REMUS 100 Transportable Mine Countermeasure Package

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Abstract **- Hydroid, Inc. is developing an ISO container-based Unmanned Underwater Vehicle (UUV) mine countermeasure package that will be used to support exploratory mine countermeasure operations from a high speed vessel for the Office of Naval Research. This roll on/roll off mine countermeasure package will be based on the REMUS 100 vehicle system and the PARADIGM tracking system. This package will be maintained and operated by the Mine Warfare Community.**

Over the past six years, the REMUS 100 system has proven itself to be a reliable and affordable means of performing minefield and hydrographic reconnaissance missions in very shallow water (3 to 12 m depths). The advantages of REMUS 100 include the ease of planning and executing operations, its high area coverage rate, its endurance, and an overall reduction in logistical issues due to the system's small size and inherent portability. In addition, REMUS 100 provides a complete solution from mission planning and execution to post-mission analysis, including the generation of reports that aid in decision-making at the command level. Navy personnel who have been trained in the operation of REMUS 100 quickly gain confidence in programming, maintaining, and operating the system; they are often ready to take the system on an operation within days of seeing REMUS 100 for the first time.

This paper reviews system enhancements that extend the REMUS 100 system operating environment into deeper waters (12-30 m) and permit it to perform a greater scope of missions for the Navy, including the reacquisition and identification of targets.

Keywords **– REMUS, AUV, UUV, WHOI, Hydroid, Inc,, autonomous, launch and recovery systems, very shallow water, moving long baseline navigation, multiple vehicle operations, acoustic communications, DIDSON, optical imaging, MCM VSW, SW**

I. INTRODUCTION

The Mine Countermeasures (MCM) Science and Technology (S&T) program at the Office of Naval Research (ONR) is funding the development and demonstration of a REMUS 100-based transportable mine countermeasure package. This package will increase the ability of the Fleet to carry out expeditionary operations, to assure our access to ports and harbors, and to enable naval combatants to successfully perform land attack missions. Use of this technology will also reduce risks to divers and marine mammals that currently support these operations.

Research undertaken by the Woods Hole Oceanographic Institution (WHOI), with support from ONR, has demonstrated that REMUS 100 vehicles equipped with low cost commercially available sonar systems are extremely effective and affordable Very Shallow Water (VSW) MCM systems. REMUS 100 vehicles have demonstrated significant capabilities in numerous ONR technology demonstrations and Fleet Battle Experiments over the past five years. "Reports of the first wartime deployment of the REMUS 100 UUV system indicate that it proved invaluable in conducting surveys in the vicinity of Umm Qasr." [1]

Figure 1 Major components of the REMUS 100 UUV system

The objective of this program is to field new REMUS 100-based MCM technologies that compliment the missions of future naval vessels such as the Littoral Combat Ship (LCS). The LCS is based on the operational concept that a high speed, multi-role, multi-mission vessel can effectively support expeditionary warfare operations. Requirements from the Chief of Naval Operations stipulate that the LCS should deploy with removable and transportable mission packages.

Hydroid, Inc. is developing a REMUS 100, UUV-based, MCM system for integration and demonstration aboard LCS prototypes. The REMUS 100-based transportable mission package will be developed over the next two fiscal years. Hydroid, Inc. will deliver REMUS 100 vehicles, auxiliary hardware, and a set of advanced tracking and communication buoys to the Coastal System Station (CSS), in Panama City, FL. CSS will integrate this hardware into a modified ISO container they will develop in cooperation with Hydroid, Inc. The fully integrated system will then be delivered to the HSV X2 (an LCS surrogate) by CSS.

Once delivered, the UUV packages will be maintained and operated by the Mine Warfare Community. For this reason, technical documentation, logistic support, and training packages will be developed and provided by Hydroid, Inc.

II. BACKGROUND

REMUS 100 was originally developed by WHOI in the late 1990’s to support scientific objectives at the LEO-15 observatory in Tuckerton, NJ. Funding was provided by the National Science Foundation and the National Oceanographic and Atmospheric Association. REMUS 100 completed its first scientific mission in 1997 in the waters off the coast of New Jersey [2].

Figure 2 HSV X1 a Littoral Support Craft

There are currently over 50 REMUS 100 vehicles in 20 different configurations that are being independently operated by nine universities, three US Navy laboratories, and one British defense laboratory, as well as three branches of the US Navy. Hundreds of people have been successfully trained to use REMUS 100. Countless missions have been performed by REMUS 100 vehicles. The longest REMUS 100 mission to date lasted 17 hours and was run off the coast of NJ in waters ranging from 15 to 20 m deep. During this mission, the vehicle traveled 60 km at a velocity of 1.75 m/s.

