RECENT U.S. NAVY UNDERWATER VEHICLE PROJECTS

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ABSTRACT

Unmanned underwater vehicle (UUV) technology received major support within the U.S. Navy during its early years of development. The support then declined just as commercial interest picked up. Today, larger UUVs are going commercial in support of offshore oilfield and pipeline route surveys. In addition, the academic community is pushing the technology in the area of smaller low-cost vehicles. Because of the high rate of commercial growth in the UUV area, the military is once again interested in the leverage provided by such vehicles. However, in today's environment, the interest is directed toward smaller, low cost vehicles that can work together to complete the assigned missions. This paper will review today's U.S Navy missions where UUVs will play a role, the vehicle systems that are either under development or planned in the future, and will assess whether the state-of-the-art is sufficiently advanced to support those goals.

INTRODUCTION

UUVs, which have been under development for decades within the U.S. Navy, are now approaching an operational status. The operating platforms for these systems range from submarines to surface ships and small inflatable craft. Although the initial systems being used are larger, relatively high cost vehicles, the future trend is toward smaller, low cost vehicles that can work together to complete the assigned mission.

On-Going Programs

Although early UUV developments in the Navy were for underwater search, the initial mission for UUVs, also known by many as autonomous underwater vehicles (AUVs), will be mine hunting; this was also the case for fleet introduction of remotely operated vehicles (ROVs).

But in the case of the first operational Navy UUV, it will operate from a submarine and not a surface ship. The submarine launched Long Term Mine Reconnaissance System (LMRS), Figure 1, a torpedo sized UUV, is scheduled for initial operation in 2003 (Wernli, 1997). The LMRS will provide a unique capability, but it will do so with a very high price tag. Accordingly, the number of units to be built will be less than desired.

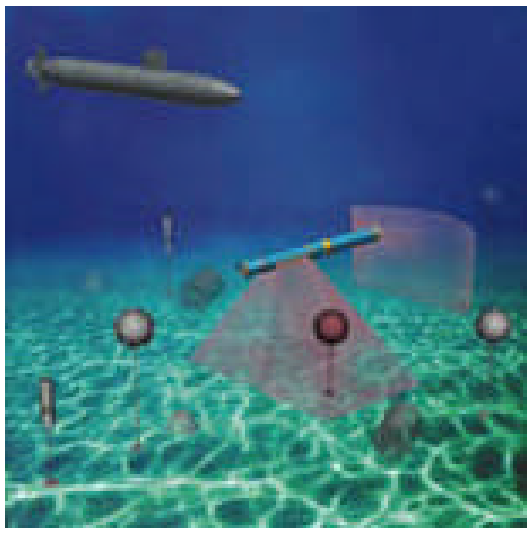


Figure 1. LMRS

The area of underwater search and survey is not being ignored. The Advanced Unmanned Search System (AUSS), Figure 2, developed by the Space and Naval Warfare Systems Center San Diego (SSC SD), is once again operational. But in this case, its primary role is not to search the ocean to depths of 20,000 feet. In an agreement between SSC SD and Ocean Workers Inc., a San Diego based firm, the AUSS will be used in the future for commercial operations. The AUSS is an acoustically controlled UUV capable of relaying real time sonar and photographic data to the surface.

Also on the search and survey front is work ongoing at the Naval Oceanographic Office (NAVOCEANO),

Figure 2. AUSS

located at the Stennis Space Center, Mississippi. NAVOCEANO entered the UUV arena in 1997 with the transfer of UUVs developed by Draper Laboratories for the U.S. Navy. The equipment was modified to create the Lazarus vehicle, Figures 3 and 4. In addition, 3 Seahorse Class vehicles are being delivered to NAVOCEANO by Penn State. The 28 foot long, 38 inch diameter, Seahorse will be operated from the T-AGS 64 (USNS HEEZEN) for underwater survey and bottom mapping. Woods Hole Oceanographic Institution (WHOI) is developing a full ocean depth Semi-Autonomous Mapping System (SAMS) for NAVOCEANO. The SAMS vehicle, which is based on the REMUS vehicle, will use acoustic communications for image transmission and position information.

