

CETUS - EOD Robotic Work Package

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LONG-TERM GOALS

The long-term goal of this project is to demonstrate the capability and usefulness of the Explosive Ordnance Disposal Robotic Work Packages (EODRWP) with the Composite Endoskeletal Testbed Unmanned Underwater Vehicle System (CETUS) platform in detecting, localizing, classifying, and identifying underwater ordnance for Navy EOD missions. The EODRWP/CETUS is intended to support the EOD diver/technician in providing a means of employing a mobile sensor bearing vehicle in the initial search, contact, and evaluation phases of interaction with potentially dangerous targets. This reduces the time required to search and identify all objects in an area of interest; ensures the fidelity and thoroughness of the search; and extends the coverage area.

OBJECTIVES

The development of these capabilities using a vehicle independent approach has allowed their prior evaluation using a tethered Remotely Operated Vehicle (ROV). While extending the diver's range and providing a useful near-term platform for evaluation, the ROV is not without its own set of limitations. Employment of a tether, which supplies power and supports communications to the surface, typically requires a substantial cable, which affects vehicle performance and induces motion forces on the vehicle. This can be a critical factor in shallow water/very shallow water (VSW) environments when operating in close proximity to ordnance. This has derived the goal of implementing the EODRWP on a lightly-tethered/tetherless system.

A fundamental premise of the "dynamic perception" approach employed by the EODRWP in the reacquisition and interrogation of targets has been the use of a platform, which can hover at position relative to the object of interest. Until recently, no small lightly tethered or autonomous Unmanned Underwater Vehicle (UUV) existed outside of a few academic implementations. In 1995 Lockheed Martin funded the development of the CETUS which was initially developed by the Massachusetts Institute of Technology/Sea Grant (MIT/SG) Laboratory during 1996. Demonstrations of extended range and simplified operations afforded by the EODRWP when fielded using a small UUV will substantiate the use of small inexpensive assets in counter-ordnance operations.

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The objectives which have been addressed in meeting the long-term goals center around the operation of the developed intelligent vehicle management and control, navigation, sensor processing, and machine-based classification in a tele-autonomous or autonomous platform.

APPROACH

The approach to meeting the technology objectives focused around completion of integration of the EODRWP and its associated sensors with the CETUS UUV and the development of enhancements required by the move to an autonomous platform.

WORK COMPLETED

The CETUS vehicle was developed and delivered by MIT as a basis for further development. The CETUS included the rotary-molded plastic hull with syntactic foam floatation, a main electronics pressure vessel with pressure relief port and a single 6-way undersea cable connector, 4 battery pressure vessels which include gel-cell lead-acid batteries and battery monitor electronics, 3 vertical thrusters with internal pressure compensation and propellers mounted in spiders in the tunnels on the CETUS hull, 2 horizontal thrusters with external pressure compensation bladders and propellers, and 5 motor controllers in oil-filled pressure compensating enclosures. The thrusters were developed by Dr. Albert Bradley of the Woods Hole Oceanographic Institute (WHOI) and are the same as used on the Autonomous Benthic Explorer and the MIT/SG Odyssey vehicles. Cabling between the battery pressure vessels, thrusters, and motor controllers was also provided. The system, as delivered, did not include any external sensors or computational electronics to communicate with or control the system.

Initial integration of the EODRWP electronics was initiated with the intent of completing a full integration, which would support autonomy. This was complicated by the 1997 objective of integrating the Doppler Velocity Log (DVL) into the system and providing a means by which to measure the accuracy of the derived Doppler-inertial approach versus the existing long-baseline acoustic method. We determined the available long baseline system could be used to ground truth the navigational approach if it were installed to run concurrently with the modified guidance algorithms, which employ the DVL. Due to overlap in acoustic frequencies between the long-baseline navigation system and the acoustic modem, it was decided that the integration of the acoustic modem be deferred until after initial navigation testing. The integration of the DVL was complicated by the lack of space in the aft area. This area was occupied by three separate motor controller assemblies, each of which measured 6 inches wide x 8 inches high x 1.75 inches in height. The DVL and its associated mounting frame would not fit in the space remaining which required that the motor controllers be reintegrated into a single housing. This was fabricated and new cabling was procured. Additional difficulties were encountered with the power monitoring electronics associated with the batteries.

The initial testing completed used a neoprene test cable, which transferred control commands from the surface computer to the thruster controllers. While the long-term goal of the program is to derive an autonomous system, a great deal of benefit was derived in the initial EODRWP development from information telemetered from the vehicle. With the lack of an acoustic modem in the initial testing to be completed, no method of data collection other than on-vehicle storage was practical. A low-cost fiber-optic telemetry system which transmits/receives 1 channel of video transmission and 3 low rate,

serial data channels was integrated into the on-vehicle electronics. This also required that a fiber-optic bulkhead penetrator be installed on the electronics vessel endcap. The output of the Reson 6012 "SeaBat" sonar is a "pseudo video" signal and is compatible. The use of an underwater video camera will also be facilitated on this channel through the use of a simple remote control video switch.

Significant efforts were made in the Vehicle Controller, a closed-loop autopilot, which provides for thruster management and stable operation of the vehicle. The software was previously implemented on a PC and instantiated on a PC-104 single board 486 processor, but now replaced with a lower power and cost single board computer based on the Texas Instruments TMS320C32 Processor. This reduced the total power dissipation required for this continuously operating processor and increased the reliability of the system. The previously instantiated controller was limited to depth set points which employed the vertical thrusters all being operated simultaneously to achieve a commanded depth setting. This limited the vehicle's forward speed insofar as the thrusters operation is not linear and the differences in each thruster's force was accounted for through the use of a "look-up" table. No adaptation to vehicle attitude was attempted in this version and the vehicle operated in much the same fashion as the previously employed ROV. This "stiff" control regime was replaced in the new version of the vehicle controller with inclinations and rates, which were available from the onboard sensors being integrated into the closed loop controller. This alleviated the need for modal control with transit and hover modes now combined into a term that evaluates commanded speed to derive stable control.