Beginning in 1997, the basic REMUS 100 design was investigated for use in and then modified to support very shallow water mine countermeasure operations. Both the Office of Naval Research and the U.S. Special Operations Command supported this research. Developmental testing was performed over a five year period to verify compliance with operational requirements that were established in December 1997 [3]. In March of 2003, the Navy’s Operational Test and Evaluation Force stated one hundred percent satisfaction with sixteen critical operational issues involving the REMUS 100 vehicle. This evaluation supported a favorable production decision in May of 2002. Full operational capability was achieved on May 31, 2003 with the delivery of 14 production units to Naval Special Warfare by Hydroid, Inc. These vehicles have been designed to support hydrographic reconnaissance and mine field countermeasure operations in Very Shallow Water (VSW) (3-12 m). They will be operated by a number of different SEAL and Special Boat Teams.

Based on this ongoing progress, the program office for Explosive Ordnance Disposal (EOD) determined that UUV technology had matured to the point that another transition program, based on a User Operational Evaluation System (UOES), could be initiated early in fiscal year 2000 [4]. The UOES concept engages war fighters by getting new technology into their hands as soon as possible in the acquisition process; its success is not only based on the quality of the people who evaluate the system, but also on the maturity, reliability, and ease of use of the system under evaluation; maintenance support therefore plays a critical role. EOD’s procurement decision, which was based on an open and competitive procurement process in which at least two other vehicle systems participated, was to purchase two REMUS 100 vehicles to support the UOES program in the fall of 2000. Two REMUS 100 vehicles and a PARADIGM tracking system were delivered to the VSW MCM Detachment in June 2001. A five day operator training course was completed at that time. Over the next 24 months, the VSW MCM Detachment completed over 150 missions, logging 250 operating hours in the water with these two vehicles. Maintenance and logistical support costs accumulated over this 24 month period were less than \$45k. Operating procedures developed during this evaluation period led to the success of the UUV platoon in Operation Iraqi Freedom. The two UOES vehicles are still operational and are currently being converted to support experiments which will investigate the use of a REMUS 100 vehicle as a Reacquire and Identify (RAI) tool for EOD missions.

Figure 3 Developmental testing of REMUS 100 system

Based on these demonstrated successes, it is fair to conclude that the REMUS 100 system has been instrumental in proving that low cost robotic systems provide a highly productive and effective means of performing a variety of very shallow water (3-12 m) mine countermeasure missions. Interoperability with existing diver and marine mammals systems has been a key factor in the vehicle’s success and acceptance by the Fleet.

It is important to realize that these missions normally involve searching regions that are on the order of one square kilometer in area in less than four hours, and involve detecting small 30 cm targets in an environment that limits the vehicle's altitude above the bottom to between 2 and 3 meters. These operations are typically conducted from small combat rubber raiding craft or rigid hull inflatable boats, and only involve searching for, locating, and classifying targets as mine-like or non-mine-like; historically, REMUS 100 has been used to support the classic Search Classify and Map (SCM) mission in very shallow water.

The REMUS 100 vehicle currently displaces 36 kg and can travel over 100 km in 20 hours at a velocity of 1.5 m/s and at depths up to 100 meters; its endurance far exceeds the requirements of typical VSM MCM missions. The REMUS 100 standard configuration includes a sidescan sonar, an up and down looking ADCP, and CT and light scattering sensors. The vehicle is programmed using a highly refined interface program which runs on a laptop computer. The vehicle can employ acoustic beacons as navigational references, or its onboard computer can automatically select another more appropriate navigation mode to use. This vehicle system has been commercially available from Hydroid, Inc. of East Falmouth, MA under exclusive license from WHOI since 2002.

