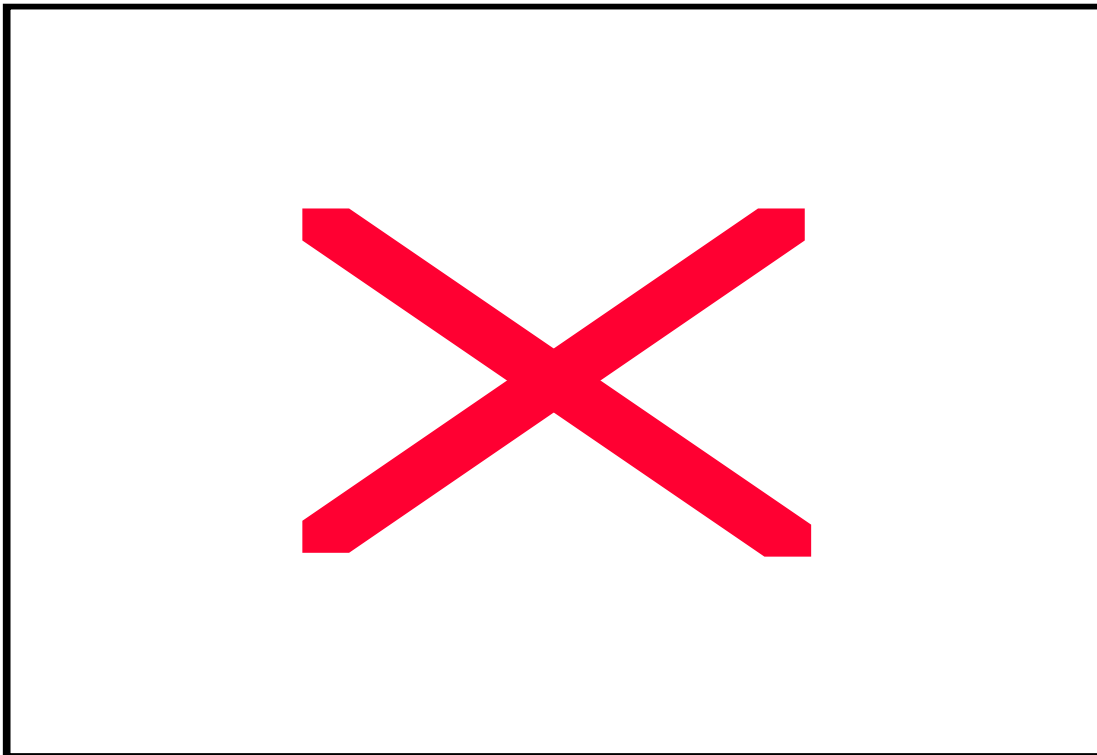


Target Reacquisition for Electro-optic Identification in the AN/WLD-1(V)1 System  
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### **Introduction**

The AN/WLD-1(V)1 is a mine reconnaissance system designed for the detection, classification, localization, and identification of bottom and moored targets in both shallow and deep water. The AN/WLD-1(V)1 will be integrated on DDG-51 Class Flight IIA ships, beginning with DDG-91. Figure 1 depicts the subsystems and primary capabilities of the AN/WLD-1. The off-board components are the Remote Minehunting Vehicle (RMV) and the towed Variable Depth Sensor (VDS) - a variant of the AN/AQS-20 towed body developed for helicopter use. After launch from the host ship, the RMV tows the VDS according to a pre-established mission plan to search a designated area for mines. The sonar sensor data is processed in the VDS for target detection and classification, recorded on the RMV for post-mission analysis and transmitted by radio link back to the host ship for real-time monitoring. Following detection and classification of a mine-like target on the seabed, the system provides the capability to revisit the target for identification by an electro-optic identification (EOID) sensor.



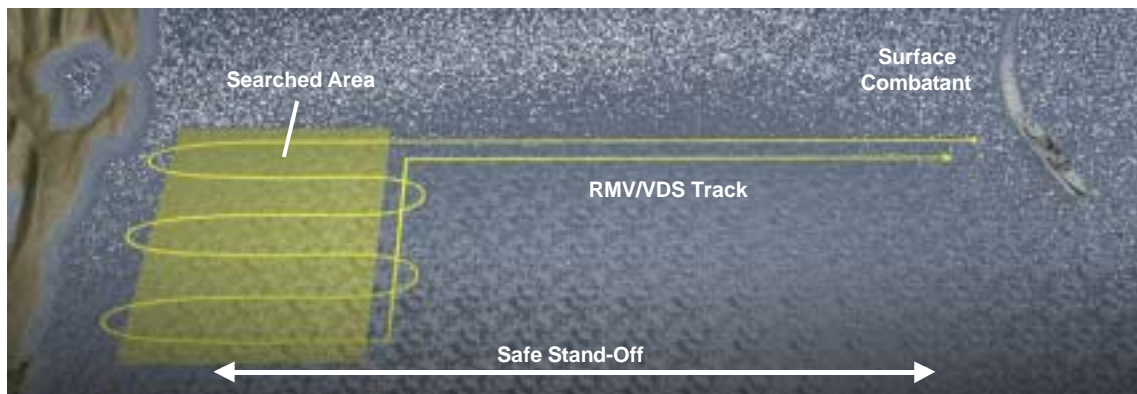
**Figure 1. The AN/WLD-1(V)1 System Overview**

