Characteristics of a maritime interdiction operations unmanned ground vehicle

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ABSTRACT

The U.S. Navy conducts thousands of Maritime Interdiction Operations (MIOs) every year around the globe. Navy Visit, Board, Search, and Seizure (VBSS) teams regularly board suspect ships and perform search operations, often in hostile environments. There is a need for a small tactical robot that can be deployed ahead of the team to provide enhanced situational awareness in these boarding, breaching, and clearing operations. Space and Naval Warfare Systems Center Pacific (SSC Pacific) performed a market survey, identified and obtained a number of throwable robots that may be useful in these situations, and conducted user evaluations with Navy VBSS team members, taking each of these robots through all applicable steps of the VBSS operation in realistic training environments. From these tests, we verified the requirements and defined the key performance parameters for an MIO robot. This paper describes the tests conducted and the identified characteristics of this robot.

Keywords: MIO, VBSS, maritime interdiction, throwable robot, micro UGV, boarding, search, seizure

1. INTRODUCTION

Every year the U.S. Navy conducts thousands of Maritime Interdiction Operations worldwide to enforce embargoes, intercept contrabands, prevent drug and human smuggling, and fight piracy. These operations are usually conducted by eight-man Visit, Board, Search, and Seizure (VBSS) teams using rigid-hull inflatable boats (RHIBs) or helicopters, operating often miles from the base ship. (Recently, the helicopter-borne function has been transferred to the Marine Corps.) Most boarding operations are "compliant" (the target ship complied with the Navy's order to stop, and lower a ladder for the boarding team), but a fair number are non-compliant, where orders are ignored. In this case, the VBSS RHIB has to match the speed of the suspect ship, and team members must board using rope ladders with grappling hooks. Figure 1 depicts a typical operation.

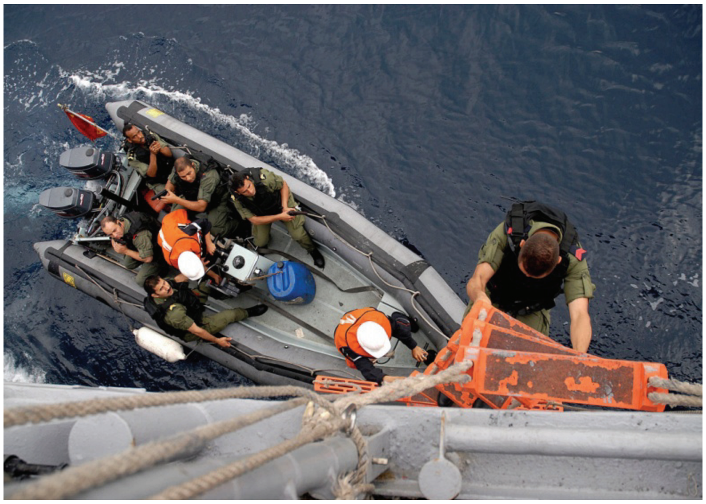

Figure 1. A typical VBSS drill.[1]

Once aboard, the VBSS team quickly secures the deck and the pilot house, and then begins a sweep of the rest of the ship. One of the most dangerous operations during this phase, according to VBSS team members, is the descent into the hull of the ship. There is usually a ladder leading down into the bowels of the ship that is referred to as the "ladder of death."

For these reasons, there is a need for a Maritime Interdiction Operation Unmanned Ground Vehicle (MIO UGV) with reconnaissance sensors that can be thrown up onto the deck of a ship from a RHIB,

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14. ABSTRACT

The U.S. Navy conducts thousands of Maritime Interdiction Operations (MIOs) every year around the globe. Navy Visit, Board, Search, and Seizure (VBSS) teams regularly board suspect ships and perform search operations, often in hostile environments. There is a need for a small tactical robot that can be deployed ahead of the team to provide enhanced situational awareness in these boarding, breaching, and clearing operations. Space and Naval Warfare Systems Center Pacific (SSC Pacific) performed a market survey, identified and obtained a number of throwable robots that may be useful in these situations, and conducted user evaluations with Navy VBSS team members, taking each of these robots through all applicable steps of the VBSS operation in realistic training environments. From these tests, we verified the requirements and defined the key performance parameters for an MIO robot. This paper describes the tests conducted and the identified characteristics of this robot.