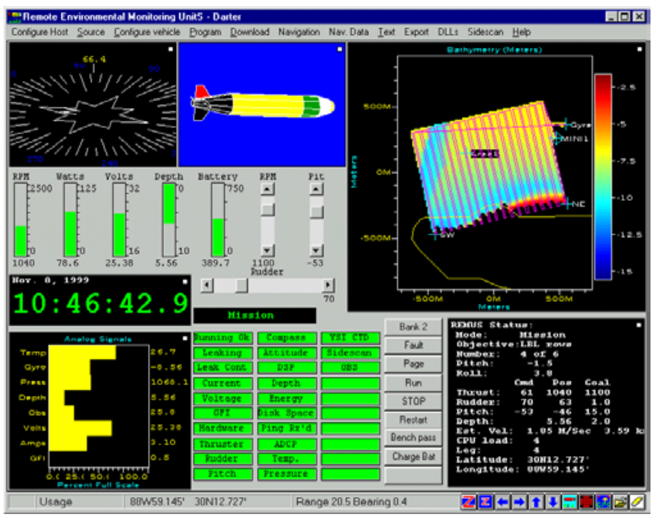

Figure 4 REMUS interface program, which among other features, provides the ability to redirect and monitor multiple vehicles during a mission

III. CONCEPT OF OPERATIONS

The transportable MCM mission package will be based on the REMUS 100 vehicle system; however, significant upgrades are required to support the investigation of the new operational concepts discussed below.

The exploratory mine countermeasure operations that REMUS 100 will support under this program will expand its utility by demonstrating REMUS 100's ability to perform both SCM and RAI missions in both shallow water and very shallow water.

Shallow water mine countermeasure operations are conducted in water from 12 to 30 m deep. The minimum target size is typically about 1 m, and the altitude that the vehicle will be programmed to fly above the bottom is now limited more by the capabilities of the sonar than the environment in which the vehicle operates. The shallow water search area also expands greatly which places new demands on the vehicle's endurance and sensors, as well as on the modes the vehicle uses to navigate and locate targets.

To address these expanded requirements, REMUS 100 will be outfitted with a dual frequency, switchable sidescan sonar. This sonar will permit the vehicle to search larger areas with less resolution and longer ranges using lower frequencies, while retaining the ability to perform high resolutions searches at higher frequencies and shorter ranges.

REMUS 100 uses two acoustic beacons to form a long baseline acoustic navigation network when operating in very shallow water. Long Baseline Acoustic navigation remains as the only proven means of maintaining the navigational precision required to support requirements of standard MCM operations in VSW. Under this program, new tactics will be developed that permit the REMUS 100 vehicle to operate outside a long baseline network with reduced precision. This capability is based on the addition of a Kearfott T-16 inertial measuring unit, which will be supported by outputs from a 600 kHz phased array ADCP and a P-code GPS receiver.

The requirement to reacquire a target and identify it as a mine involves the use of high resolution sensors. This program includes the development of an electronic still camera and strobe module, as well as a DIDSON high resolution forward looking sonar module to support this requirement [5]. Providing the operator with the option to use either one of these sensor modules, depending on the water clarity and mission needs, requires either dedicating a vehicle to each sensor, or developing a reliable means of reconfiguring a vehicle to support these different sensors. This program will focus on developing a generic payload interface that will permit any vehicle to be reconfigured with different sensor modules.

The RAI mission also requires experimentation with new tactics. The capability for a vehicle searching for mines to pass information that it acquires from a sensor to another vehicle or back to the LCS via a communication link will be provided. Capabilities that support human interventions, as well as the ability to have the first vehicle communicate directly with another vehicle so it may autonomously redirect its own mission based on this information will be explored. Clearly, this concept can be extended to multiple vehicles, or this information could be confined to a single vehicle that completes both missions. These cooperative relationships exemplify the emerging potential of multiple vehicle operations; however, extension of this concept beyond two or three vehicles invokes the need for water space management and collision avoidance.

Embedding software such as a Computer Aided Detection and Computer Aided Classification (CAD/CAC) system into a vehicle provides information that permits the vehicle to intelligently alter its (or another vehicle's) mission based on measurements from a sensor it carries. This capability provides the potential for a vehicle to perform both SCM and RAI missions or for multiple vehicles to work cooperatively to achieve the same results in less time, or over a wider area. Demonstrating the ability for an autonomous vehicle to alter the vehicle's current mission based on measurements from the sensor(s) it carries and direct it automatically toward the target will greatly simplify MCM operations as well as reduce the time it takes to relocate and identify a target. Software and hardware will be provided that will permit experimentation with these new concepts.

