Naval Special Warfare Support with REMUS

Christopher von Alt & Roger Stokey
Oceanographic Systems Laboratory
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: 508-289-2290 fax: 508-457-2104 email: cvonalt@whoi.edu
phone: 508-289-3323 fax: 508-457-2104 email: rstokey@whoi.edu
Award # N00014-98-1-0135
http://adcp.whoi.edu

LONG-TERM GOAL

The NSW Concept of Operation, which REMUS supports, is based on the use of small semi-autonomous vehicles to perform shallow water reconnaissance in support of amphibious landing and hydrographic mapping operations. Missions of this type require the vehicle to be launched and recovered from a small craft, such as a Combat Rubber Raiding Craft; to operate in water depths from 3 to 6 meters in the open coastal ocean; to navigate itself in a geographic coordinate system; and to support sensors which can detect and locate moored or bottom laid mines as well as other obstacles. To successfully complete a shallow water reconnaissance mission, the data collected by a REMUS vehicle must be compiled, forwarded, and made available to the task force commander and the fleet. This information must be forwarded in a timely manner in a format that supports decision-making.

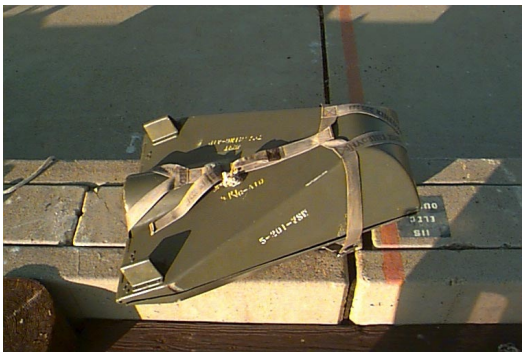

Figure 1 Typical Threat, a GMI Rockan Mine

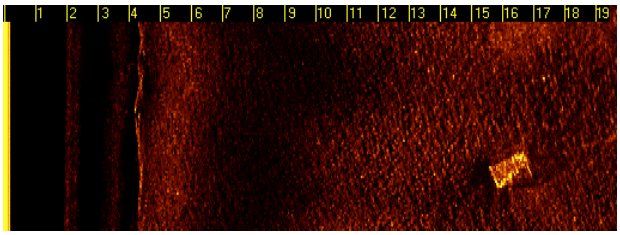

Figure 2 REMUS Sonar Record of Rockan

OBJECTIVES

1. To provide NSW teams with an Initial Operating Capability (equipment and training) to conduct shallow water reconnaissance with small autonomous underwater vehicles by FY00.
2. To develop a technical specification for the procurement and support of a TBD number of small autonomous vehicles, like REMUS, in the first quarter of FY 00.
3. To develop and refine tactics for autonomous vehicle operating procedures that will support the initial Concept of Operation. This will be accomplished by working in the field with NSW teams.
4. To refine the vehicle design, its operator interface, the procurement specification, and the Concept of Operation based on experience gained operating REMUS in the field with NSW teams.
5. To provide training and create awareness among NSW teams of the long term potential and near term practical use of small AUV's like REMUS

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
1998		**00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Naval Special Warfare Support with REMUS	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Woods Hole Oceanographic Institution,Woods Hole,MA,02453**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**6**	

6. To create among the engineers developing REMUS an awareness of the problems and constraints which NSW teams encounter in the field so that the final procurement specification describes a useful tool.

APPROACH

This program addresses Naval Special Warfare operational requirements and proposes the development of a technical specification through a field driven development, test, and transition program. The program establishes an affordable means of integrating autonomous underwater vehicle technology into Special Operations Forces mission areas. The program addresses both long and short-term objectives.

NSW needs are addressed at two levels. Level one objectives involve two to three year horizons. Level Two objectives involve longer-term issues. Level one objectives involve the rapid transition of the REMUS technology base and are focused on utilizing off-the-shelf technologies. Level one objectives emphasize field interaction between NSW team members (operators) and WHOI engineers who have developed REMUS with the intent of getting a useful tool into the field rapidly.

Level two objectives involve longer-range goals. Identified level two goals include areas such as improved sonar mine detection/classification, precision acoustic navigation, acoustic telemetry, multiple vehicle operations, and improved/automated mine detection/classification software. Level two objectives will be met by working with the Office of Naval Research, NAVSEA PMS 325J, and the Naval Coastal System Center at Panama City to prepare guidance to develop these capabilities.