Figure 3. Lazarus AUV

Figure 4. Lazarus AUV in Launch Cocoon

While not technically an “underwater” vehicle, the Navy’s Remote Minehunting Vehicle (RMV), Figures 5 and 6, provides a hybrid approach to locating underwater targets. The surface ship launched RMV is powered by a 370 hp diesel marine engine, which can move the 23-foot-long vehicle at speeds of 10 knows on the surface. While the main body of the vehicle remains below the surface, the snorkel rises above the waves providing the engine’s air intake and a platform for the RF antenna. Below the surface, the vehicle has the capability of lowering a tow fish, which is a variation of the Navy’s AN/AQS-20 minehunting variable depth sonar that can detect and classify bottom and moored mines.

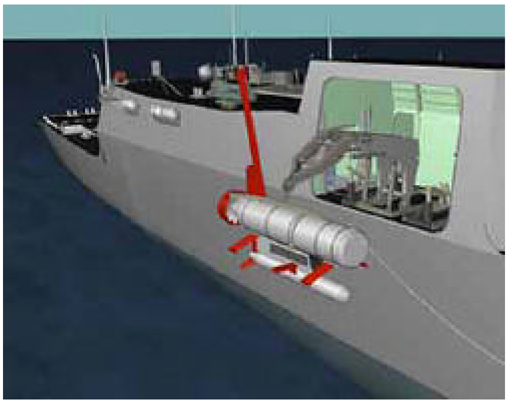


Figure 5. Remote Minehunting Vehicle Launch

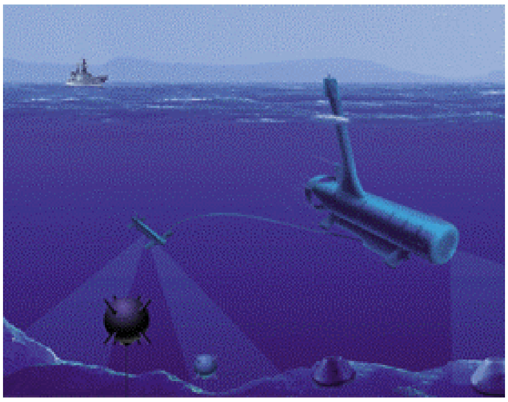


Figure 6. Remote Minehunting Vehicle Operation

Another vehicle program undergoing technical evaluation by the Navy takes advantage of recent advances in autonomous vehicle technology. The Airborne Mine Neutralization System (AMNS), Figure 7, being developed by Lockheed Martin Naval Electronics & Surveillance Systems, is a helicopterdeployed system used to reacquire and destroy previously located mines using a one-shot expendable remotely operated vehicle. The vehicle is based on STN ATLAS Electronik's SEAFOX. The Bremen, Germany, company has teamed with Lockheed Martin on the program.

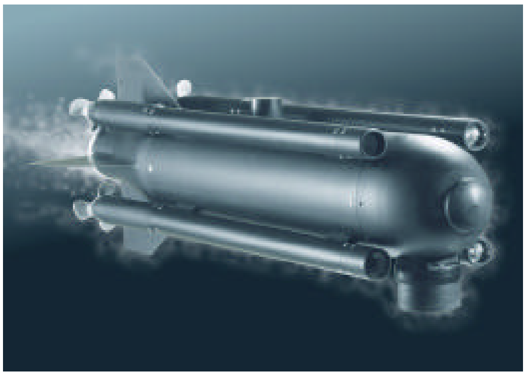


Figure 7. Airborne Mine Neutralization System

U.S. Navy's UUV Master Plan

A study of the broader scope of UUV mission applications for the U.S. Navy was recently completed (April, 2000) by an ASN/RDA (Assistant Secretary of the Navy, Research, Development and Acquisition) chartered study team (Dunn, 2000). The study, which looks ahead 50 years, provides a roadmap for the Navy to use in integrating unmanned undersea vehicles (UUVs) into the battlespace of the future. Critical missions identified include Intelligence, Surveillance, Reconnaissance, Mine Countermeasures, Tactical Oceanography, Communications, Navigation, and Anti-Submarine Warfare. The Navy UUV Master Plan incorporates near-term acquisition efforts while establishing the direction for long-term development and technology investment.