Shipboard based operations offer new opportunities and new complications. ISO container-based roll on/roll off systems have been utilized in the oceanographic and naval communities for decades. Configuring an ISO container to support MCM operations utilizing REMUS 100 AUVs represents a new level of organization that has not been provided before. Under this program, experimentation with operating, tracking, communicating with, and redirecting multiple REMUS 100 vehicles simultaneously will be undertaken. In addition, it is expected that multiple REMUS 100 vehicles will also be working cooperatively with other UUVs, such as Bluefin Robotics' BPAUV. The REMUS 100 system will be modified to support a central command and control software package that will minimize the complications associated with the complex multi-vehicle operations that are envisioned.

Two communication/PARADIGM buoy systems will provide a link between the LCS and deployed vehicles. An Iridium modem integrated into this buoy system and each vehicle will make vehicle to ship communication range independent, as well as permit any other system that is appropriately configured with access to the network or an Iridium modem to communicate with vehicles operating in this network. The buoy network will also serve as an independent tracking network and as acoustic beacons supporting vehicle long baseline navigation.

IV. OPERATIONAL REQUIREMENTS

A total of six vehicle systems will be provided by Hydroid, Inc. over the course of two fiscal years. Four vehicles will be in a Search Classify and Map (SCM) configuration, and two vehicles will be in the Reacquire and Identify configuration (RAI). The REMUS 100-based UUV mine countermeasure packages will be designed to investigate the value of UUV systems that meet the following requirements:

- Provide the capability to perform SCM missions in very shallow to shallow water (3-100 m) with an onboard CAD/CAC [6] system and an onboard bi-directional acoustic communication system;
- Provide the capability to perform RAI missions in very shallow to shallow water (3-100m) with a high resolution (1.8 MHz) sidescan, a forward looking high resolution sonar (DIDSON), or an Electronic Still Camera and Strobe system;
- Provide the capability to redirect the SCM or RAI vehicles during a mission from the LCS;
- Provide the capability to reconfigure the SCM or RAI vehicles with different payload packages - both DIDSON high resolution forward looking sonar and an electronic still camera and strobe package will be incorporated as candidate technologies for further investigation and evaluation;
- Provide P-code GPS assisted navigation capabilities, with an Iridium based communication link;
- Provide both long baseline acoustic navigation capabilities as well as non-acoustic dead reckoning capabilities;
- Provide a bi-directional gateway communication link from the HSV to any of the operating AUV's via a buoy outfitted with acoustic and iridium links as well as a GPS receiver for experimentation and evaluation of candidate command and control capabilities;
- Provide the ability to track the vehicles using the PARADIGM [7] tracking system;
- Provide the capability to launch and recover the demonstration vehicles and support equipment from Combat Rubber Raiding Craft (CRRC) or Rigid Hull Inflatable Boat (RHIB).

V. TRANSPORTABLE MCM PACKAGE

The transportable MCM package that will be developed under this program is described below. The package, when fully assembled, will consist of six REMUS 100 vehicles that will be configured to support either SCM or RAI missions. These vehicles will be supported by a set of four gateway buoys that provide a communication and tracking link between the LCS and the deployed vehicles. The vehicles and buoys will be stored in an internally modified ISO shipping container that also supports vehicle maintenance, programming, and post mission analysis tasks. The system is self-supporting and includes all equipment and software that is required to operate the vehicle and analyze and process the data it collects. The system will support a number of different MCM reporting formats including MEDALS and EOD tracker.

A. Internally Modified ISO Freight Container

"Malcolm McLean invented the shipping container in the 1930s in New Jersey, while sitting at a dock waiting all day for cargo he had carried there in his truck to be reloaded onto a ship. He figured out a better way to pack goods and transport them by sea - which was to secure them in large steel boxes that could be easily loaded onto ships. And in so doing he came up with an idea that changed the face of global trade." [8]

Today over 90% of the cargo that is moved by sea is carried in what is known as the International Organization for Standardization (ISO) freight container. Mr. McLean not only conceived the idea of the container, he also held the patent on the design of the corner fittings, which established the ISO standard 1161 corner fitting that is the basis for the success of the shipping system.

The Coastal System Station (CSS) in Panama City, FL, will internally customize a standard ISO container to house the REMUS 100 mission package. These ISO containers are 6.1 m x 2.4 m x 2.6 m (lwh), and are rated to carry 20,000 kg. The ISO container will be modified to include environmental controls and other equipment required to support vehicle maintenance tasks, as well as the programming and monitoring of the vehicle during operations. Up to six vehicles and four gateway buoys will be stored, operated from, and shipped in this modified ISO container.

