Surveillance Unmanned Underwater Vehicle

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Abstract - A self-powered unmanned underwater vehicle (UUV) outfitted with forward looking, side scan sonar and laser imaging systems will provide a highly effective clandestine mine survey. A similarly outfitted system provides a new cost effective commercial site survey and pipeline inspection capability.

I. SYSTEM ENGINEERING ANALYSIS

In 1992, Applied Remote Technology (ART) initiated a detailed study and at-sea demonstration/validation (DEM/VAL) program which concluded that a UUV would provide a highly effective way to perform subsea surveillance operations. The resultant baseline UUV is depicted in Figure 1.

A. Trade Studies

The system analysis was broken into five key tradeoff areas:

- propulsion/power
- navigation
- communications
- sensors
- life cycle costs

Since the UUV is a volume limited, self-powered platform, a subsystem weighting scheme was developed to quantify the various tradeoffs between performance, size, power, etc. of various options for each subsystem.

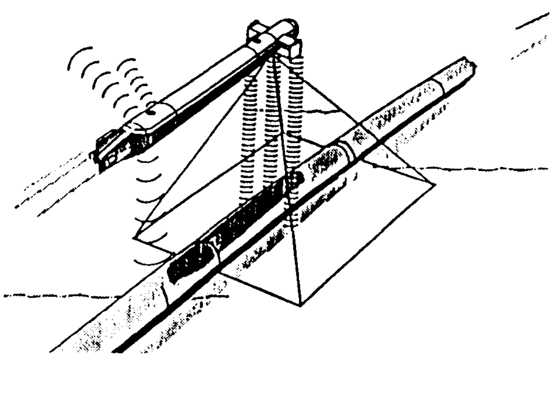

Figure 1 Baseline Vehicle Configuration

B. Propulsion/Power

Two vehicles were sized to bracket operationally useful mission capabilities. A small diameter (0.54 M diameter) vehicle could be launched from a submarine while the larger diameter (0.76 M diameter) would provide longer endurance.

It should be recognized that there are interdependencies between each of these key tradeoff areas. For example, although a goal is to perform the mission as quickly as possible (maximize coverage rate), this results in a major penalty in power consumption (and hence total mission endurance). Furthermore, high speed survey operations in a shallow water mine field would represent a high risk of impacting obstacles placed to obstruct landing craft.

A less obvious tradeoff exists between onboard energy sources. A fundamental power source trade exists between energy and power density. Invariably, higher power output power sources tend to result in lower energy densities further contributing to the improvement in endurance by operating at slower speed of advance.

Certain power sources such as lead acid batteries provide a relative flat voltage-current curve. That is, the energy available out of these batteries does not differ appreciably over a relatively wide power draw. The drawback is that this chemistry has only about a third the energy density of silver zinc batteries and about ten percent of fuel cells. Conversely higher power draw on silver zinc batteries and fuel cells tend to reduce their energy density.

A third consideration is life cycle costs. Although silver zinc batteries provide about three times the energy density of lead acid batteries, at high discharge rates, these cells typically last for only a few cycles.

C. Command, Control Communications

The long term UUV solution is a fully autonomous platform not requiring any communication with the host platform until the mission is completed. This autonomous solution will require high level vehicle controllers that are capable of dealing with both expected (such as fault recovery and obstacle avoidance) as well as unexpected events. Although work is proceeding in these areas, near-term solutions will require a certain level of man-in-the-loop supervision and decision making.

Four communication schemes were evaluated including electromagnetics, laser, acoustics and fiber optics. Radio Frequency (RF) was discounted for a variety of reasons. The fact that a mast must remain above water would either require towing an RF mast or maintaining the vehicle near surface. The towed mast would significantly increase vehicle drag whereas the near surface operations prevent the sensors from being operated at the optimum depth above the bottom. The requirement for above water mast increases the probability of detection and interception.