A major technical challenge is reacquiring the target within the rather narrow EOID sensor field-of-view, which has a very limited footprint on the seabed because the VDS is operating at low height above bottom. Whereas RMV navigation and absolute target localization rely on GPS (with a 1-sigma accuracy on the order of 12 m), reacquisition for identification requires much higher accuracy. The VDS must over-fly the target within a lateral distance of 3 m. This is exacerbated by the fact that the VDS is towed from the RMV on up to 1500 ft of cable.

The AN/WLD-1 approach to high accuracy target reacquisition is to navigate the RMV and VDS relative to the detected target. The data from the VDS navigation sensors (a high precision inertial navigation unit and a doppler velocity log) are integrated in a Kalman filter to provide a running estimate of VDS location. This is compared to the pre-planned reacquisition path and used to generate steering commands to the RMV and VDS. This approach has been extensively simulated and has been shown to provide the required accuracy in support of target identification.

### Concept of Employment

The AN/WLD-1(V)1 concept of employment starts with launch of the RMV from a surface combatant that is standing off in safe waters (Figure 1). The RMV proceeds to the reconnaissance area. The RMV conducts area reconnaissance search by executing a pre-programmed mission plan that consists of maneuver way-points for parallel tracks within the search area and instructions for RMV and VDS actions at each way-point.

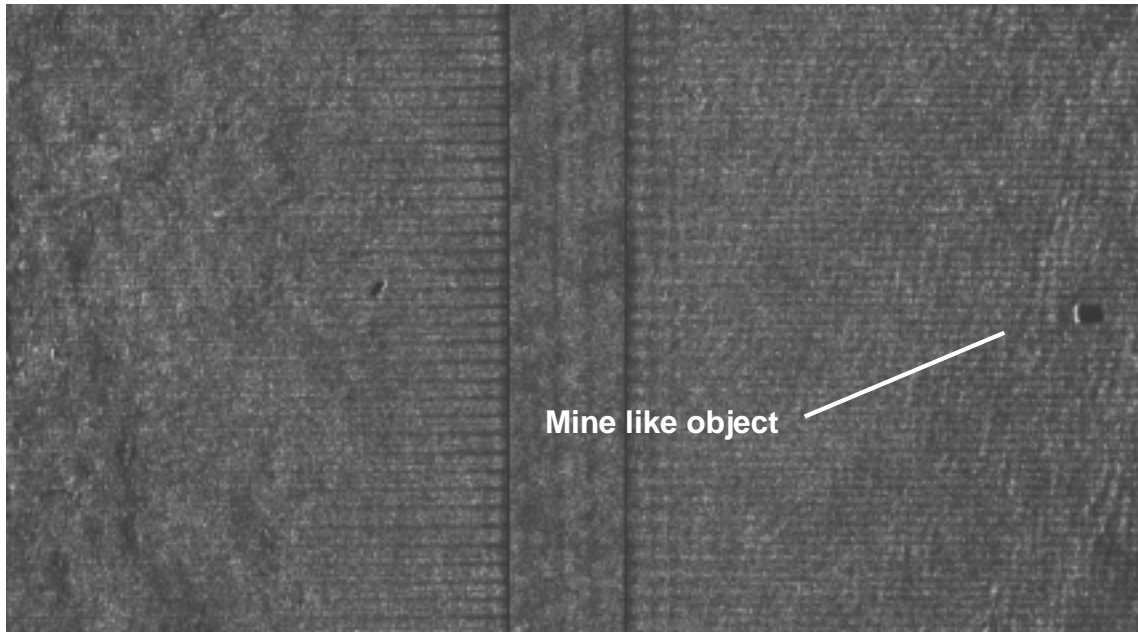


**Figure 2. Schematic Representation of the AN/WLD-1(V)1 Concept of Employment**

Computer-aided detection (CAD) and computer-aided classification (CAC) processing on board the VDS uses the acoustic sensor data to detect, classify and localize mine-like objects. Both the sensor data and target classifications are radioed back from the RMV to the display and control subsystem on the surface combatant. The operator views the sensor data to confirm CAD/CAC decisions and may also manually classify sonar contacts as mine-like. By the time the object is declared to be mine-like, the RMV

