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Commercial ROVs for Ships' Maintenance and Husbandry: Increasing Overall Situational Awareness While Reducing Downtime and Hazards to Personnel

Abstract
It is critical for naval vessels to be prepared for any emergency, as well as have the ability to maintain complete situational awareness at all times. US Navy ships' crews are the best trained in the world and are supplied with the highest quality maintenance and damage control equipment. In order to ensure the safety of personnel and prevent the risk of damage to equipment essential to the mission, thorough and stringent procedures and policies have been developed to cover virtually any issues that require intervention by personnel; anything from a faulty toggle switch in an instrumentation panel, to a major fire in the engine room.

Ships' crews receive routine and recurring training. They participate in shipboard and dockside drills and undergo regular performance evaluations. In order to earn their surface or submarine warfare pin, they must prove proficiency in their knowledge of the layout and operation of most of the vessel's critical systems, often demonstrating the ability to create schematics of most systems from oxygen generation to main seawater cooling systems. When the time comes to perform routine maintenance or respond to casualty situations, they respond with the latest in equipment, from oscilloscopes to thermal imagers.

What about outside the hull, below the waterline? What is technically required for ships' crews to respond to incidental issues and damage on the outside of the hull or even loss of equipment in surrounding waters? How do diving operations (a vital and necessary skill set for ships' husbandry) compare to employing newer technologies such as underwater remotely operated vehicles (ROVs)? This paper will explore how ROVs can greatly increase overall situational awareness, reduce downtime, and prevent hazards to personnel.

Introduction: What is an ROV?
To understand how ROVs can benefit a ships' crew, it is important to understand the technology including both the capabilities and limitations.

ROV systems generally consist of a topside control console, a tether (cable with wires and, sometimes, fiber optics) and an underwater vehicle with at least three axis of control; forward/reverse, rotation/turning, and up/down (vertical control). Nearly all ROVs also have at least a fourth axis, lateral, or side-to-side control. These flight characteristics allow the operator to pilot the ROV to a desired location and "point" the sensors and/or tooling in the direction where observation is needed, all while offsetting and/or overcoming currents.

Figure 1: An Explosive Ordnance Technician, Task Group 56.1, deploys an ROV in the Arabian Gulf. (Courtesy of the Defense Video & Imagery Distribution System)

The sensors usually consist of streaming video with lighting, depth, heading, and temperature. As video cameras are limited by the water clarity, specialized sonars have been developed allowing for observation of objects such as anodes on ship hulls in zero visibility. Acoustic tracking systems are also common, but they have very limited capability around ships and near critical infrastructure, which tends to disrupt signals resulting in "data holidays."

ROVs are piloted real time, from the surface, as opposed to autonomous underwater vehicles (AUVs) that are pre-programmed to follow a route and gather data for subsequent analysis. The tether is required between the control console and the vehicle as there is no known way to wirelessly send the amount of data required for observation with cameras and sonars any appreciable distance through water (typically 40-50Mb/sec).

ROVs are used for real-time observation. Other than some autonomous piloting to target features, they must be manned at all times. Failing to continuously monitor and control the ROV if it does not have autonomy features can lead to drifting off target and, around infrastructure, the possibility of entanglement of the tether. In addition, machine intelligence is not to the point where the ROV can perform the observation on its own, then make decisions on corrective actions that may be necessary.

Some ROVs have the ability to "attach" to critical infrastructure such as ship hulls and seawalls, where they can then be "driven" along the surface. This can be (a) a skid attached to the standard ROV that generates a vacuum in water, (b) magnetics (only works on ferrous materials), or (c) directing the flow of certain vehicle thrusters, etc.

