INTEGRATED CONTROL SYSTEM FOR AUTONOMOUS SEARCH CAPABILITY

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Abstract
Concepts for autonomous underwater search now involve Unmanned Surface Vehicles (USVs) as method of deploying Unmanned Underwater Vehicles (UUVs) to do search and survey missions. Using a USV minimizes transit time, allows for local recharging and data download between missions, and provides a more robust communications link to a human-operated control center. The challenge to implementing a fully autonomous search capability is adding automation to every part of vehicle launch and recovery. VCT has been developing each piece of the system as a "smart" component with a control system to accomplish its piece of the task. Integrating each control system together will result in a completely autonomous search capability using UUVs.

Introduction
There is a need to develop an autonomous search capability to detect/classify, identify, and neutralize, mine like objects. The complex and dangerous nature of this mission requires integration of multiple technologies that include USVs, UUVs, towed vehicles, launch and recovery systems, and autonomous operations, among others.

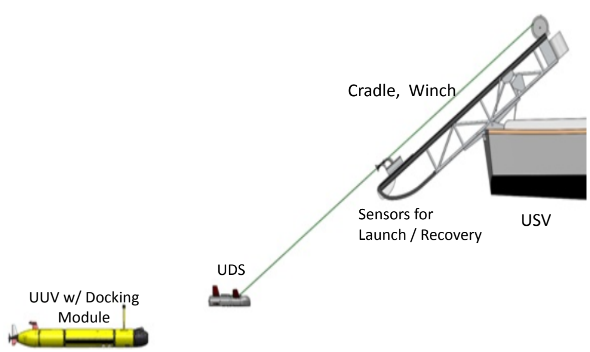

Figure 1: Foundation of Autonomous Launch and Recovery Concept

Figure 1 shows the concept for an autonomous launch and recovery system (ALARS) for a UUV. This system is at a prototype level and consists of a towed docking vehicle, cradle, winch, and control software. The advantages of this overall concept include:

- Underwater docking capability with complexity located in the ALARS, not the UUV
- Scalable to different UUV sizes and weights, ranging from approximately 125 lbs to 2000 lbs
- Cradle designed with integral winch and cable reel for low weight, self containment – weight can be reduced with carbon fiber construction
- Cradle can also be used with tow bodies or powered tow bodies, adding a higher speed or longer endurance element to autonomous search capability

Figure 2: ALARS prototypes in use with towed docking vehicle (top) and Powered Tow Body (bottom)

Concept of Employment
The USV will be deployed and on station in a minefield tasked with conducting mine search, identification, and neutralization activities.

The UUV is deployed and retrieved underwater using the towed docking vehicle. The towed docking vehicle is based on VCT's Universal Docking System (UDS) prototype. The UDS is a maneuvering tow body that homes on a UUV and captures it for recovery. It employs six fins for five degree of freedom control capability (roll, pitch, yaw, heave, sway), and a ultra-short baseline (USBL) acoustic positioning system for relative position measurement. The UUV only needs to be outfitted with a standalone USBL beacon and docking mast.

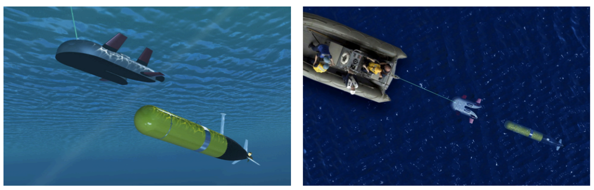

Figure 3: UDS Concept of Employment

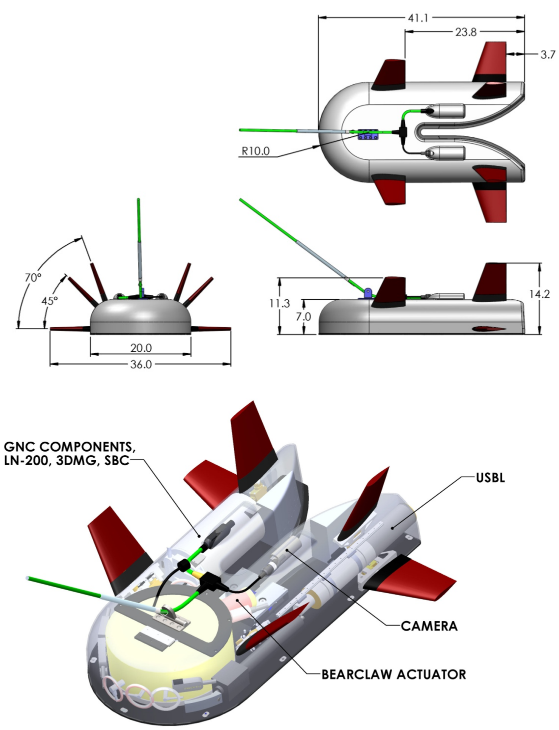

Figure 4: UDS Arrangement

The following description will outline the recovery process including required UUV and USV behaviors and approximate times, totaling 35 minutes.