B. Core Capabilities

Two configurations of the REMUS 100 vehicle system will be delivered under this program: the SCM configuration and the RAI configuration. The core capabilities of the SCM vehicle include the integration of dual frequency switchable sidescan sonar, a Computer Aided Detection and Computer Aided Classification (CAD/CAC) system, a bidirectional acoustic modem, a P-code based Global Positioning System (GPS), an Iridium communication system, and a Kearfott T-16B navigation unit. The RAI configuration will include all the capabilities of the SCM configuration with the exception of the dual frequency sonar and CAD/CAC system. The RAI vehicle will support either a DIDSON sonar system or an Electronic Still Camera (ESC) system. The generic payload interface will provide this capability.

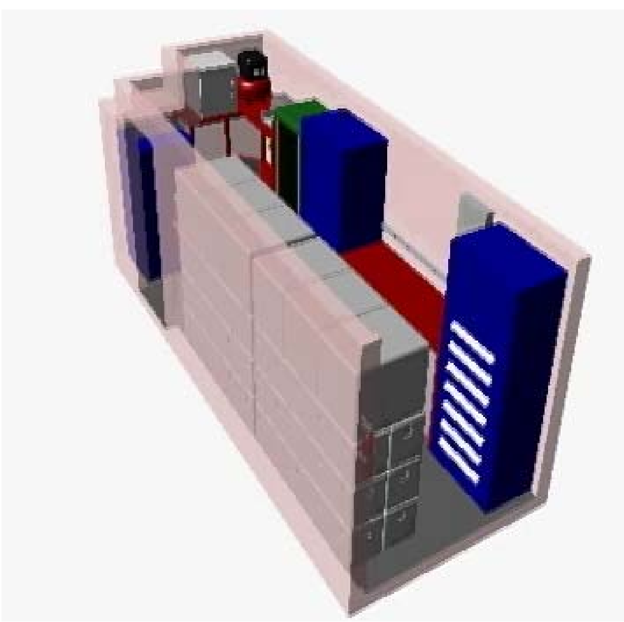

Figure 5 Internally modified ISO freight container

C. Generic Payload Interface

The requirement to configure a reacquisition vehicle with either a DIDSON forward looking sonar or an electronic still camera package, onboard the HSV, will be met by developing a generic payload interface section. A primary concern in addressing this requirement is maintaining an overall system reliability of 0.8 or greater.

The generic payload interface will permit a vehicle to be configured with different mission specific sensor packages in a controlled environment. Ideally, this interface will permit the exchange of sensor packages between vehicles that are manufactured by different vendors.

The generic payload interface consists of three major components: a mechanical interface, an electrical interface, and a software interface.

D. Gateway Buoy System

Two Gateway Buoy Systems will be provided with the system. The Buoy system will be based on the field proven PARADIGM tracking systems, a product currently available from Hydroid, Inc under license from WHOI. The PARADIGM system will be modified to include a WHOI utility acoustic modem with a multi-channel acoustic array, a P-code GPS receiver, and an Iridium modem. The P-code GPS receiver will provide the capability for the buoy to transmit its position to the HSV via the Iridium modem, or to any operational vehicle via the acoustic modem. In a similar manner, the Iridium modem will be coupled to the acoustic modem, permitting bidirectional communication between the vehicle and any other system with an Iridium modem.

VI. CONCLUSION

Existing REMUS 100 systems collect data during the survey which is then downloaded and analyzed after the vehicle completes its mission. The REMUS 100 systems provided with this MCM package will be configured with a computer aided detection and classification system that autonomously detects mines in the sidescan sonar images and logs their location along with a confidence rating to a file. This file is monitored by the vehicle’s control program, which prioritizes this information and broadcasts highly rated locations over the acoustic communication system that are received by other vehicles in acoustic range, or by personnel on the LCS via the gateway buoy system. A REMUS 100 vehicle configured for the RAI mission or any other vehicle may then act on this information autonomously by investigating each target location, or these assets may be directed by an operator aboard the LCS after the snippets of the targets that are also transmitted via the communication link have been analyzed.

Operations conducted in shallow water place different requirements on a vehicle and its sensors than are placed on a vehicle operating in very shallow water. These requirements impact the selection of the sidescan sonar frequency and vehicle navigation modes, as well as the way the vehicle is tracked and communicated with. Exploring the ability of a small set of inexpensive vehicles to provide the capability to meet all of these requirements discussed above will provide extremely important information to Fleet.

VII. ACKNOWLEDGEMENTS

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