllers to guide the vehicle around obstacles and then return it to its original path.

6 IMPACT/APPLICATIONS

Docking capability will enable the OEX and any of its modular payload sections to achieve extended mission durations. This makes possible certain types of sampling that have never before been successful such as adverse weather missions. Currently no other small size AUV provides that combination of the selection of mission payloads and extended mission duration. The mini auv will lead to greatly reduced costs of development, integration, operation, and maintenance. This would provide a modular reconfigurable vehicle in the same size range as the REMUS. A full spectrum of AOSN and mine reconnaissance tasks could be accomplished cost effectively using this platform.

7 TRANSITIONS

Several payloads are currently under development that will benefit from docking and hover capability.

8 RELATED PROJECTS

AUV Navigation and Self-Motion in Shallow Water, ONR.
Autonomous Oceanographic Sampling Network Development, ONR.
Enhancing AUV Operational Capabilities, ONR.
Synoptic Data Collection With Multiple AUVs, ONR.
ACOMS Acoustic Communication between UUV and Submarine, ONR ATD.
ONR MURI on Nonlinear Control
University of Miami RSMAS (Proposed NSF), University of Hawaii (Proposed NSF)
USF Projects, CoBop, UK Autosub, WHOI Remus, MIT Odyssey
Advanced Machinery Control Architecture (ACMA) Laboratory Development for Automated
Navy Ship Auxiliary System Control, Reconfiguration and Failure Recovery, ONR.
Dependable Network Topologies with Network Fragment Healing for Component Level Intelligent
Distributed Control Systems for Naval Shipboard Automation, ONR.

9 REFERENCES