WORK COMPLETED

The following tasks have been completed in fiscal year 98.

1. UPGRADE AN EXISTING REMUS VEHICLE

A second REMUS vehicle has been upgraded to include a 1.2 MHz Doppler Velocity Log; a 600 kHz side scan sonar; a Conductivity, Temperature, and Depth sensor; and an Optical Backscatter Sensor.

2. REFINE VEHICLE DESIGN

A number of refinements to the vehicle system have been undertaken and completed. These include.

- *Battery Technology*: A number of primary cell chemistries were investigated. Of those suitable for use in REMUS, Lithium Sulfur Dioxide was the most cost beneficial at 0.54 dollars/watt-hour. Lithium Thinyl Chloride chemistries have the highest energy capacity; however, they cost approximately 0.85 dollars/watt-hour. Lithium Sulfur Dioxide batteries were selected because they provide an NSW configured REMUS with a range of 60-80 km at 3.2 knots for under $800. A number of battery packs have been assembled and tested in the vehicle. The vehicle completed a 60-km open ocean run during July, 1998.
- *Long Base Line Navigation:* This task involved improvements required to further reduce the electrical and acoustic noise floor in the vehicle in the 5 -30 kHz range and improve out of band signal rejection. The task also involved upgrading the motherboard on one vehicle to the new

docking version. Ranges of 2km at 27 kHz and 5 km at 10 kHz have been obtained in the VSW regime.

- *Track Line Following:* This task focuses on improving the vehicle's ability to acquire and remain on a desired track line without degrading the quality of the sonar records. Field evaluations indicate that REMUS will follow a desired track line to within +/- 2-m in the VSW environment.
- *Rate Gyro implementation:* This task involved the installation of a low cost angular yaw rate gyro in both REMUS vehicles. The task also involved modifying the vehicle's software to permit the control system to servo on the rate gyro signal. In addition, an algorithm which low pass filters the rapidly changing heading from the compass was developed so that the slow drift rate of the rate gyro may be compensated for.
- *Operator Interface:* The man-machine interface has been upgraded to include many new features. These include: (1) computer aided layout of ladder searches; (2) automated HTML report generation; (3) generation of MATLAB plots of bathymetry, currents, salinity, temperature, and optical backscatter from within the REMUS program; and (4) developed interface to 8 new sensors.

3. Field Evaluations I & II

Two REMUS vehicles were used to demonstrate their ability to conduct hydrographic and mine field reconnaissance in shallow water. The evaluations were conducted near the Naval Amphibious base on Coronado Island in San Diego. Field Evaluation I was conducted from 17 to 27 February 1998. Field Evaluation II was conducted from 8 to17 September 1998. The Explosive Ordnance Disposal Group One VSW/MCM Detachment supported the Field Evaluations. The Field Evaluations were conducted under the direction of LT Scott McMahon of PMS 325J. Representatives from Panama City Coastal Systems Center, COMOPTEVFOR, and PMS-EOD also witnessed these evaluations. Field Evaluations I included nine tests that consisted of 22 missions. Field Evaluation II consisted of 10 major mission scenarios that included 22 hours of in-water time. Results of these tests are provided in the next sections.