RESULTS

During FY98, CETUS was tested several times in Monterey Bay. This testing evaluated the system in increasingly complex trajectories and initial attempts at search patterns. Improvements in the closed-loop autopilot were only marginally quantified due to the failure of the Long Baseline navigation electronics, which were intended to evaluate the EODRWP on CETUS. This was compounded by the CETUS system's lack of an overall power control and anomalies in the closed loop controller which did not allow for the thrusters to be turned off when sensors determined conditions beyond limits. Modifications to both the closed loop controller and the basic power wiring for CETUS are being completed for final demonstrations of capability. Tests completed used the integrated high-frequency Doppler coupled to the inertial sensor with the achievement of a ladder search (equally spaced parallel tracks). These tests were not quantified due to the lack of an adequate external reference. Provisions to complete this testing using a differential GPS coupled to an Ultrashort Base Line system are being completed and testing/demonstrations of the derived capability will complete this contract and provide the basis for follow-on efforts.

IMPACT/APPLICATIONS

The impact of the technologies developed in this program is underscored by the significant transitions initiated recently. The application of advanced "intelligent" control, which is tractable within constraints and defined parameters is required in any guided system that cannot be in constant communication with human operators. Provisions for safe operations of autonomous systems are defined for a number of prototyped and planned systems including unmanned aerial and terrestrial search and identification systems. Reduction of the reliance on fixed navigational systems which require extensive support can provide a useful enhancement to any system which must penetrate a hazardous area including divers, marine mammals, and surface craft. Support for automatic

classification of objects in the presence of incomplete descriptions or poor quality sensor information is required in all underwater image processing based systems.

The EODRWP/CETUS can provide the basis for rapidly deployable underwater search and intervention systems. This directly addresses a number of Navy capability shortfalls underscored in scenarios where currently employed assets (divers, dolphins, deep-water search systems) are not optimally effective. In situations where search area or water depths make diving impractical, the Navy must employ its large underwater systems or turn to outside contractors to provide this service. An example of this is the TWA 800 crash, which restricted dive time due to water depths averaging 30 meters. The Navy was required to move dedicated search vessels and their associated assets to the scene prior to operations. The advantage of the portability and capability of the EODRWP/CETUS in this application are obvious.

The EODRWP/CETUS directly support requirements defined for the EOD Mobile Units and newly defined VSW Mine Warfare Detachments insofar as it provides a sophisticated search and classification system which does not require operational specialists or dedicated support systems.

TRANSITIONS

A significant transition of EODRWP technology was completed in 1997 with the adoption of a significant portion of the Multisensor Intelligent Robotic Architecture (MIRA) by the Remote Minehunting System. The adoption of the MIRA control methodology which asynchronously couples evaluative and reactive “intelligent” procedures to vehicle control functions has provided the basis for the initial development of the Remote Minehunting Vehicle (RMV). Additional functionality developed under the EODRWP Program and transitioned to the RMV includes health and safety monitoring, network-based telemetry and command handling, interprocessor data management, and some guidance, navigation, and control capabilities. Sensor signal processing for the ahead-looking sonar and automatic classification for the ahead-looking and side-looking sonar is being considered for later revisions of the RMV.

The CETUS system configuration emerging from this project, with the EODRWP installed, is transitioning to two new starts in FY99. One of these is the Cooperating Autonomous Underwater Vehicles project, which will investigate the issues involved in heterogeneous AUVs cooperating for EOD related tasks. The other is the Office of Naval Research (ONR) VSW/Surf Zone Mine Countermeasures 6.3 core program, in which the CETUS system will be used as a reacquisition and identification platform in the previously proposed Shallow Water Autonomous Robotic Minehunting concept.

RELATED PROJECTS

In 1997 a contract was awarded by the NAVEODTECHDIV to implement the Robotic Work Package on an Unmanned Ground Vehicle (UGV) as part of the Undersecretary of Defense (Technology Acquisition, Land Warfare Strategic and Tactical Systems) Joint Robotics Program. This program embraces the vehicle independent nature of the EODRWP in its integration on an existing system providing a least-cost enhancement. The REmotely COntrolled Reconnaissance Monitor (RECORM) UGV is a “man-in-the-loop” platform that is currently operated via a radio or fiber-optic link. The EODRWP will automate all UGV actions and facilitate tele-autonomous interaction with a mission

level control station. Several enhancements to the Robotic Work Package will be developed under this program including the integration of global positioning system navigation and the employment of infrared and standard video cameras as the detection/classification sensors. These will be evaluated for applicability to the underwater Work Package.

The EODRWP employs an “off-the-shelf” ahead looking sonar (the Reson 6012 “SeaBat”) as its primary search and classification sensor. This device represents the best compromise of detection range and feature resolution in commercially available systems. A closely related ONR program in high-frequency acoustic sensor development for high-resolution 3-D imaging may provide a sensor enhancement supporting the classification of mine-like targets.

The use of small, inexpensive vehicles for area oceanographic data sampling is being conducted by the MIT/SG Program’s ONR funded Multidisciplinary University Research Program which is headed by Dr. James Bellingham. A number of technologies under development in this program are directly applicable to the problem of area search for ordnance including long-term survey using small UUVs, acoustic communications, acoustic navigation, and data collection/integration.



Figure 1. CETUS Vehicle In-Water Testing



Figure 2. EODRWP/CETUS