One of the most significant recommendations in the UUV Master Plan was that many missions could be completed using multiple, inexpensive, small vehicles rather than fewer large and expensive UUVs. The goal is to develop a standard interface design for the smaller vehicles that would eventually be in the 6 – 12 inch diameter range. This is a major step away from the earlier thrusts by the Navy in the UUV area, i.e. large deep ocean and mid depth vehicles (AUSS, Lazarus) and tactical submarine launched, 21 inch diameter, vehicles (LMRS).

A New Philosophy

In the past, much of the undersea vehicle technology was developed in the Navy laboratory system and transitioned to industry. Eventually, this technology made its way to the academic community when the cost came down, unless direct funding from the Navy was available. The interesting aspect of the Navy's new requirement for smaller vehicles is that the technology resides primarily in academia. Thus, the tide has turned. Now, the institutions that have learned to build small, low cost, easily handled, reliable UUVs are the ones in the driver's seat. This is not to say that the Navy has ignored this area, to the contrary, the Office of Naval Research (ONR) has been funding such technology for some time. What has been missing is a commitment by the Navy to accept the tactical importance of the smaller vehicles along with the belief that the technology is here to begin adapting them for Navy missions (Wernli, 1999).

The biggest philosophical change is the acceptance of expendability, i.e. when many inexpensive vehicles are used to solve a problem, losses are acceptable; whereas losing one of the few expensive UUV platforms developed by the Navy to date could end one's career. The battle cry "It's time to lose some UUVs" is not new; but now it is finally being heeded.

ONR TAKES ON THE CHALLENGE

This philosophy is being embraced by the U.S. Navy's Office of Naval Research (ONR). ONR worked with the UUV Master Plan team when the report was being completed and became proactive in incorporating its recommendations. This small vehicle thrust, which had been resident in ONR in various forms, has now been focused into a cohesive assault on the problem. ONR has dropped the gauntlet with the Undersea Search and Survey and Communications/Navigation Aid Demonstration BAA (broad area announcement) (ONR, 2001).

The ONR capabilities and related technologies have been identified through the Future Naval Capabilities (FNC) process. The Autonomous Operations (AO) FNC addresses critical autonomous operations gaps in the ability of Naval Forces to conduct successful warfare campaigns. The vision of the AO FNC is to enhance the mission capability of Naval Forces by developing technologies that will dramatically increase the performance and affordability of Naval organic unmanned vehicle systems. The goal of the AO FNC is to provide technologies that can eliminate manned operations in hostile environments.

The Unmanned Undersea Vehicle Technology project will address the capability to perform missions with UUVs that will allow submarines, surface ships and other Naval Forces to clandestinely expand their sphere of influence while reducing potential vulnerability in the littorals, Figure 8. The technology demonstrations that are planned are in alignment with the Navy's UUV Master Plan.

The UUV Master Plan identifies four basic signature capabilities, and provides an outline for the development of the underlying technologies required to implement these signature capabilities for littoral operations. The signature capabilities include:

- **Maritime Reconnaissance (MR)** – centers on the Intelligence, Surveillance, Reconnaissance (ISR) functions; target designation; launch and coordination of UUVs for battle damage assessment; and intelligence collection.
- **Undersea Search and Survey (USS) –** provides the ability to rapidly survey selected areas through the use of networks of small UUVs, performing functions such as mine hunting/neutralization, underwater object location and recovery, and hydrographic/bathymetric surveys.
- **Communication/Navigation Aid (C/NA)** – provides a communication/navigation relay for other underwater vehicles operating within the immediate area, and is expected to serve as a gateway for an autonomous underwater communication/navigation network.
- **Submarine Track and Trail (ST&T)** – provides a mobile cueing function, but could grow into a fully autonomous system offering multiple levels of engagement

UUV DEMONSTRATIONS

ONR is working in conjunction with the AO FNC to demonstrate each of the 4 key signature capabilities from the Navy's Master Plan. Accordingly, ONR will award contracts for UUV demonstrations of undersea, autonomous operation capabilities in Maritime Reconnaissance, Undersea Search and Survey, and Communication/Navigation Aid. The ST&T mission will not begin until approximately 2006. Additionally, ONR will award contracts for the research and development of related technologies that support these and future demonstrations. The planned demonstrations, which will mitigate the risk in future Navy acquisition programs, are described below. Anticipated funding is also provided.