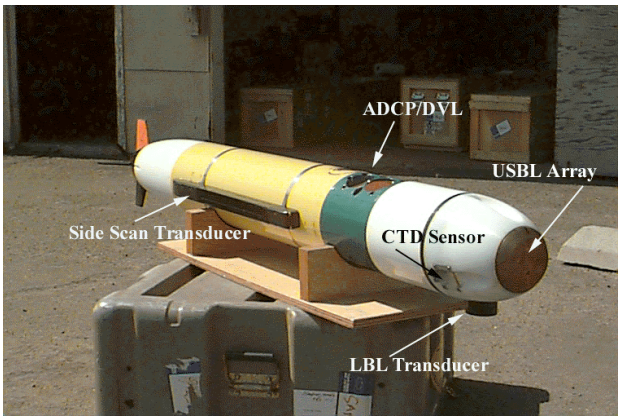

Figure 3 REMUS/SAHRV Vehicle

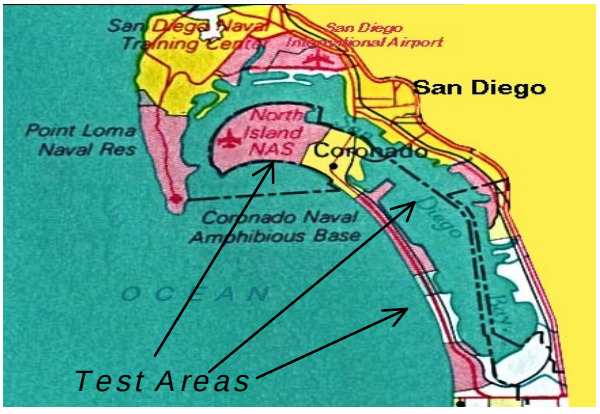

Figure 4 Test Areas for Evaluations I & II

RESULTS

An evaluation of the two REMUS vehicles by NAVSEA PMS 325J has established that they are capable of greatly improving MCM and hydrographic reconnaissance operations in very shallow waters. Evaluation I established that the existing vehicle systems, with minor design changes, can be operationally effective in the VSW environment. Evaluation II established the level of performance of REMUS's major subsystems.

The SAHRV/REMUS vehicles have the following configuration:

- *PHYSICAL:* The vehicle is 19 cm in diameter, 178 cm long and weighs 44 kg. It has a depth rating of 150 m.
- *SENSORS*: The vehicle is equipped with: (1) a 600 kHz side-scan sonar; (2) a 1.2 MHz Acoustic Doppler Current Profiler (up and down looking) with bottom lock velocity capabilities; (3) a Conductivity, Temperature, and Depth sensor; and (4) an Optical Backscatter sensor which provides an indication of water clarity.
- *NAVIGATION*: The system includes hardware and software that supports three modes of navigation. These are: (1) ultra-short Base Line (USBL) which provides range and bearing to a single transponder; (2) long base line to two or more transponders; and (3) dead reckoning, which is based on integrating bottom locked velocity data from the ADCP with heading information from the compass, or by propeller turns and the compass. The vehicle's USBL and LBL navigation systems are supported by acoustic transponders that are anchored to the seafloor and rigged to rest in mid-water. These small units are geographically located using some form of a GPS receiver (P-code or differential). The positional error associated with the location of the transponders is the largest source of error in the system if a commercial differential station or P-code is used. The transponders may be operated continuously for up to three months, or they be may be operated intermittently for up to three years. The vehicle supports ladder searches, homing, and other more complex mission scenarios, by switching between these three modes of navigation during a mission.

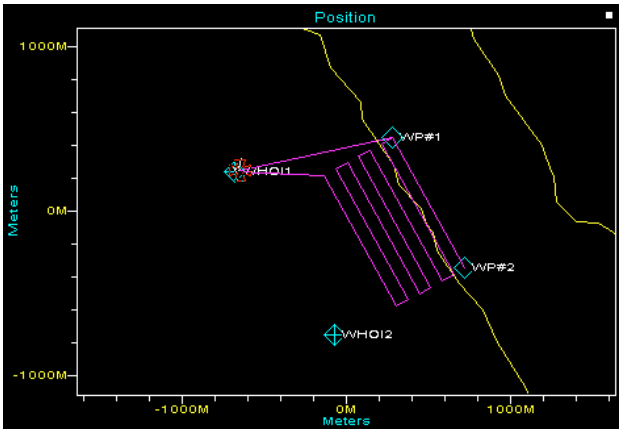

Figure 3: 1 km x 500 m Phase 1 Near Shore Survey, showing transponder locations and vehicle path

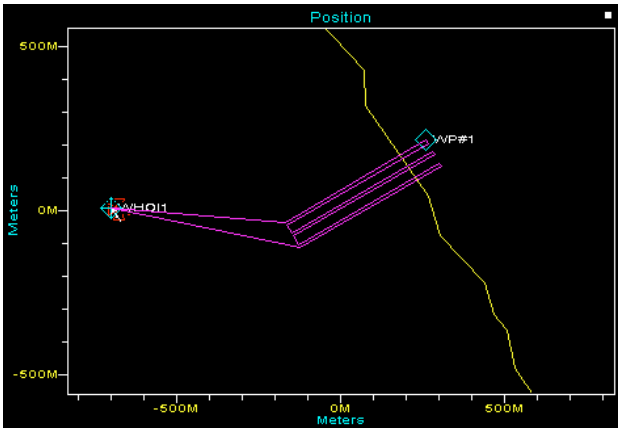

Figure 4: 100 m by 500 m Phase 2 Boat Lane Survey from 3 m to 6 m depth using the same transponders as phase 1