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down a hatch once the deck has been secured, as well as into individual ship compartments during clearing operations. From interviews with VBSS team members, no existing tactical robot was deemed entirely suitable for these operations. However, the fundamental designs of a number of these robots can be seen as starting points for the development of such a robot.

2. USER TESTS

To verify the requirements and establish the performance parameters for the MIO robot, we arranged for five highly experienced Navy VBSS trainers to act as a boarding team and test the capabilities of a number of existing throwable robots in a relevant environment. We then collected feedback on the pros and cons of the features of each robot. The following subsections discuss the VBSS operation, the robots used in the test, and the test procedures. Section 3 describes the key performance parameters that emerged from these tests.

2.1 VBSS Concept of Operations

A normal RHIB-based VBSS operation includes several main phases:[2]

1. The *deployment* phase covers the VBSS team's trip on their RHIB from the mother ship or base to the target vessel.

2. The *insertion* phase represents the team's actual boarding process. It is the most dangerous phase of the operation.

3. The *infiltration* phase describes the team's movement from the insertion point to the first objective area.

4. The *objective* phase is the longest phase and includes the actual search, seizure, rescue, or other operations.

5. The *exfiltration* phase is the reverse of the infiltration phase and covers the team's movement from the last objective area to the RHIB.

6. The *extraction* phase is the reverse of the insertion and deployment phases. It begins with the team's exit from the target vessel and ends when the team is back on their mother ship or base.

We designed test procedures to include phases 2 to 5. MIO UGVs were deemed not required for phases 1 and 6, although their ease of handling and factors such as water resistance, which are relevant to these phases, were considered.

2.2 Tested Equipment

We selected five robots of various sizes and functionalities for the user tests (see Figure 2). Our intention was to provide the VBSS operators exposure to as many different features as possible in order to evaluate the applicability of each feature to the operational requirements. (It was not to identify an existing robot best fit for the mission.) Two of these systems (Omnitech *Toughbot* and ODF Optronics *EyeBall*) were already available from our robot pool. The other three (iRobot *FirstLook*, MacroUSA *Armadillo*, and ReconRobotics *Recon Scout XT*) were obtained on loan from their manufacturers for these tests.

1. <u>ODF *EyeBall*</u>: The *EyeBall* is a small, rugged, throwable wireless video and audio sensor. It can be rolled, thrown, or dropped into place. It has a small weighted base to enable upright orientation when it comes to rest. It also has a standard threaded socket at the bottom that allows it to be mounted on a telescopic pole for around-the-corner covert looks. The sensor head can be rotated 360 degrees on its base. Each *EyeBall* system is delivered with two *EyeBall* sensors and a remote operator control unit (OCU) that can switch between the two *EyeBall* devices.