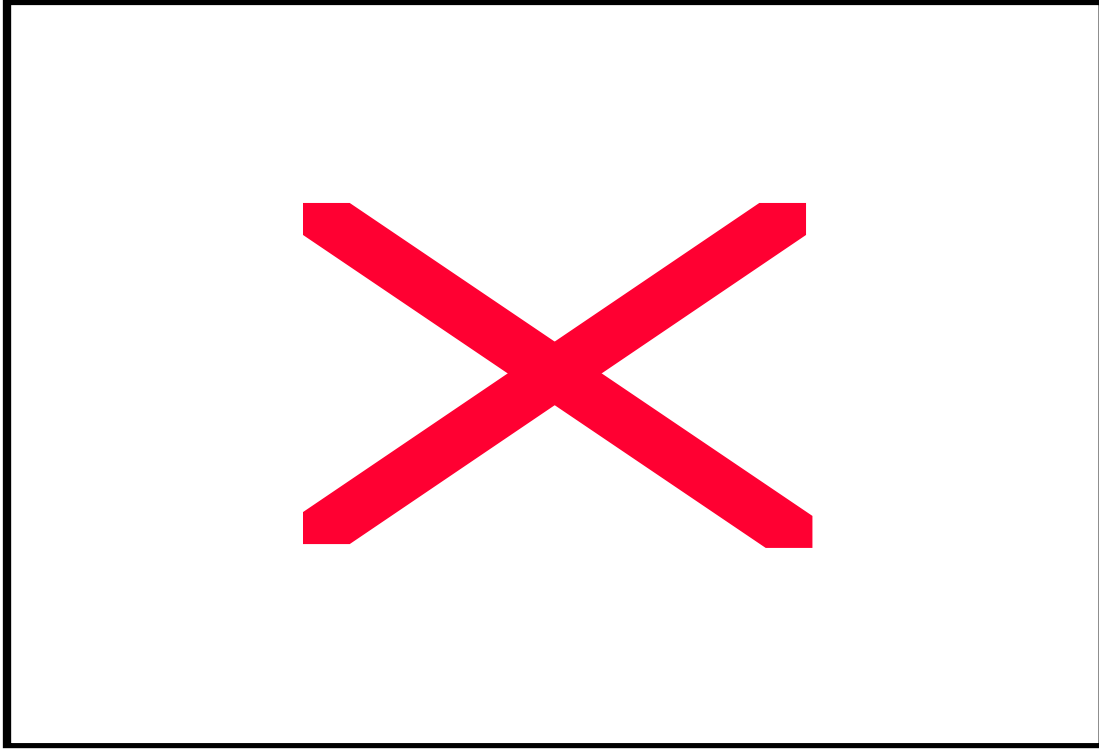
and VDS have both passed the object's position and are further down the search track, due to CAD/CAC latency and operator decision time.

The operator can select any mine-like object for identification from the Side Look Sonar (SLS)/Gap Filler Sonar (GFS) search display, in which case the RMV executes a reacquisition maneuver without any further operator intervention. Figure 3 shows an example of SLS/GFS data. The operator's reacquisition command is transmitted from the surface combatant to the RMV. Alternatively, the RMV may, at the operator's discretion, automatically classify and reacquire mine-like objects for identification without any operator intervention.