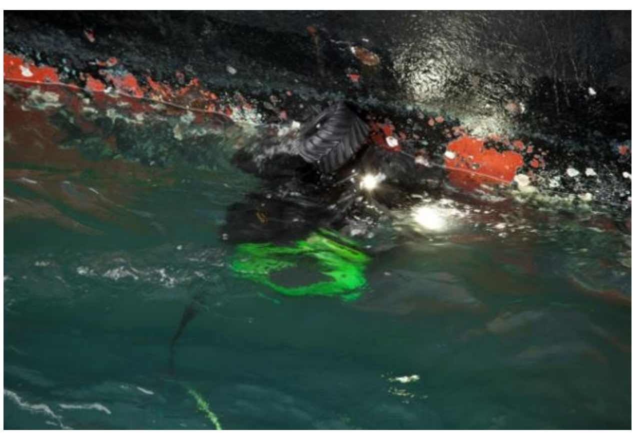

Figure 2: ROV with Vortex Generator attached and driving on a ship hull breaches the surface during an inspection. (Courtesy of Teledyne SeaBotix)

There are several advantages to this. They are not subject to drift as described above and can operate unattended in high currents and sea states. This also allows the sensors and video systems to remain completely stable with no relative motion between them and the object under inspection, providing the highest-quality data possible. In this configuration, it is possible to image objects as minimal as weld seams using only imaging sonar in zero visibility. In addition, operator fatigue is greatly reduced as they do not have to constantly focus and fight sea conditions to stay on target.

Classification of ROVs

Various organizations differ in how ROVs are classified; weight, power (hp), capability (multi-articulated arms for work, ability to carry larger sensors, trenching, etc.), and whether they are primarily electric or hydraulic. A simplified conglomeration of these classification methods might be:

1. Micro Observation: Less than ~8 kg (17.6 lb.) and typically not able to carry sensors such as imaging sonar and tracking systems – visual inspection only.

2. Mini Observation: Able to be lifted by one person (by OSHA standards, ≤ 22.75 kg [50 lb.]), capable of deploying full range of typical sensors, can do some light work such as manipulation, scrubbing, etc.

3. Light Work Class: Up to one ton (909 kg), capable of heavy work, deploying multi-articulated arms, electric or hydraulic.

4. Large Work Class: Over one ton, usually full hydraulic.

Within the various classes of ROVs, from Micro to Work Class, the Mini-Observation Class systems are designed to be one to two person portable, deployable, and retrievable without special launch and recovery equipment. Systems in this range are typically 10-25kg (22-55lb). They are small enough to meet this objective but still large enough to handle the payload of sensors typically required for critical infrastructure inspection while remaining stable in the water column for quality data. These systems typically take up two to four ruggedized, wheeled cases and can be stored in a ~1cubic meter (3.28 cubic feet) space. They are typically powered by portable generators, or ship/shore power.

Current Operators and Applications of MiniROVs within the US Navy

There are well over 100 MiniROV systems currently deployed in the US Navy. Current operators include, but are not limited to:

- Explosive Ordnance Disposal Units (EOD)
- Mobile Diving and Salvage Units (MDSU)
- Underwater Construction Teams (UCT)
- Submarine tenders and Regional Maintenance Centers

Applications include, but are not limited to:

- Ship hull inspection for limpet mines and contraband, as well as ship's husbandry
  - Complete inspection of the hull and running gear
- Inspection of critical infrastructure
  - Piers, seawalls, moorings, degaussing stations, nets and barriers, etc.
- Various mine countermeasure applications
  - Locate, identify, render safe
  - Waterborne improvised explosive devices (WBIEDs)
- Salvage and recovery including everything from downed aircraft parts to dropped tools to drowning victims
- Diver observation
- Harbor clearance

ROVs vs. Diving Operations

Safety: First and foremost, *the primary application of ROVs is to avoid putting divers in hazardous situations whenever a robotic, remote system can perform the mission*. This is not to say the ROV is there to replace divers; they will always be invaluable in specific situations. Divers have dexterity and cognizance for certain applications that ROVs do not possess.

Divers also tend to make good ROV pilots as they are familiar with the "3D" environment and navigating in it. Navy divers have come to realize that ROVs *augment* their capabilities and make them more efficient, while reducing the chances of being injured.

A major study on health risks associated with US Navy diving found that, between 1969 and 1981, there were 1,174 accidents during all 706,259 dives performed. That translates to a one in ~ 602 chance that a diver will be injured. Almost two-thirds (63%) were a combination of decompression sickness and barotrauma. [2] This implies that the actual job being performed is not the cause of the majority of injuries (placing charges, retrieving unexploded ordnance, welding around running gear, etc.), but simply the act of diving itself.