Plan & Execute Mission
In planning the USV and UUV missions, the mission manager software plans a "UUV Recovery" event by commanding the UUV to end its mission in a fixed speed (3-5 knots), fixed depth, race-track or box maneuver beginning at a specified time, and commanding the USV to be in the vicinity at approximately the same time. An advanced feature for the mission manager here would be to alter the UUV track line based on seas and weather conditions so that recovery will be accomplished at the optimum orientation relative to the waves.

Search (10 min)
Upon arriving at the rendezvous location, the USV needs to precisely locate the UUV. Two approaches are used (1) a second USBL located on the USV and 2) USVs ACOMMS system to communicate with the UUV and obtain its location. The USV may require a search behavior if ACOMMS communication or USBL contact is not immediately established. With knowledge of the UUV's planned track line and its current speed and location on that line, the USV then maneuvers onto the same track line ahead of the UUV.

Homing (10 min)
The USV then activates the ALARS system, deploys the UDS and uses its USBL to obtain a precise track on the UUV. The USV continues to maintain a track line parallel to that of the UUV within some distance (~ ±20 ft). Currently a human operator makes these refinements using a "heads-up display", however it is anticipated that the mission manager or even the UDS itself would issue steering commands to the USV to accomplish this task. This may include a search behavior if USBL track is not established immediately. During these operations, the UDS maintains steady lateral flight behind the USV with UDS commanded depth equal to UUV depth, and UDS roll and pitch angles controlled to zero. While the USV is maneuvering UDS uses yaw damper control to follow the USV gently during any turns or other maneuvers.

Capture (10 min)
Once the UUV is in the capture zone, the USV makes the decision to begin the capture process by slowing down and maintaining a speed of 0.5 – 1.0 kts less that that of the UUV. When the USV has achieved a steady track and valid UUV tracking data is being received, UDS will actively maneuver to close lateral

and vertical distance with the UUV, capturing its docking mast. During this stage, the winch will engage motion compensation to further reduce the motion of the UDS for docking. The ability of the winch system to receive sensor data, issue commands, and conduct motion compensation is called “Smart Winch” capability.

Once the mast is captured, the UDS “flys-down” and engage a secondary latch to fix the UDS to the top of the UUV. Measurement and indications of a successful latching will be forwarded to the mission manager for approval to proceed.

Retrieval (5 min)
Upon a successful latching, the ALARS deploys its cradle recovery mechanism, and winches the UDS and the UUV onboard as a single unit.

What modifications are required of the UUV to operate with this system?
The UUV requires two key components in order to dock: a docking mast and a USBL responder. As demonstrated in the prototype system, these components can be entirely self-contained and bolt-on, or they could be integrated with fold-down capabilities or other features that would increase the automation of the system.

A docking mast kit will be required for integration into each individual UUV. Note that the docking mechanism is independent of vehicle size.

Maturity of VCT’s Underwater Docking System
A central technology to autonomous retrieval of a UUV is the ability to dock or capture it autonomously. UDS was designed to accomplish that goal. The UDS has been prototyped and demonstrated in-water to a TRL5. VCT has demonstrated homing and docking with a submerged tow body. Demonstrating docking with a free-swimming UUV would constitute a TRL6, and operation in sea state > 2 would constitute a TRL7.

The next step that is required to accomplish free-swimming UUV docking is automating the process of aligning the boat on a track ahead of the UUV, which in the past has been a difficult task. A “Docking Heads-Up Display” has been developed but not demonstrated to accomplish this task, and is the first step in developing automated steering commands.