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Raytheon/ART is developing a proprietary electromagnetic communication system that offers the potential for long range communications at relatively high bandwidth. The technique is limited to shallow water operations, however. Due to its developmental nature, it was discounted as a near-term solution.

Laser communications were also discounted due to the very limited range in water and the requirement for line of sight operations for above water communication.

Raytheon/ART's Adjustable Diversity Acoustics Telemetry System (ADATS II) provides up to 2500 bits/sec and lower baud rate at up to two nautical miles range in high multipath environments with up to ten knots of relative velocity. Introduction of improved signal processing algorithms offers the promise of improving this performance by an order of magnitude. Even with this improved performance, acoustic communications will remain bandwidth limited and not be able to provide real time continuous sensor data to the host platform. Raytheon has and continues to develop improvements in computer aided detection, classification and identification softwater. Coupling this work with data compression techniques will allow the UUV to send only the useful sensor information over the acoustic channel, thereby reducing bandwidth requirements.

Fiber optics provide the necessary bandwidth for real time covert multi-sensor data transfer. Single mode fiber can provide up to 100 km of range without the need for a repeater. ART and others have demonstrated the use of free spooling fiber to minimize drag and hence propulsion load. The penalty is volume used onboard the UUV to carry the fiber and the environmental concern of leaving fiber on the ocean bottom. Based on these considerations, a free spooling single mode fiber optic cable was chosen as the best near term communication solution.

D. Navigation

A key part of performing a surveillance operation is navigation accuracy. The level of accuracy is driven by specific operational requirements. For commercial applications such as subsea pipeline pre-installation surveys, navigational accuracies on the order of ±50 M are usually adequate.

For mine avoidance operations, safe standoff distance must include a margin for navigational error. Ultimately the density of the mine field will be such that penetration cannot occur unless the entire field can be circumnavigated. Reducing the navigation error and vehicle signature will allow the standoff distance to reduce, hence increasing the probability the UUV could penetrate the minefield.

If mine neutralization is the goal, the navigational accuracy of the vehicle position needs to be better than the sonar target detection range to support target re-acquisition.

Using the above assumptions, it was felt that a Doppler-aided inertial navigation unit, similar to one we are using on another UUV program, would result in a navigational error build up of approximately 15 meters per hour. Based on the navigational accuracy requirement for reacquisition, it was determined that a GPS update to the INU would be required approximately once per hour during the survey operation. For operation where the host ship is outfitted with GPS, and follows the UUV with an ultra-short baseline navigation system, this is not a problem. When the surface ship does not follow the UUV, the UUV would have to surface for local GPS updates.

E. Sensors

Acoustic Sensors: Raytheon is the US Navy supplier for both the SQQ-32 variable depth mine hunting sonar and the AQS-20 helicopter towed sonar replacement for the existing AQS-14 side scan. ART is an industry leader in underwater laser imaging and has operated flux gate magnetometers on the XP-21 to demonstrate the ability to track buried pipelines.

Raytheon's broad experience with acoustic, optical and magnetic sensors, leads us to conclude that a combination of acoustic optical and magnetic sensors is necessary. This was confirmed during at-sea mine reconnaissance testing performed using ART's XP-21 UUV in 1993.

The smaller diameter (0.54M) UUV allows for a much broader set of host platform alternatives and a reduced cost for the handling systems. This broader set of host platform options increases mission utility significantly. The drawback to the smaller diameter vehicle is less available space for sensors and energy. When non-recurring engineering, recurring and operational costs are all considered, cost benefit analysis weighs in favor of the smaller diameter platform.

The smaller diameter does result in reduced aperture, and hence performance, for a forward looking sonar. To offset this, we concluded that a multi-beam high performance side look sonar, (similar to the AQS-20 side scan that Raytheon is developing for the U.S. Navy), would provide the best performance for "macro" acoustic surveys.