Figure 3: ROVs are used by EOD to perform many hazardous missions that have traditionally been completed by divers. (Courtesy of the Defense Video & Imagery Distribution System)

ROVs, however, operate independent of decompression tables with typical navy systems having depth capabilities to 300m (1,000ft). ROVs operate indefinitely as long as there are willing operators and power supplied to them. Finally, the consequences from an accident, such as entrapment in a suddenly activated propeller, are incidental compared to the same situation involving a diver.

Consider the following comment regarding routine ROV operations by a master diver with over 30 years' experience in navy diving.

"Southwest Regional Maintenance Center (SWRMC) Navy Divers routinely utilize Remote Operated Vehicles (ROV) to document ship, carrier and submarine damage for engineering review, assessment and determine repair recommendations (Author's note: *prior to putting divers in the water)*. Additionally, the ROVs are used to recover lost items dropped by personnel into the harbor, inspect piers, ships' hulls and harbors for anti-terrorism / force protection (AT/FP) when requested by naval security commands. ROVs are also used to search and identify deep water dive sites increasing dive team operational bottom times and increase mission success of salvage, diving and recovery operations. Lastly, SWRMC ROVs are used to inspect (pre and post dive) NAVSEA 00C diving contractors that routinely clean USN ship hulls of marine growth." [1]

It is important to emphasize many of the above described operations are performed without the need to tag-out the ship, which will be discussed in more detail later.

Fleet-wide, this capability is predominantly limited to shore-based facilities. ROVs are providing rapid situational awareness and reducing the time to gain it. They are used by dive teams to determine if diving is even required – if tag-outs are required – reducing ship downtime and hazards to personnel. It is logical that this capability be extended to the ships' crew, providing them with the tools necessary to have complete situational awareness of their vessel regardless if they are in port or at sea.

Cost and Training: Another consideration when comparing ROVs to diving operations is cost. The military does not tend to look at costs for a mission as directly as a commercial company might, but "time is money" to both military and commercial entities. In some cases, ships in ports may employ the services of commercial divers, which can easily exceed $5,000/day.

A properly equipped ROV as standard equipment aboard ship including the vehicle, tether, control console, sonar, manipulator with complement of grabbing and cutting attachments, and training will have an approximate minimum starting price of ~$60,000 USD and can approach ~$150,000 with the highest quality imaging sonars and hybrid infrastructure crawling capabilities. When considering the following scenario, an investment in ROV technology can be rationalized as it is not unusual for them to pay for themselves after the first deployment.

Contrary to popular belief, the piloting of an ROV is relatively simple to learn for most people. COTS ROVs are often operated by fishermen, volunteer fire Search and Rescue teams, and even private citizens on yachts. The vast majority of ROVs operated within the US Navy are piloted by persons with little to no prior ROV experience. Training classes are typically three to five days, depending on the complexity of the sensor suite, and can be performed on-site or at the respective factory in most cases.

Preparation and manning; Diver vs. ROV ops: Consider a specific scenario; dropping an object overboard:

Scenario A: The USS Neverhome is in a foreign port conducting various engine room systems tests required prior to departure the following morning. The evening before departure, a topside watchstander accidentally drops his weapon overboard between the pier and the ship. It is required that the weapon is recovered immediately.

Scenario A with divers [3]: *Provided that divers are available and they are within a window of time that diving operations are allowed…*

- A diver tag-out will be required, which will suspend the engine room tests as certain seawater systems will need to be secured to allow diving operations. This could easily delay the ships required departure.

- If another vessel is abreast, it may require that vessel also be tagged-out for diver operations, doubling the efforts described below.

- In some cases, diving operations will require the removal of security barriers around the vessel.

- For diving operations, a small craft for emergency recovery will be required.

- Depending on the type of ship or boat, a few to several personnel will be required to perform the tag-out. This will involve the review of the required tags, printing the tags, a second check of the tags, then reviews and signing by the Duty Chief and Duty Officer.

- The tags then must be hung and must undergo a second check to ensure they are complete and hung properly. Finally, the Dive Team must review the tag-out.

  Note: New tag-out procedures have been implemented in some areas that involve different methods and can reduce some of the time to perform the tag-out.

- The divers then must perform a dive brief.