- *SPEED AND ENDURANCE:* The vehicle is typically operated near 1.5 m/s; however, its speed is variable and can be set anywhere between 0.5 and 2 m/s. At 1.5 m/s, the vehicle has an endurance of four hours with lead acid batteries. This provides an effective range of 20 km. When operated

with Lithium Sulfur Dioxide batteries, it has an endurance of 12 hours or more, which provides an effective range in excess of 60 km.

- *SURVEY RATE:* Vehicle search rate is dependent on the mission, the bottom type, and the threat, as well as other factors. On average, the system provides an effective search rate that is on the order of 0.15 sq-km/hr. This rate may be improved by deploying multiple vehicles to perform the search. The search rate is based on using a 20 meter range for the side scan sonar and maintaining a high probability of detecting small targets.
- *TARGET LOCALIZATION:* Two Navy sponsored tests of REMUS' navigation system have been performed. The 27 kHz LBL and USBL systems have been shown to be robust at ranges of 2 km in water depths from 3 to 6 m. Both systems have been shown to be repeatable to within +/- 2 meters at ranges of up to 2 km from the transponders. The bearing resolution of the USBL system is within one degree; however, the quality of the compass calibration can greatly affect the positional accuracy of this array. At 10 kHz, the overall resolution of the system is lower, but navigation ranges of over 5 km have been achieved. The positional accuracy of this system is dependent on the navigation system that is used to locate the transponders. Using differential GPS, the cumulative errors associated with target location using the side scan sonar can be kept within 10 m at 2 km ranges from the transponders.
- *TARGET DETECTION AND CLASSIFICATION*: The vehicle configuration described above has provided images that permit the detection of mine-like objects under controlled conditions. Additional testing is required to establish detection and classification probabilities for various threats in differing environmental conditions.

IMPACT/APPLICATION

The United States Special Operations Command in Tampa, FL has approved an Operational Requirements Document (ORD) which describes a very shallow water mine counter measure and a semi-autonomous hydrographic reconnaissance system. This document details a system which is essentially identical to the technology which has been developed at WHOI and states that no change in the Naval Special Warfare force structure will be required to support this technology. The ORD also establishes that a full operational capability will be achieved when a complete inventory of 28 vehicles with full logistic support and training is in place. Currently, full operational capability is called for in FY01.

TRANSITIONS

As stated above, one objective of this proposal is to provide NSW teams with an Initial Operating Capability (equipment and training) to conduct shallow water minefield and hydrographic reconnaissance with small autonomous underwater vehicles by FY01.

RELATED PROJECTS

ONR BAA 98-008 Diver and UUV Systems and Technologies for VSW/MCM Missions

REFERENCES

Semi Autonomous Hydrographic Reconnaissance Vehicle (SHARV) Field Evaluation One Report, Program Executive Officer, Expeditionary Warfare (PMS325) May 1998

Operational Requirements Document (ORD) for Very Shallow Water Mine Counter Measures (VSW MCM), Semi-autonomous Hydrographic Reconnaissance Capability (SAHRC), Semi Autonomous Hydrographic Reconnaissance Vehicle (SAHARV) Annex A, and Hydrographic Reconnaissance Littoral Mapping Device (HRLMD) Annex B.

PUBLICATIONS

1. Allen, B., Stokey, R., Austin, T., Forrester, N., Goldsborough, R., Purcell, M., von Alt, C. (1997). REMUS: A Small, Low Cost AUV; System Description And Performance Results, Proceedings Oceans' 97, Halifax, Canada

2. Austin T., Stokey, R., von Alt, C., Arthur, R., Goldsborough, R. (1997). "RATS", A Relative Acoustic Tracking System Developed for Deep Ocean Navigation", Proceedings, Oceans '97, Halifax, Canada.

3. Purcell, M., Stokey, R., Goldsborough, R., Austin, T., Forrester, N., von Alt, C., Allen, B., (1998), The REMUS AUV Docking System: Overview and Test Results, Proceedings, MTS Conference '98, Baltimore.