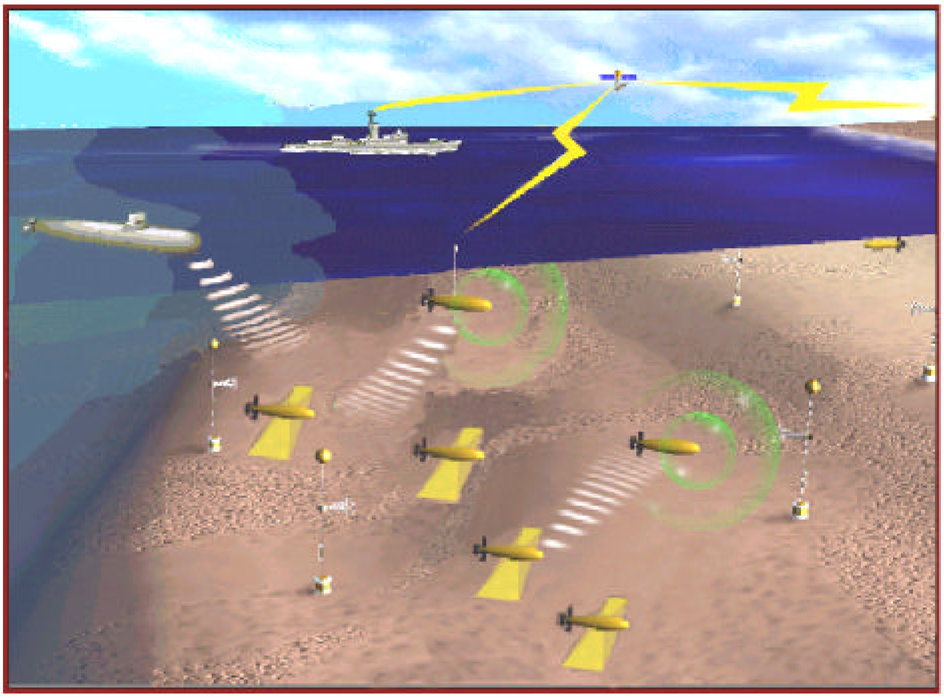


Figure 8. Multiple Cooperative UUVs

Maritime Reconnaissance (MR) – (Up to $14,000,000 from FY2002 through FY2004). A UUV will transit clandestinely for up to 100 nautical miles from a host platform, arrive at the designated location, and conduct its littoral mission for up to several days. The vehicle will transmit or return with environmental data, such as bathymetry and water properties, and intelligence, surveillance, and reconnaissance (ISR) data such as radio and radar transmissions, and optical imaging.

The Maritime Reconnaissance mission will be used by the following systems:

- AN/BLQ-11 Long Term Mine Reconnaissance System (LMRS), a submarine launched UUV.
- Mission Reconfigurable Unmanned Underwater Vehicle (MRUUV); 21 inch diameter x 240 inch long vehicles being developed through FY10.
- Semi Autonomous Hydrographic Research Vehicle (SAHRV), a 7.5 inch diameter UUV being acquired by the Navy's Special Operating Forces.

Undersea Search and Survey (USS) – (Up to $14,000,000 from FY2002 through FY2005). An UUV(s) will collect hydrographic and oceanographic data, find mines, unexploded ordnance items, wrecks, lost objects, pipelines, cables and other objects of interest, leading to possible intervention efforts such as mine neutralization, object recovery, and connection to in-situ equipment. Multiple small UUVs may be used to meet the mission requirements: 100 square nautical miles to be covered in less than three days in depths ranging from 40 feet to 200 feet.