- For the diving operations, per US Navy regulations, the following diving personnel are required:
  - One (1) Dive Supervisor
  - One (1) comms/logs operator (may be reduced by the Dive Supervisor performing this at their discretion
  - One (1) Diver
  - One (1) Standby Diver
  - One (1) Dive Tender

- Lastly, the dive must be performed. Using handheld lighting and touch, the divers eventually locate the dropped shotgun and carefully bring it to the surface.

- Subsequent to the recovery, the Dive Team must break down and clean and store their equipment, then hold a post-dive debrief. Tags must be removed and shipboard systems must be restarted/reconfigured back to the desired state.

In the author's experience aboard submarines, this evolution would involve more than ten people and take anywhere from several hours to a day. The duration could actually run much longer, as the scenario above *does not include* any additional time and personnel considerations if the vessel is nuclear powered.

Figure 4: Ships underway have little direct and immediate situational awareness of the condition of the ship's hull and related gear. (Courtesy of the Defense Video & Imagery Distribution System)

Scenario A with an ROV:

- It is determined a tag-out is not required for these specific ROV operations.

  One to two personnel retrieve the ROV vehicle, reel, and control console from ships' storage. All items weigh less than 50lbs, but additional persons may assist in bringing the equipment topside via ladders.

- Standard AC power is supplied from the ship or shore via a commercial extension cord.

- The Duty Officer elects to observe.

- The system is set-up and undergoes "pre-flight checks."

The total time from the decision to deploy the shipboard ROV and this point, reasonably, is 30-min to one hour.

The operator navigates the ROV along the surface to the point where the topside watch says the weapon went overboard.

- Primarily using the ROVs imaging sonar due to poor visibility/night operations, the operator spots an adjacent piling to the point specified, which she follows down to just above the seafloor.
- Adjusting the sonar to the minimum range, the operator then pans the ROV/sonar until a distinctly rifle shape image comes into view. She then uses the sonar image as a navigation tool to approach the shape until in comes within visual range of the ROV's video camera, augmented by onboard lighting. She visually confirms the suspected sonar image is the shotgun.

- Using the manipulator with the properly pre-selected end-effector, she makes a few attempts and is able to grasp the shotgun by the stock within a few minutes.

From experience, the total time from splashing the ROV to recovering the object on the dock in this scenario would be 5-30 minutes.

- Breakdown involves the freshwater wash down of the ROV reel and vehicle, then re-stowing the system below decks.

From experience, the total time for this mission, start to end, would be about 45 minutes to two hours and involve one to three persons.

Scenario B: During open water transit, the USS Neverport experiences an issue; temporary shuddering reported in the starboard running gear and loud banging noises along the hull. Topside watches report large sections of partially submerged wooden structures, possibly tsunami debris.

Concerned the running gear and/or prop may be damaged, the Captain needs to have it inspected as soon as possible. Transit time to port is over six hours and even longer running with only port power.

The Captain elects to deploy the onboard ROV to investigate. Two responsible personnel assemble the ROV system in about 30 minutes at the stern, in-line with the starboard propeller. A small, portable davit with a manual sheave is strapped to the gunwale using tie-downs to assist the operators in lowering the ~15kg vehicle over the considerable freeboard and to ease retrieval. Once they notify the bridge they are operational and ready to begin, the Captain gives the order for all-stop and the ROV is quickly lowered to the water.

Once in the water, the operator pilots toward the area of concern. Flying laterally from the stern-starboard forward toward the bow, the operators inspect first the propeller, then the running gear. They note and record video of some large scrape marks on the hull with no deformation, as well as an undamaged propeller. However, they do note damaged and missing anodes in two areas that will need to be replaced when back in port.

Supervisors have witnessed the live video feed and confirmed to the bridge that all systems appear good. Once the ROV breaches the waterline during retrieval, the Captain orders All-Ahead Slow and receives confirmation of normal indications from the related watchstanders. Normal operations resume. The video is saved for Command review in port to plan any subsequent dive work required to effect repairs. Total time: ~1.5-2 hours.