Figure 5: Early UDS Prototypes and Successful Docking Event

Automation for a Cradle Retrieval System
Once the vehicle is captured, it must be recovered through the air-water interface in sea state. The prototype cradle system is a two-level ramp – a pair of rails for the UDS to ride on, and a lower tray to support the UUV. The cradle has the ability to extend aft and tilt up, creating a ramp and submerging the aft end. The winch is mounted to the cradle so the cable passes directly down the ramp, through a “trumpet” and to the UDS. As the UDS is winched in toward the trumpet, it aligns itself with the flow behind the boat. There are no motion constraints or locks until the UDS and UUV are pulled into the cradle. In the existing prototype the UUV is not secured in the cradle by anything other than its connection to UDS.

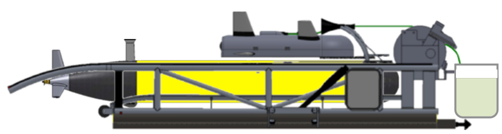

Figure 6: Profile of Existing Launch and Recovery Cradle in Stowed Position

The current cradle recovery system is operated by personnel on the boat for safety reasons. VCT plans to convert it to a “one-button” recovery system with additional automation features. This requires knowledge and control of the winch system (cable scope, drum speed, etc.), USV condition (speed, heading), and location of the UDS.

Smart Winch Capability
The smart winch concept has been developed in concert with the UDS. The goals of the smart winch are to provide:

1. A “smart” interface with software commands and sensor inputs
2. A motion compensation capability to mitigate boat motion effects on the tow body
3. A means to couple winch control system with other (UDS) control systems (future)

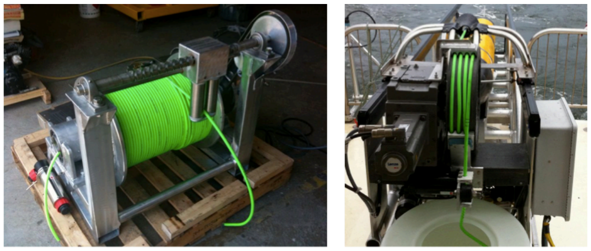

Figure 7: VCT Smart Winch Hardware (Level-wind winch at left, Capstan winch at right)

The “smart” interface for the winch is the standard VCT Vehicle Controller hardware and software architecture. This computer has been interfaced with the capstan style winch shown above right.

From a hardware standpoint, there are two starting point designs to build off of. The customized winch (above left) weighs less than 500 lbs, and has a fully electric drive, and integrated level wind. The capstan winch at right has a carbon fiber drum with four wraps. The cable feeds of the capstan into a bucket. Avoiding a slip ring and large drum, this is a lightweight, low cost alternative to a traditional winch. The capstan winch is in constant use by VCT to launch and recover its line of vehicles.

VCT’s Prototyping Approach - Simulation Based Design

VCT’s vehicle design approach is based firmly on its hydrodynamic modeling and simulation capabilities. During the development of UDS, design decisions on vehicle shape, weight, fin placement, fin design, actuator specs, operating speeds, and control system design were analyzed with VCT’s hydrodynamic toolset and traded off against other design factors. Smart Winch control algorithms done to date have used the toolset to simulate boat motion, tow body, and winch system response. When design changes are made to UDS and Smart Winch, simulations are conducted during design and prior to in-water testing, and data are compared to results.

Integration & Test Approach

The existing UUV launch and recovery system was refined through extensive on-the-water testing and refinement. Decisions on refinements are made by a combination of engineers with mechanical design experience and watermen/boat builders with experience on the water and also building UUV launch and recovery systems currently in Navy use. With VCT’s lab facilities and boat on the Chesapeake Bay, rapid, low-cost modifications and changes are possible to our equipment and an iterative integration and test approach is used. This approach is beneficial both for refining the ALARS design. VCT owns a 36ft Boat, UDS prototype, a launch and recovery cradle, a UUV docking transponder and mast, and a prototype Powered Tow Body/UUV vehicle.

On the software side for UDS and Smart Winch, VCT remains committed to an open architecture approach to vehicle control. VCT’s existing vehicle controller is based on the ASTM F41 architecture, has published interfaces, and provides a high level of access to vehicle functionality such as the extensive fault monitoring function.

Figure 8: VCT 36' Test Boat

Conclusion

VCT has developed a prototype autonomous search capability consisting of a UUV, an underwater docking system, a cradle retrieval system, and a smart winch, and has integrated them together on a test boat the size of an 11m RHIB. Each of these systems uses a control system to reject disturbances from the environment and operate autonomously without human intervention. Major components such as the Universal Docking System and Smart Winch controller have been demonstrated. Automating and integrating each of the remaining components will realize the vision for USV-based UUV search missions that are completely autonomous.