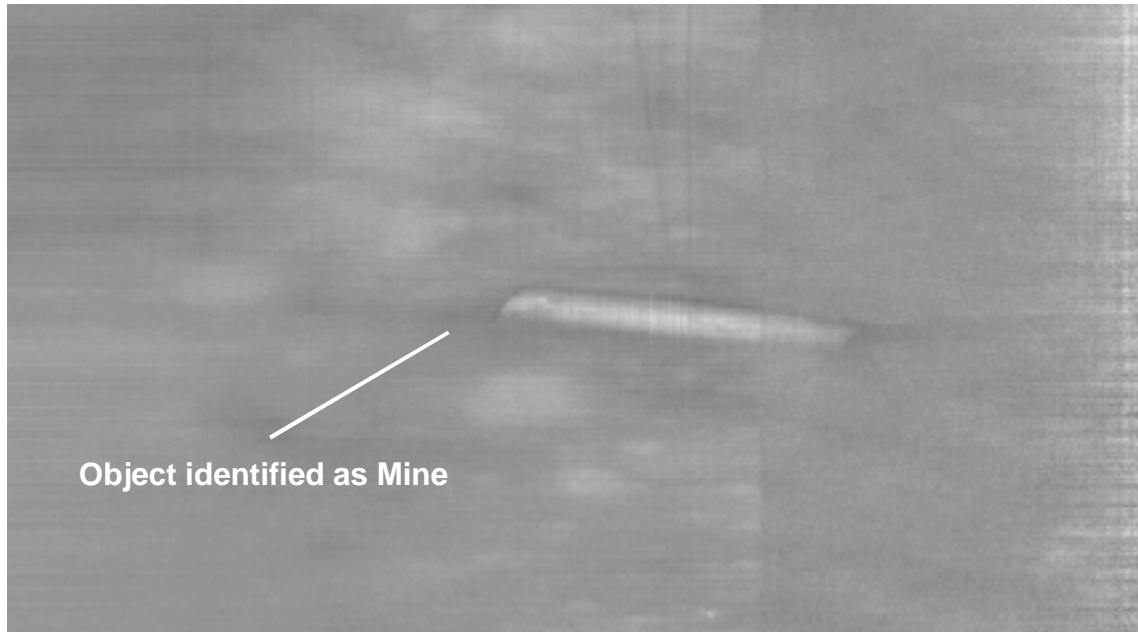
**Figure 3. Side Look Sonar/Gap Filler Sonar data**

In either automatic or operator-initiated reacquisition, the RMV control software computes a reacquisition path that accounts for the water current profile, the distance to the contact at detection, the distance of the VDS past the contact along the track and various system parameters. The path is radioed back to the operator and the RMV begins to execute the first turn towards the contact. The planned RMV and VDS paths and the actual positions are displayed to the operator on the tactical map display. Figure 4 depicts a typical reacquisition path at the moment that the VDS over-flies the target. Note that the reacquisition path has a figure eight shape – this was determined to be the shortest path possible for most combinations of speed, tow scope and target position.



**Figure 4. An Artist's Depiction of the Reacquisition Path**

The RMV tows the VDS, containing the Electro-Optic Identification (EOID) sensor, through two passes over the contact. Kalman filter software in the VDS is constantly tracking the path of the towed body. The RMV control software monitors the VDS position estimates relative to the initial acoustic sensor measurement and maneuvers the RMV in such a way that the VDS is stable and the EOID sensor captures a picture of the contact. The EOID sensor is a streak tube imaging LIDAR, developed by Arete Associates for the AN/AQS-20 VDS. This device provides both range and contrast data in scan line format. The images are recorded in the RMV and radioed back to the operator for identification analysis. The operator observes the EOID image and either positively identifies the mine-like object as a mine or dismisses the mine-like object as a non-mine. Figure 5 is an example of EOID contrast data. The operator captures a snippet of the EOID image containing the identified mine and stores it in a database along with the operator's observations and an associated acoustic snippet, generated when the reacquisition maneuver was initiated.

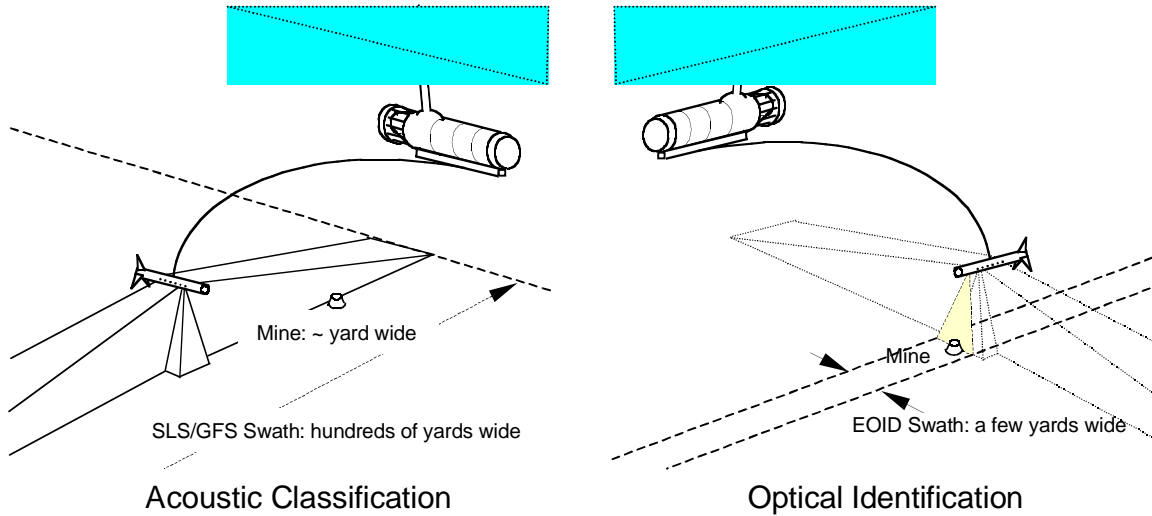


**Figure 5. An Example of EOID Contrast Data**

After both passes of the reacquisition maneuver have been executed, the RMV returns to track and resumes the area search.