Scenario C: With current technology, it is possible to envision even more radical uses for ROVs on vessels at sea. For submarines, simply surfacing to evaluate or fix an issue could degrade or end a mission. More and more, unmanned underwater vehicles are being deployed from submarines. Here is a scenario that could be accomplished with existing technology:

During special operations in open waters, a submarine notes a clapping noise on the exterior of the hull. It is suspected that an anechoic tile may be loose and flapping, degrading the stealth of the boat. Due to the nature of the mission, it is determined the situation requires an immediate repair using onboard divers at depth. As the noise only occurs at or above three knots speed, locating the exact location of the tile will prove difficult and dive time will be limited by the dive tables.

The boat does, however, have an ROV with the ability to "attach" to the hull with significant force, allowing it to stay attached in currents over five knots. The boat has an optional Tether Management System (TMS) for its onboard portable ROV allowing it to be deployed from a tube and operated from within the submarine. The system includes optional imaging sonar, video cameras and lighting, as well as dual manipulators allowing both cutting and grasping. The Captain decides to deploy the ROV, attach it to the hull, make headway with the submarine at three knots, then "crawl" the hull with the ROV in search of the suspect tile. This will allow the divers to pre-plan the repair including the equipment needed in order to minimize dive time.

It is theorized that the suspect tile is at or forward of the sail, however tether paid out can be controlled such that the ROV cannot transit aft past any desired point.

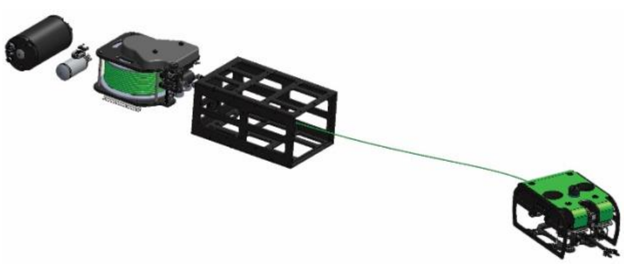

Figure 5: An ROV "Flyout" system, which is designed to be mated to other UUVs, manned submarines, even fixed rotor AUVs. (Courtesy of Teledyne SeaBotix)

The ROV system is deployed from the tube and "attached" to the hull near the bow. The boat gets underway at three knots and the clapping noise commences. As the ROV transects the port side of the hull in a planned "mow the lawn" pattern, the operator notices a synthetic line with a floatation device slapping the hull wrapped around a protruding sensor at centerline, ahead of the sail. The boat comes to an all stop and the ROV operator disengages from the hull to get an "angle of attack" with the ROV's simple cutter. After a few cuts, he then grasps the remaining loose line and disengages from the hull, piloting vertically to lift the remaining line from the sensor and away from the boat.

The ROV is then retrieved and the boat resumes its mission. The issue has been corrected without divers in the water, the ship surfacing, or requiring a transit to port.

Conclusion: ROVs on naval vessels as standard maintenance and emergency equipment would increase situational awareness in areas where vessels traditionally have had none without divers (i.e., below the waterline, outside the hull). MiniROVs have been used extensively in the US Navy for several years now and they have been proven to significantly reduce harm to personnel by preventing the need to perform many hazardous operations that have traditionally required diving.

Their benefits have been noted and adopted so rapidly that much of the doctrine describing how they are to be used is only now being written, even though they are in operation daily by regional maintenance centers, EOD units, MDSU units, and UCTs among others. The cost to acquire an ROV, train shipboard personnel, then operate and maintain them is minimal compared to the benefits and potential for rapid returns on investment. It is a matter of time before we find them deployed across the fleet.

Acknowledgements

[1] **Armstrong**, Richard, Department Head, Code 360 Divers, Navy Southwest Regional Maintenance Center (SWRMC).

[2] **Hoiberg,** Anne, Naval Health Research Center, *Health Risks of US Navy Diving*, 1987, Pg. 24.

[3] ***U.S. Navy Diving Manual*,** Naval Sea Systems Command, Revision Six (6), 2008, pp 6-30 through 6-38.

Sean Newsome is the Global Business Development Manager for Teledyne SeaBotix. In his role, he primarily works with domestic and foreign Navies and other government agencies in programs related to unmanned underwater vehicles. Formerly, Mr. Newsome was a Nuclear Reactor Operator onboard Trident Submarines and has over 21 years of experience in unmanned and manned underwater vehicles.