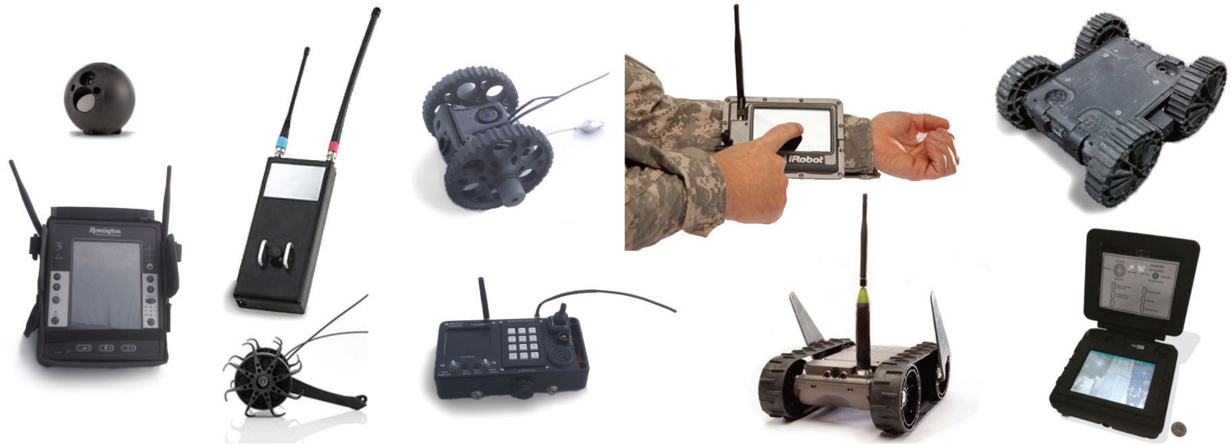

Figure 2. The robots used in the tests and their OCUs, left to right: ODF Optronics *EyeBall*, ReconRobotics *Recon Scout XT*, Omnitech Robotics *Toughbot*, iRobot *FirstLook*, and MacroUSA *Armadillo*.

2. ReconRobotics *Recon Scout XT*: The *Recon Scout XT* is a two-wheel throwable robot. A tail stabilizes the cylindrical body and keeps it from rolling backward as the wheels roll forward. The handheld OCU is very simple to operate, with just one on/off switch and a joystick for movement control. It has infrared illuminators that activate automatically in low-light conditions to improve the video image.

3. Omnitech Robotics *Toughbot*: The *Toughbot* has a similar design to the *Recon Scout*, but is slightly larger and drags a weighted cable for its tail. It has two cameras: one forward- and one upward-looking equipped with a fish-eye lens that attempts to provide close to 360-degree surveillance of the area being investigated. It is also equipped with visible light LED illuminators. Its OCU is relatively simple and is equipped with one joystick and a color LCD display.

4. iRobot *FirstLook*: The *FirstLook* is the smaller of the two four-wheel-or-tracked designs we tested. It has a set of flippers that enables it to climb over obstacles taller than its height. It comes with a suite of software that provides behaviors such as automatic self-righting and stair climbing (although the unit we tested was a prototype and the stair climbing behavior had not been perfected). It also has a small wrist-mounted OCU with a touch screen for movement control and other commands.

5. MacroUSA *Armadillo*: The *Armadillo* is the largest robot tested. It can be equipped with tracks or wheels and has three cameras providing views forward and to the sides. It has a bandolier sling or MOLLE-mountable carrying case for its OCU, which has an internal antenna built into the lid.

2.3 Test Procedures

Testing was conducted over a 4-day period, with 2 days of user training and 2 days of testing. Training was performed at Navy Afloat Training Group San Diego's facilities. Testing was conducted at a US Navy's Ship-in-a-Box (SIB) facility and onboard a tugboat normally used for VBSS training. The SIB is a simulated ship built from modified Conex boxes (see Figure 3) and is located on dry land.

During training, all users were briefed on the capabilities and limitations of each system. Each operator was then provided with time to practice operating the systems. In order to maximize the use of available training time, two or three

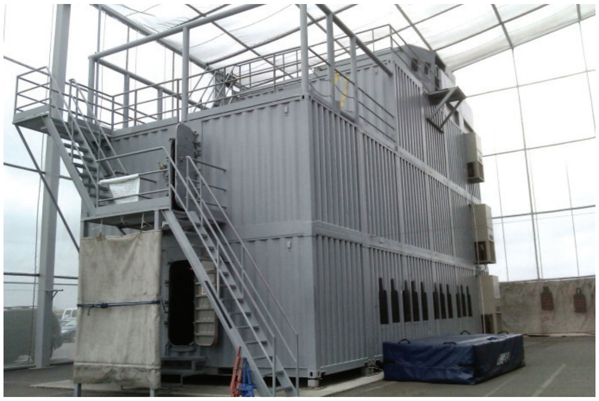

Figure 3. The Ship-in-a-Box (SIB)

systems were operating simultaneously, with the users encouraged to observe the robots when they were not themselves operating a system. Manufacturer's representatives from iRobot and MacroUSA provided training on their respective systems. All other instruction was provided by SSC Pacific personnel.