Demonstrations will focus on transitioning USS technology into acquisition programs in the FY 2006 timeframe through the use of small (7.5 inch diameter) autonomous vehicles deployable by hand from a Combat Rubber Raiding Craft (CRRC), Figure 9. UUVs for Explosive Ordnance Disposal (EOD) and Mine Countermeasures (MCM) "Reacquire, Identify, Neutralize mines" missions are notionally small autonomous vehicles, less than 12 inches in diameter, deployable manually from small, rigid hull inflatable craft or CRRCs.

Communication and Navigation Aid (C/NA) – (Up to $16,000,000 from FY2002 through FY2005). A UUV will provide long-range communication and navigation functions via Low Probability of Intercept (LPI) communications links between underwater, surface, air and ground assets/systems. The C/NA should also provide clandestine, GPS-quality navigation fixes for underwater systems. Spatial scales associated with the MR and USS missions previously defined apply to the C/NA vehicle.

Figure 9. CRRC Launched UUV

KEY TECHNOLOGIES

Recent demonstrations of UUVs at events such as NAVOCEANO's "AUV Fest" and military exercises such as *Kernel Blitz* held at Camp Pendleton have proven that significant accomplishments can be achieved with commercial off the shelf technology. But this technology can be taken further, especially in the reduction of size and power consumption. With this in mind, the ONR initiative is concerned with the advancement of key UUV related technologies. These technology requirements, which are in concert with the conclusions of the UUV Master Plan, Figure 10, include the following.

Communication

Acoustic and RF communications in depths from 40 feet to 600 feet. Acoustic interests include low-cost, low power, small aperture, two-way, modular systems and those with a low probability of intercept (LPI). RF interests include low cost, low power, low profile, two-way, sea surface systems including over the horizon and global via satellite.

Navigation

Underwater navigation interests include the following:

- Acoustic positioning (e.g., static transponder nodes, mobile nodes)
- Integrated acoustic navigation and communication
- Inertial systems
- Feature-based localization (e.g., bathymetric, gravitational, magnetic field maps)
- Quick-look GPS

	Maritime Reconnaissance		Undersea Search & Survey								Navigation/ Communication Aid			Submarine Track and Trail				
			Object Sensing & Intervertion					Oceanography										
	Pass.	Active	Detect (SLS)	Class (SAS)	ID	Neut	Interv.	Bottom Char	Bathy	Volume Meas.	Comm.	Nav.	Data Ex	Detect	Class	TMA	Trail	Hand-off
Communications	Yellow	Green	Green	Green	Green	Green	Green	Y-G	Y-G	Green	Green	Green	Green	Green	Green	Green	Green	Yellow
Navigation	Green	Green	Y-G	Y-G	Y-G	Y-G	Green	Y-G	Y-G	Green	Green	Green	Green	Green	Green	Green	Green	Green
Energy	Y-G	Y-G	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow	Red	Green
Propulsion	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Green
Mission Equip.	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Sensors	Green	Green	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Green	Yellow	Green
Data Processing	Green	Green	Green	Yellow	Yellow	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Autonomy	Yellow	Yellow	Green	Green	Yellow	Green	Red	Green	Green	Green	Green	Green	Yellow	Yellow	Red	Yellow	Red	Yellow

- **Definitions:**
  - Mission Equipment: Specific HW items associated with the Mission, not on-board sensors, but includes deployed equipment
  - Sensors: UUV Installed Sensors Specific to accomplish the mission function
  - Data Processing: Data processing and management specific to the mission requirements
  - Autonomy: Software / artificial intelligence and decision making associated with performing the mission without human guidance
- **Ratings for near term Acquisition (assuming minimal risk mitigation):**
  - Green: Low Risk ; Y-G Risk Low-Moderate dependent on size
  - Yellow: Moderate Risk
  - Red: Significant Risk

Figure 10. UUV Master Plan's Risk vs. Technology vs. Capability Matrix

- Cooperative, multiple-vehicle, multi-day navigation with over 100 square nautical mile area coverage and minimum reliance on GPS

Energy

Power sources capable of providing air-independent, electric power to a fully submerged vehicle that meet Navy operational constraints such as low acoustic signal, safe handling on-board the host vessel (submarine, surface ship or aircraft), acceptable total ownership costs, and full environmental compliance. Technologies of interest include fuel cells, rechargeable batteries, turbo-alternators, semi-fuel cells, and thermal engines (Stirling, Brayton, other). Energy density and management for prolonged deployments (several weeks or more), possibly utilizing docking stations, is also of interest.