Synthetic aperture sonar (SAS) offers the promise in the long run for greater swath coverage and the ability to detect buried objects such as mines or buried pipelines. The difficulty with synthetic aperture is that array position must be known at all times to within 0.1 of a wavelength. Although our in-water testing has determined that a torpedo shaped UUV is relatively stable in turbulent near coastal waters, the risk of being able to compensate for this unpredictable motion is high.

Magnetic Sensors: Similarly high sensitivity Superconducting Quantum Interference Device (SQUID) magnetometers present some of the same motion risks due to magneto-hydrodynamic noise induced by the turbulent water. Furthermore, to take advantage of this sensitivity, the magnetic sensor would have to be magnetically isolated from other parts of the UUV with significant magnetic signatures. In water testing of conventional flux gate magnetometers we have demonstrated that the vehicle noise levels and platform stability are adequate to track 8 cm buried pipelines as deep as 3 meters. Similar to SAS, we believe that although highly sensitive SQUID magnetometers offer the potential for future buried mine hunting improvements, the use of flux gate magnetometers provide a low risk near term operationally useful adjunct sensor.

Optical Sensors: ART is presently developing underwater laser line scan imaging systems that have demonstrated two to three times the range and field of view and up to ten times the resolution of conventional underwater cameras. As a result, this technology adds an entirely new dimension to underwater surveillance capability.

Although optical systems cannot provide the swath width of acoustic systems, the ability to develop high fidelity images (at up to 4096 pixels/line of resolution) at a panoramic 70 degree field of view provides a dramatic improvement not previously available.

Sensor Summary: For mine surveillance operations, a combination of a multi-beam side scan for classification survey, a forward looking sonar for obstacle avoidance and mine relocation, a conventional flux gate magnetometer to provide statistical samples of buried mines and a laser line scan imager for final mine identification can be provided today as a low risk sensor suite for a mine reconnaissance operation. Future improvements in synthetic aperture sonar and high sensitivity magnetometers should be introduced to increase coverage and buried mine detection capability when the technology has matured.

For commercial operations such as subsea pipeline inspection, a similarly outfitted platform using three flux gate magnetometers to locate the UUV over buried sections provides a highly cost effective alternative to today's towfish/ROV operations.

Life Cycle Cost Analysis: Our approach proposes a modular UUV that can be quickly modified to carry a variety of mission specific payloads. For initial mine survey operations, the UUV would be outfitted with forward looking and side scan sonar. Within the constraints of a submarine (6 M long by .54 M/diameter volume) torpedo tube, the UUV can carry a 100 km energy pack and a laser line scan imager to perform identification operations during the initial deployment. Alternatively, an additional 50 km energy pack could be included in lieu of the laser line scan identifier.

A modular approach (Figure 2) requires that only one UUV baseline design is required. Depending on the specific nature of the mission, various payload sections can be added to perform survey, above water reconnaissance, neutralization or tactical oceanography.

This approach minimizes both non-recurring engineering and recurring costs resulting from a single vehicle point design and scale of economies. Furthermore, operational costs are reduced due to lower logistics support costs than would result from multiple mission specific UUV designs.

The small diameter option facilitates operations from smaller surface ships, submarines, aircraft and other host platforms. Being able to deploy from all of these platforms increases system utility and, therefore, overall cost effectiveness of the system.

To provide an integrated "turn-key" capability, ART engineers developed a patented Sea State Tolerant AUV (Launched) Recovery System (SSTARS). The SSTARS system includes the UUV control consoles and displays a sea state four capable launch and recovery system all integrated into 3Mx12M ISO container van. The integrated SSTARS can be shipped by land, air or sea. Shipment for deployment from any ships of opportunity with an aft footprint capable of accommodating the system. This additional turn-key feature further minimizes life cycle costs by reducing shipment costs, increasing weather windows, and maximizing host platform options.

II. DEMONSTRATION/VALIDATION PROGRAM

Energy density of existing power sources is limiting UUV utility and effectiveness. With its partner Alupower, ART demonstrated the first aluminum oxygen semi-cell on board a UUV in the fourth quarter of 1993. Although production "hardening" will be required, these tests demonstrated that this chemistry can, in fact, provide two to three times the energy density of silver zinc batteries. With the production improvements, it is expected that the cost of these semi-cells will also be significantly less than silver zinc.