The first day of evaluation was conducted at the SIB. Prior to the actual robot trials, a series of tests were conducted where the boarding team members attempted to throw weights onto the upper deck of the SIB. These weights were used to simulate the ability of the team members to throw systems of similar mass onto the deck of a larger vessel from a small boat alongside. (The weights were used instead of the actual robots to prevent damage to the test robots. The boarding team members sometimes missed their targets and the robots would have fallen a long distance to the concrete floor.) The team members then practiced throwing weights and the actual robots onto a padded outdoor mat and provided feedback about the "throwability" of each system.

Following these preliminary tests, the team members were asked to simulate phases 2 to 5 of the VBSS mission (see section 2.1 above) while employing the robots as appropriate to each robot's abilities and the scenarios. SSC Pacific personnel observed and recorded a variety of data including specific system performance metrics, photographic records, video recordings, and boarding team members' spontaneous comments. SSC Pacific also provided support such as having sailors hiding in various locations to simulate crew of the vessel being boarded. At the end of each simulated mission, the team members completed a survey that was tailored to collect information specific to the individual mission phases. The surveys asked the team members to respond on a 1-to-5 scale regarding the importance and performance of each system in a variety of areas. They also provided space for team members to submit comments in order to capture additional information not explicitly addressed by the survey questions.

The sequence of events was very similar on the second day but conducted on a tugboat, although the preliminary throwing-distance tests were not repeated. Each system was again used to conduct a simulated mission with a focus on phases 2 through 5. The team members also filled out a survey for each system that was evaluated.

After the tests were completed, the team members were asked to fill out a final survey concerning specific desired operational capabilities and asked to rank each of the existing systems in several areas. Again, the surveys included extensive space for specific comments in order to insure that valuable information wasn't lost due to too narrow a focus by the survey's authors. Following completion of all of the surveys, the questions and numerical scores were transcribed into a spreadsheet to facilitate easier review of the data.

3. DESIRED CHARACTERISTICS OF AN MIO UGV

Feedback from the VBSS team members were fairly consistent, and led to some surprising findings.

3.1 Size and Weight vs. Advanced Mobility Capabilities

The VBSS operation is very fast and agile by design. In most instances, there is no time to stop and maneuver a robot across large obstacles or door thresholds. The robot is almost never driven from one room or compartment to another. The VBSS team often would toss a robot into a compartment for a quick look before entering (Fig. 4), then pick up the robot and toss it into the next compartment. Clearing each area takes only seconds. The main mobility requirement of the robot is to be able to rotate quickly for a 360-degree view, and perhaps moving very short distances for a better viewing angle. Typical obstacles on the deck that the robot should be able to traverse include ropes, cables, and anchor chains (Fig. 5). Thus the ability to cross obstacles 3.75 cm to 5 cm tall (with rounded edges) would enable to robot to move freely in most environments. Ship compartments are usually small, so long-distance movement is not required. The robot operates synergistically with the human operator, who would fill in whatever functions the robot cannot do.

For these reasons, the operators preferred a small and light-weight robot rather than one with advanced mobility capabilities. Ideally, they would like a robot that can fit into their cargo pocket or a Modular Lightweight Load-carrying Equipment (MOLLE) pouch. Alternately, the robot may be clipped onto their MOLLE vest, as long as it does not impede movements.

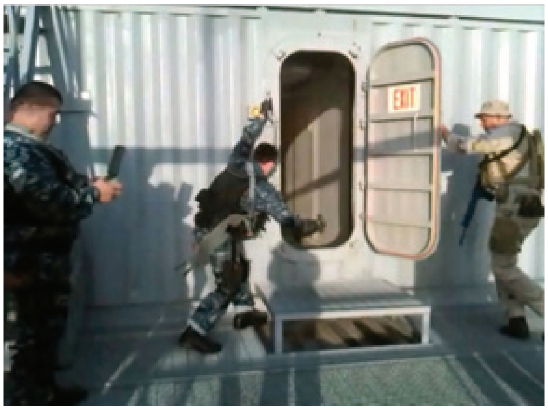

Figure 4. Typical deployment mode for VBSS robots.