Sensors

The following UUV sensors are needed in miniaturized, low power configurations:

- Sonars that provide resolution on the order of four inches out to a range of 800 feet and minimize the number of channels.
- Sonars that can replace a number of distinct arrays operating at various frequencies on current vehicles (e.g., a forward look sonar array, an acoustic communications array and a side looking sonar array) with a single, conformal, multi-mode array with onboard processing to enable automated obstacle detection and target recognition.
- Electro-magnetic (EM) and electro-optic (EO) ISR sensors that will enable extremely broad-band above-water signal detection, classification, localization, and collection.
- Inexpensive sensors and distributed sensor fusion that enable autonomous, three-dimensional object imaging.

Autonomy

This includes system and subsystem level technology developments that will increase the survivability and adaptive control of vehicles in complex/dynamic/tactical environments; reduce communication and human supervision requirements; enable cooperative, multi-vehicle operations with navigation aids and communication relays; and provide increased levels of situational awareness.

Specific areas of interest in autonomy include:

- Planning and control architectures
- Path planning (including obstacle and dynamic threat avoidance, adaptive route planning)
- Behavior development
- Mission planning/replanning
- Multiple vehicle behavior and control
- Multiple vehicle imaging, localization, and data fusion
- On-board mapping of environmental variability, identified objects and moving contacts
- Effective man-machine interface with a limited communication capability.

CLOSE ENOUGH FOR GOVERNMENT WORK

The old adage “close enough for government work” is being taken to heart by the U.S. Special Operations Command (USSOCOM). In a joint program with ONR, USSCOCM is developing the Semi-Autonomous Hydrographic Reconnaissance Vehicle (SAHRV) (von Alt, 2000). The vehicle will be used for reconnaissance in very shallow water (VSW). In an effort to demonstrate that the technology is sufficiently advanced to field first generation UUVs, the SAHRV program is initially leveraging a project known as the Remote Environmental Monitoring Unit (REMUS), a program under the National Oceanographic and Atmospheric Administration’s (NOAA) National Undersea Research Program (NURP). The goal is to achieve an initial operational capability within 4 years of program initiation. The system, which is presently based on the WHOI developed REMUS vehicle, Figure 11, will be small, inexpensive, meet the operational requirements and be operable by a 3-4 person crew of VSW and Explosive Ordnance Disposal (EOD) Mine Countermeasures (MCM) Detachment divers and support personnel.

The future goals of the EOD MCM teams are also being supported by the ONR’s Chemical Sensing in the Marine

Figure 11. WHOI’s REMUS UUV

Environment Program (CSME) (Fletcher, 2001). The CSME program targets the development of novel means to detect and locate UneXploded Ordnance (UXO) in marine environments, and to detect, characterize, and quantify explosives and their derivatives in seawater and marine sediments. Hydrodynamic field tests, conducted at SSC SD using a specially configured REMUS vehicle, have shown positive results, providing data for the development of detailed models capable of forward and reverse tracking of UXO plumes, Figures 12 and 13.