### **The Technology Challenge**

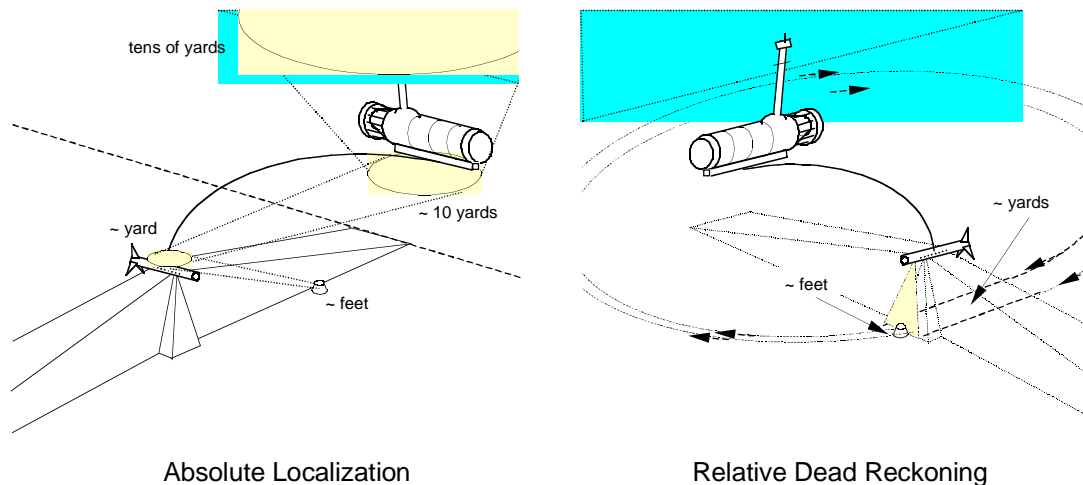
The reacquisition challenge is one of comparative scales. When the RMV or operator detects, classifies and localizes mine-like objects with acoustic sensor data, the area covered by those acoustic sensors is hundreds of yards wide. A potential mine-like object is on the order of a yard to several yards. It is relatively easy to re-approach such an object and regain contact within the wide swath of the acoustic sensors. However, to identify a mine-like object as a mine (or reject that hypothesis) with significant confidence requires an optical image of fairly high resolution. Most optical devices, including the AN/AQS-20 EOID sensor, have a limited field of view for high-resolution imaging. In addition, optical scattering in typical sea water limits the height above bottom at which the EOID can be effectively operated. This means we have an area no more than a few yards wide in which to image the mine-like object. Figure 6 depicts this situation schematically.



**Figure 6. Acoustic Classification versus Optical Identification Scales**

In order to reacquire a mine-like object for identification, the RMV and VDS must maneuver back to the object location with an error of no more than a few yards. The object location is known very accurately (1 sigma error of inches to feet) relative to the acoustic sensor. For conventional target localization, the position of the object relative to the sensor must be transformed to geographic (latitude, longitude) coordinates. This transformation introduces significant errors inherent in the determination of VDS position relative to the RMV and in the GPS position of the RMV. The resulting accuracy of target location in geographic coordinates (1 sigma error of tens of yards) is not adequate to do target reacquisition for identification. (Note that this absolute position accuracy is acceptable for conventional contact localization.) The probability of revisiting the object using an absolute position estimate is low on any one pass so it would take many passes to regain the object with high confidence.

The solution to this problem is to maneuver the RMV and VDS relative to the detected object without transforming to geographic coordinates. Figure 7 compares relative dead reckoning to navigation in the Earth reference system. With relative dead reckoning, the position errors introduced when translating the contact location from VDS to geographic coordinates are absent.