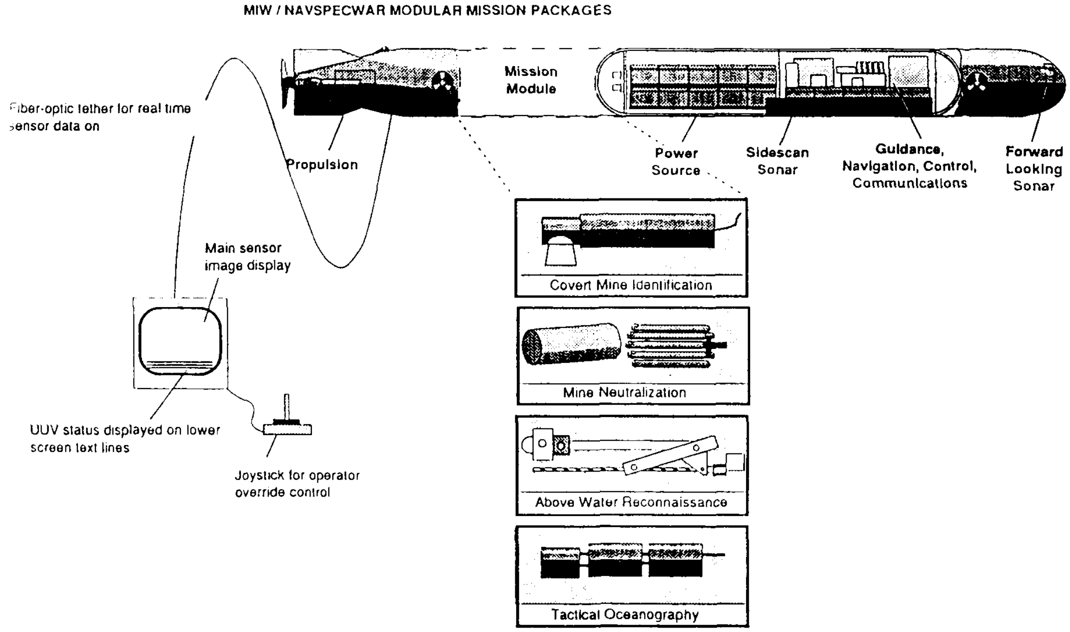

Figure 4 Modularity Provides Minimum Cost Multi-Mission Capability

III. RECOMMENDATIONS FOR FUTURE DEVELOPMENT

A. UUV Power Source Development

Although the energy density goals of aluminum-oxygen semi-cells were met, the present implementation power is limited to nominally 2.0 kw. This power level is adequate for many, but not all UUV missions. Alupower is also nearing completion on a lower energy density, but higher power density design. Combining the lessons learned from these programs, we believe that the higher power levels can be reached with only a small impact on energy density.

B. Sensors

Work should continue in synthetic aperture sonar development to minimize the affect of platform movement. This problem should be attacked from both the vehicle stability and electronic compensation stand point.

Continued work in laser line scan imaging should be pursued to reduce hardware size & introduce electronic motion compensation.

C. Command, Control and Communications

Development of robust long range UUV compatible communications system should be continued to ultimately eliminate the need for a fiber tether. High level controllers need to be introduced to facilitate reliable autonomous operations. These control systems will provide for improved fault tolerance, mission planning, obstacle avoidance and sensor information management functions.

IV. CONCLUSIONS

Raytheon/ART has just completed a two year study and at -sea test program demonstrating that the technology exists today to perform a semi-autonomous surveillance operation.

The basis of this work was the contractor developed modular XP-21 UUV which was used to evaluate various subsystems required to meet the mission need. A similarly outfitted UUV has direct dual use potential for commercial offshore surveys and pipe tracking.