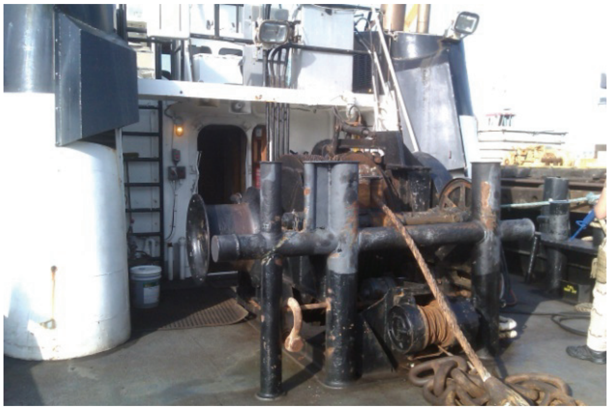

Figure 5. Deck area of a tugboat, showing chains and ropes that are the usual obstacles.

Weight is also a major concern for the Insertion Phase, when the robot may have to be tossed from a RHIB onto the deck of a ship that could be 20 meters higher. We found that the ideal weight is approximately 1.5 kg for this operation.

3.2 Stability and Traction

Ship decks are usually contaminated with oil, dirt, and metal particles. On tugboats and dhows, they are also often slanted. Depending on the sea state, the deck surface can experience moderate to severe pitching and rolling. Therefore, an MIO robot needs to be stable enough under these conditions to stay where it is thrown and not slip when being driven. Another surface that proved problematic to some robots is the steel deck grating found on some larger ships (Fig. 6). Robots with tails and spiny wheels tend to get caught on this surface. Those with wheel or track width smaller than or equal to the spacing of the grating also encountered problems.

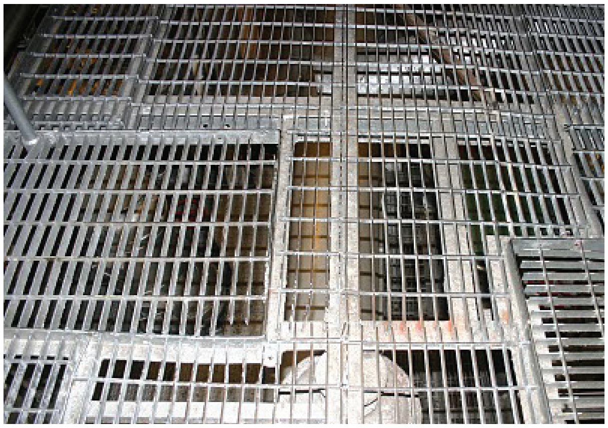

Figure 6. Deck grating between levels of an engine room.[3]

3.3 Ruggedness

Although the height of a ship's deck could be as much as 20 m above the water surface, when thrown from the RHIB the robot only has to withstand the impact of falling from the flight's apogee (ideally just clearing the railing) to the deck. This distance is normally less than 2 m. However, in the Infiltration and Objective Phases, the robot sometimes needs to be dropped down stairwells to lower decks. This distance can be much farther. We believe the threshold drop-survivability distance should be 5 m, with an objective distance of 10 m, onto a steel deck.

3.4 Waterproofing and Flotation

Being a maritime system, the robot and its OCU must possess some degree of waterproofing. At the minimum, the OCU should be splash proof (IP64), while the robot should be waterproof to 1 m depth (IP67). Throwing a robot onto a ship deck 20 m above is not an easy task. During testing at the SIB, we found that sometimes the robot-surrogate weight would not reach the required height, hit the side of the ship, and fell backward onto the concrete floor. Other times it would overshoot the deck and land on the far side of the ship. A mechanism for recovery of the robot from the water at the completion of the mission is desirable.

There is also a need for the robot to be able to cross flooded spaces (commonly found inside dhows). To satisfy both of these objectives, a robot must either be negatively buoyant with a floatation device that deploys at a certain depth, or positively buoyant with the ability to drive on the water surface.