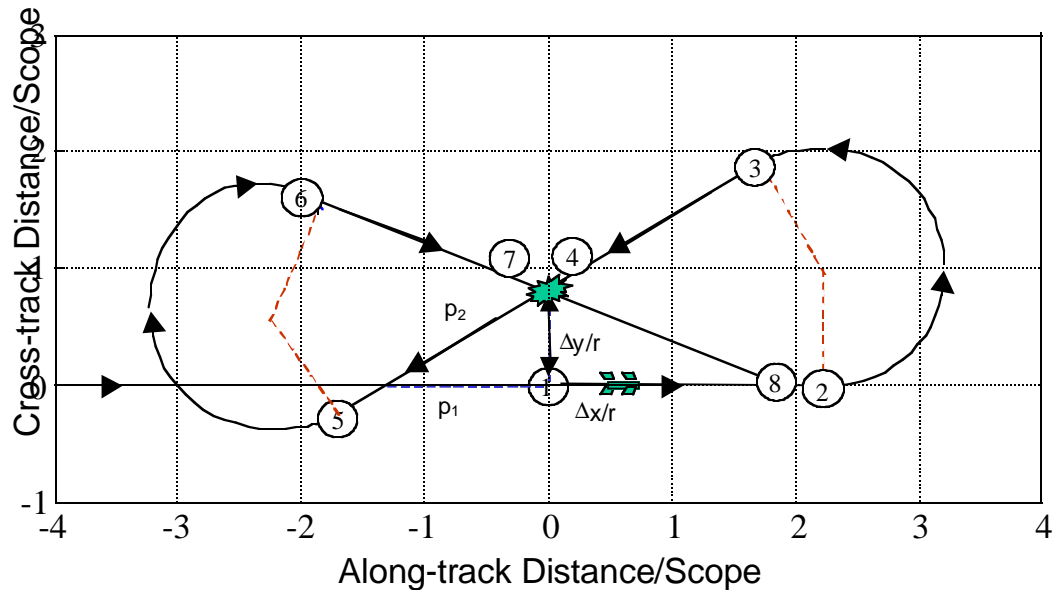
**Figure 7. Absolute Localization versus Relative Dead Reckoning**

The RMV tows the VDS and the VDS path is dead reckoned through the water using Kalman filter software that combines VDS Inertial Measurement Sensor readings with VDS Doppler Velocity Log sensor readings. The Kalman filter output provides a VDS position estimate more accurate than that of either sensor alone (on the order of feet over the maneuver duration). The Kalman filter software resides in the VDS data processors. RMV software controls the motions of the RMV based on the Kalman filter estimates to put the VDS with its EOID sensor over the contact (within a few feet). The VDS control software cooperates with the RMV software to accomplish the reacquisition maneuver. The roll-up of position errors due to the acoustic sensor, the Kalman filter estimates and the control software places the contact within the EOID field of view with high probability.

A realistic example of a reacquisition path is shown in Figure 8. The numbers in the figure correspond to the steps in the maneuver that are outlined below. At “1” in the figure, the VDS sensors have collected acoustic data on the target of interest. Shortly afterward, VDS CAD/CAC processing declares a mine-like target and the operator commands target identification. The RMV control software computes reacquisition paths for the RMV and VDS. These paths account for the water current profile, tow cable scope, RMV speed and other parameters of the encounter. At “2” the RMV starts the first turn of the reacquisition maneuver. Note that a key factor in determining the size and shape of the path is the length of the straight leg after the VDS exits the turn, and before it passes over the target. The turn induces excess angular motion in the towed body. The straight path must be long enough for this motion to decay to acceptable limits for acoustic and EOID sensor operation. Nominally, a distance of two tow scopes is sufficient for VDS stabilization.

When the RMV exits the turn during either pass (“3” and “6” in Figure 8), it jogs a bit toward the outside of the turn to bring the VDS in behind it more quickly. This minimizes the length of the straight path to the target. After the VDS exits the turn, the RMV begins to monitor and correct for VDS cross-track error by shifting the RMV track plan. This minimizes the miss distance at CPA to the target (“4” and “7” in Figure 8). The RMV and