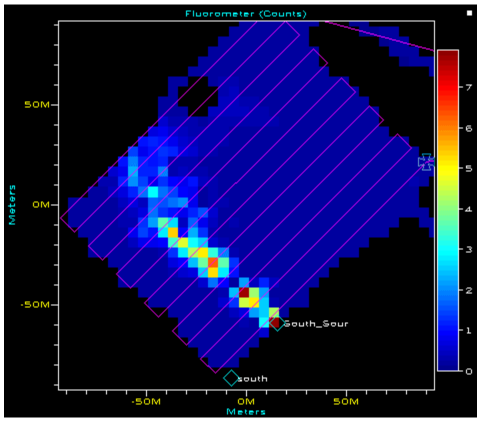


Figure 12. Data Plot of Plume Distribution

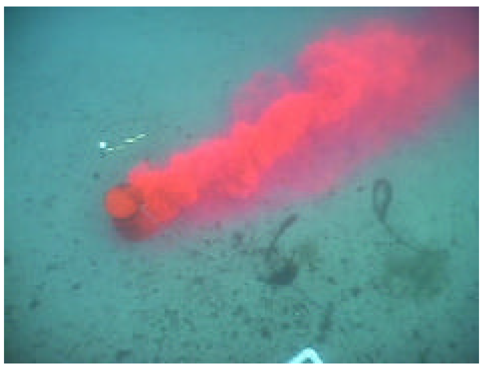


Figure 13. Rhodamine Plume

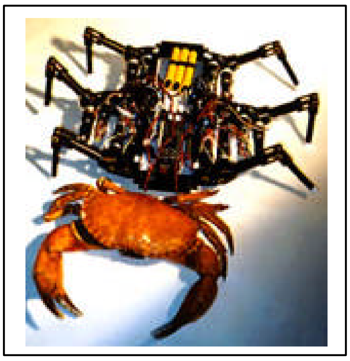
CONCLUSIONS

The operational and planned UUVs previously discussed are the predominant thrusts in the Navy today. Although other programs are ongoing at Navy laboratories and research centers, they will not, in most cases, have the high visibility or influence on the acceptance of UUVs by the Navy as the thrusts supported by ONR and others, which are based on the Navy's UUV Master Plan.

Figure 14. Today's Autonomous MCM System

Can the technology for UUVs be advanced further to where the vehicles can do a better job? The answer is obviously yes. Is this advancement necessary to field operational UUVs in the near future? The unequivocal answer is NO. The technology is at hand. Yes, UUVs can achieve more, and in the future they will. Acceptance of UUVs and incorporating them into the battle group using today's technology is the primary barrier; one that finally appears to be falling. The Navy has usually been the first to field advanced technology, but in the case of UUVs, it led the pack, then fell behind as academia and commercial offshore firms embraced and fielded the technology. Finally, the Navy is again moving in the proper direction (Wernli, 2000).

An overriding fact of military operations is that losses are inevitable, and in many cases, acceptable. Today, VSW MCM is conducted by EOD divers (Figure 14). By the end of this decade, UUVs will be in routine use by the U.S. Navy. Hundreds of vehicles will be launched into the sea on MCM and other military missions. Many will be lost. But in this case, a letter to a grieving relative will be unnecessary (Figure 15).



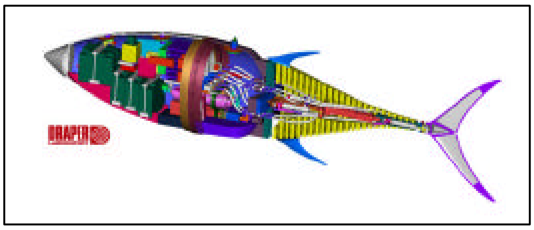


Figure 15. Tomorrow's Autonomous MCM Systems?

REFERENCES

Dunn, P. 2000. "Navy Unmanned Undersea Vehicle (UUV) Master Plan," *Unmanned Underwater Vehicle Showcase 2000 Conference Proceedings*, pp 105-126

Fletcher, B. 2001. "Underwater Platforms for Chemical Detection," *Pacon 2001 Conference Proceed*ings.

Office of Naval Research Broad BAA Solicitation Number: 01-012, Published in the Commerce Business Daily on 18 April 2001.

von Alt, C. 2000. "News From the Front – Why some UUV's are in demand," *Unmanned Underwater Vehicle Showcase 2000 Conference Proceedings*, pp 133-142

Wernli, R.L. 1997. "Trends in UUV Development within the U.S. Navy," *OCEANS 1997 MTS/IEEE Conference Proceedings*.

Wernli, R.L. 1999. "AUV'S—The Maturity of the Technology," *OCEANS 1999 MTS/IEEE Conference Proceedings.*

Wernli, R.L. 2000. "AUV Commercialization – Who's Leading the Pack," *OCEANS 2000 MTS/IEEE Conference Proceedings*.

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Florida Atlantic University AUVs:
http://www.oe.fau.edu/AMS/auv.html
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