3.5 OCU Characteristics

One of the desires expressed by the VBSS team, which we have found to be similar to those of other tactical military users, is for a small, light-weight, and simple OCU, with as few joysticks and buttons as possible. If there are any on-screen menus, they should be simple and only required at system start-up. Imagine the problems the users would encounter if they have to fumble with complicated menus and buttons while under fire. Touch screens should not be used. Their operation requires delicate movements not possible under high-stress conditions, and they require the operators to remove their tactical gloves.

The OCU screen should be a minimum of 8.5 cm (diagonal) in size and should be sunlight readable but with automatic dimming in dark environments. There should preferably also be a capability for manual brightness override. Having internal antennas (built into the lid or body of the OCU) is a plus since it minimizes chances that the antennas would be caught or snagged during operation.

OCU neck strap should be avoided because they can be used by the enemy to choke the operator during hand-to-hand combat. Bandolier strap is desired instead.

3.6 Sensors

The robot's video camera must work in both daylight and near total darkness (which can be assisted with infrared or visible lighting). It should have a wide dynamic range and/or auto-iris function with manual override. The camera should be able to see an entire door opening 2 m away, either through the use of a wide-angle lens or by remote control of the camera's tilt angle.

At a minimum, the robot should provide one-way audio feedback to the operator. On-command two-way audio is even better, so that the operator can communicate or negotiate with a remote subject.

There is also a desire to have a Picatinny rail on the robot. This would allow the VBSS team to attach other sensors (e.g., gas sensors) to the robot for certain missions.

3.7 Physical Extensions

The VBSS team occasionally used the robot as a simple remote camera or corner mirror to look down into bilges and engine compartments, through crevices, and around corners. For these instances, there should be a mechanism (e.g., a screw socket) to allow a light-weight telescoping pole to be attached to the robot. There should also be an eyelet where a rope can be tied, with which the operator can lower and retrieve the robot through openings in the floor.

3.8 Communications

The RF communications link between the robot and OCU must be robust enough to work at 1000 m from the mother ship's radar (AN/SPY-1 on a US Navy ship). It should also allow the robot to operate robustly 20 m non-line-of-sight from the OCU in a shipboard environment with aluminum and steel structures.

3.9 Strobe Distracter

Although not a critical requirement, the VBSS team also expressed the desire for the robot to carry a remotely activated strobe distracter. This would be used to draw the attention of hostile forces in a room or temporarily blind their dark-adapted vision prior to the team's entry. With a different strobe frequency and duration, the same strobe could also be used as an aid to locate an overboard robot at the end of a mission.

3.10 Power Requirements

The robot should be able to be driven continuously for a minimum of 1 hour on flat terrain. The users also expressed preference for having field-replaceable batteries. However, from discussions with the manufacturers, we have found that this feature is difficult to implement along with the waterproofing requirement.

3.11 Multi-robot Systems

Since it is anticipated that some robots may be temporarily lost during the Insertion Phase, it is highly desirable that the system includes two or more robots per OCU. To further increase the added value of this configuration, the operator should be able to switch control among various active robots simply by selecting its ID on the OCU. While deselected, a robot's camera should remain active and be able to detect and alert the operator of any movement in its field of view. This would allow the VBSS team to deploy one or more robots along the insertion route to cover their exit or prevent hostile forces from approaching them from the rear, while using the remaining robot(s) for the look-ahead function.

4. CONCLUSION

The MIO VBSS operation is a fast-paced, dangerous operation that will benefit from the availability of a tailored throwable robot. We have conducted user assessments and compiled a list of key performance parameters for such a robot. This list, in turn, has been used in a Request for Proposal for industry to develop a prototype unit. We anticipate that this prototype will be completed sometime in 2012, after which it will undergo user validation tests.

Although some of the parameters presented were guided by maritime operational requirements, the majority are common to all fast-paced tactical operations. They should also be useful in the development of a pocket-sized throwable robot for all tactical operations.

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