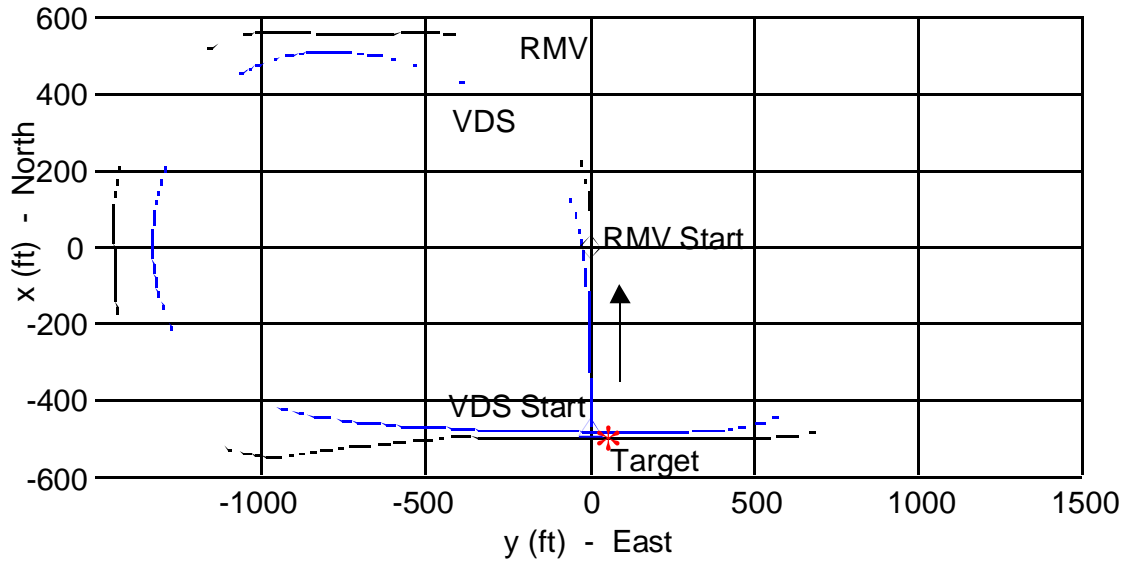
VDS return to the original search track after the VDS over-flies the target for the second time.



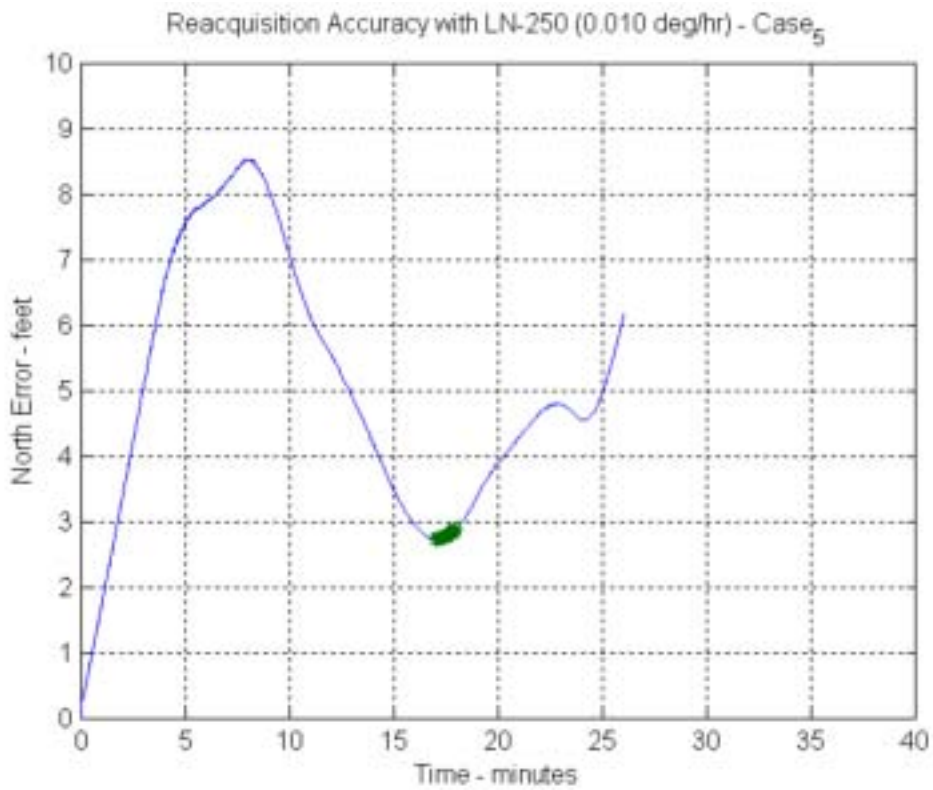
**Figure 8. Details of Target Reacquisition Path**

Target reacquisition has been extensively simulated to determine the correct maneuver strategy and to estimate accuracy of target over-flight due to errors in control and navigation. The control simulation was based on a six degree-of-freedom two body model developed by Lockheed Martin NE&SS (Riviera Beach, FL). The model includes operational RMV control software, the AN/AQS-20 control laws, a finite-element model of the tow cable and a 360-degree seaway model to stimulate the RMV with external wave forces. Figure 9 shows an example of a simulated target reacquisition, with the paths of both RMV and VDS. Note that the paths in the figure are not the same as the final path selected to minimize maneuver time.

The two body simulation includes external forces, the interactions between the RMV and VDS, and the response to controls for both RMV and VDS. The accuracy of the Kalman filter VDS Navigation Function (VNF) has been modeled separately. Figure 10 shows an example output of this simulation for a typical reacquisition maneuver. The RMV/VDS control errors and the VNF errors, together with all other error sources, are combined statistically to estimate the overall target reacquisition accuracy. Results to date indicate that the adopted approach is within the limits required by the EOIDS sensor.



**Figure 9. VDS and RMV Paths During Simulated Reacquisition**



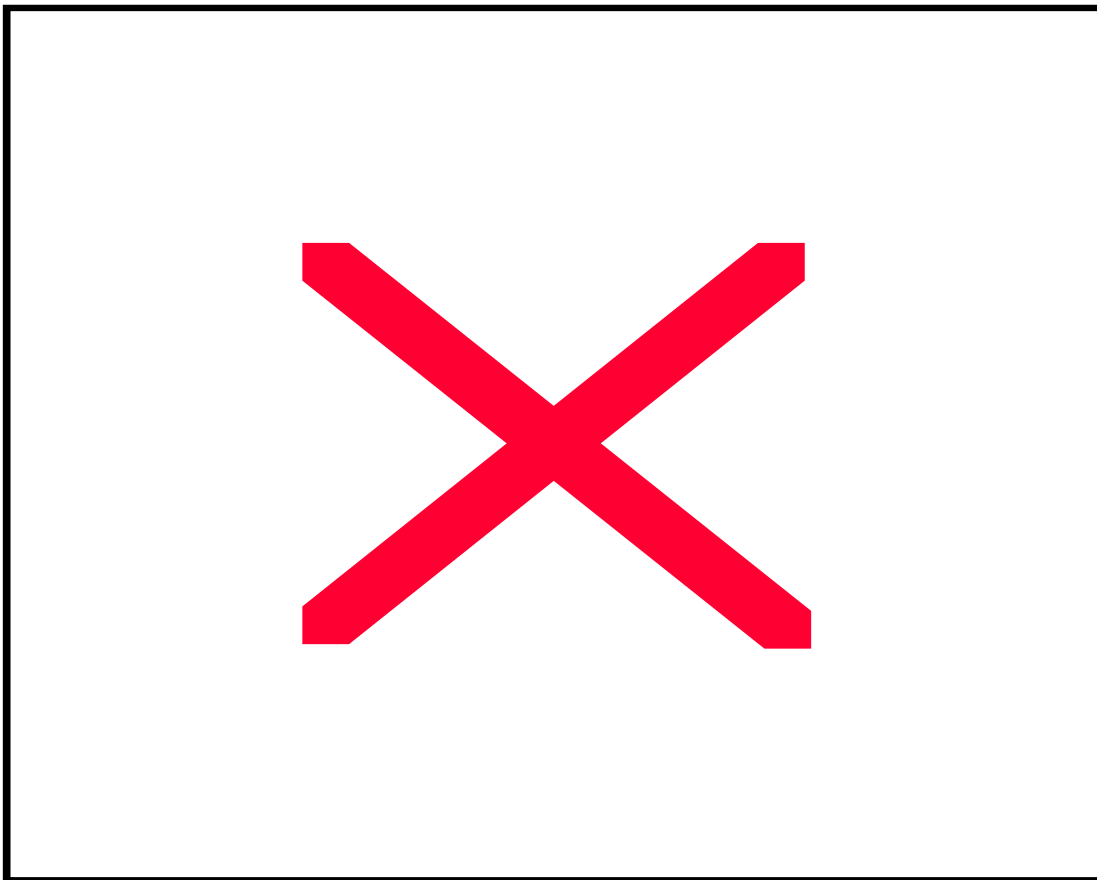
**Figure 10. Accuracy of VDS Navigation Function During Simulated Reacquisition**

## Testing Schedule and Conclusion

Analysis has shown that the RMV and VDS can use the relative navigation approach to maneuver back to a location of mine-like object with an error of no more than a few yards. This is adequate to reacquire the object for identification. This underwater vehicle navigation problem is being solved by the integration of capabilities developed by the following Lockheed Martin companies:

- Lockheed Martin/NE&SS – Sunnyvale, CA, provides the Kalman filter to optimize the navigational position estimates of the VDS.
- Lockheed Martin/NE&SS – Riviera Beach, FL, designs the RMV, including the integrated control system for conducting the maneuver.
- Lockheed Martin/NE&SS – Syracuse, NY, is the prime contractor for AN/WLD-1(V)1 and provides systems engineering, software, integration and test leadership.

Figure 11 shows these Lockheed Martin technology contributions pictorially.



**Figure 11. Lockheed Martin Technology Contributions**

Sea tests in the summer of 2003 will validate the simulations and support final adjustments to the reacquisition algorithms. Formal verification tests are planned for the fall of 2003.