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Unmanned surface vessels for surface and subsurface threats in harbours: background and practical lessons

Thomas J. Pastore, Ronald T. Kessel,

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Unmanned Surface Vessels for Surface and Subsurface Threats in Harbours: Background and Practical Lessons

Thomas J. Pastore, Dr. Ronald T. Kessel
NURC
Tel: +39 0187 527 473
Tel: +39 0187 527 248
Fax: +39 0187 527 331
pastore@nurc.nato.int
kessel@nurc.nato.int
www.nurc.nato.int

Abstract

The use of Unmanned Surface Vehicles (USVs) in harbour protection missions has been studied through technology surveys and experimentation within the programme of work at NURC. The crucial subsystems and vehicle payloads which provide a vessel's capability were assessed. The mission of harbour protection can be broken down into representative subtasks, and possible application of USVs to each is discussed. The important conclusions of the earlier work can be summarized as follows:

• The potential benefit of USVs ranks with that of other classes of unmanned systems – reduced life-cycle cost, personnel safety through increased standoff distance, and reliable performance of tedious repetitive tasks (not subject to operator fatigue).

• A productive overlap exists between the USV community and other classes of unmanned systems.

• The USV market is mature: there are numerous vessels with semiautonomous control systems available commercially.

• Several universities and laboratories worldwide are conducting important research into autonomy as related to USVs.

• Most, if not all, commercially available USVs lack sufficient autonomy to be of immediate use in a harbour protection role. In fact, their reliability concerns and uncertain legal status could render them liabilities in the close confines of a harbour environment.

• The necessary advances in autonomy depend in part on close integration of the onboard sensors and the onboard decision making tools.

At-sea experimentation begun in 2007 and continuing through 2009 has provided practical lessons on the use of USVs and further refinement of the “state of the art” or “state of the practice.” This experimentation has focused on a subset of the missions and shortcomings previously identified – particularly the missions which require seamless integration of surveillance plus response against underwater threats such as divers, mines, or IEDs on the bottom or in the water column of a harbour environment. Results and analysis derived from these experiments are used to plot the course for future trends in practical operational use of USVs.

1. Introduction

Motivation

In recent years, port and harbour protection have been recognized as missions which can be conducted with the use of unmanned surface vehicles (USVs) [1-4]. The use of one or more USVs to counter subsurface threats in harbours offers appealing advantages when compared with the alternatives of relying only on fixed sensors or use of AUVs. These include speed of response, platform endurance on patrol, visible deterrence, and high-bandwidth connectivity to a shore station for fusion and assessment of sensor data from the sensors aboard [5-8]. Work in recent years at NURC has evaluated the use of portable high-frequency sonars from a small boat (manned or unmanned) for classification of divers [9,10]. This complements a wide body of work using unmanned undersea vehicles (UUVs) to conduct searches of the sea floor or piers, quays or other structures [11-13].

Organization of this paper

The remainder of this paper is organized as follows: section 2 describes some of the missions which are or could be performed by USVs. Section 3 describes the presents a sample of relevant USVs in harbour protection missions. Section 4 summarizes important conclusions of experimentation at NURC in recent years (practical lessons based on at-sea measurements). Finally, section 5 details important challenges which remain, some of which form the basis for current work at NURC.

2. Example USVs for Harbour Protection

The mission of protecting a harbour can be characterized by the following steps (adapted from [1])

2.1 Baseline

A threat to a harbour is by its very nature an unusual event. It is essential to know what is usual before one has the ability to distinguish that which is unusual. This explains the need to establish a baseline of a harbour environment. Baseline tasks include survey of the bottom, inspection of piers, breakwaters and quays, and inspection of hulls that are already in the harbour. A USV of any size and speed capable of carrying a sidescan sonar or other useful survey/inspection sensor is a good match for the task of collecting data which could be used to establish a baseline. The task is monotonous, time-consuming, and ongoing; all of which make it a prime candidate for automation.

2.2 Detection

With knowledge of the norm of a harbour, any alteration from that baseline can be detected. Of course, a harbour is only useful if it allows the expedient transit of legitimate traffic, and all legitimate traffic constitutes change to the baseline. This is where fusion with AIS and/or vessel traffic control must enter into the port protection mission. One part of detection might involve inspection of vessels on arrival. Another aspect would be detection of fixed objects which were not previously part of the baseline – frequently called “change detection.” A final form of detection would be detection of a moving contact which is not authorized or seen by other sensors. With the appropriate sensors, USVs can serve an important role in all aspects of detection. Inspection upon arrival could be assisted or accomplished by USVs equipped with hull-search sonars, electro-optics, and chemical-radiological-biological (CRB) sensors. Change detection of fixed objects is a logical follow-on to baseline tasks. Detection of moving contacts from a USV in motion would present challenges which have not been fully explored.

2.3 Tracking

In the case where a moving contact has been detected, tracking is the next logical step. Periodic updates on the position of a threat object are necessary to assist in determining intent (is the unknown contact making headway towards a protected asset?) Tracking is also essential if re-acquisition is required before the subsequent steps can be performed. This is not an area where USVs have been used as yet, but if USV sensors are able to detect, then a rudimentary form of tracking can be accomplished just by moving the USV to keep the unknown contact in the field of view of the sensor.

2.4 Characterisation and Verification

Characterization and Verification (alternatively classification and identification) are the first steps of a response to an unknown threat. In the case of response to detection of a fixed object, the body of knowledge from MCM operations applies directly. As for response to a detection of a moving contact, the challenge becomes one of coordination and timely updates from the detection sensor and the response craft. Because the sensors used for classification and identification generally have quite short effective ranges, this is the task which is most applicable to a moving platform, which can be readily brought to bear at the location of the unknown contact. UUVs are well suited to re-acquisition and identification of fixed subsurface objects, but with an appropriate sensor such as side-looking sonar, a USV could accomplish the same. This is especially true in the relatively shallow depths typical of most harbours. As a response to a detection of a moving contact, the challenges of coordination and timely updates from the detection sensor to the response craft must be carefully dealt with. If automation is not sufficiently advanced, teleoperation of this task garners some of the benefits of unmanned operation.

2.5 Engagement

This covers a scaled response from warning to non-lethal deterrence to potentially lethal measures as dictated by local threat and rules of engagement. Any engagement which allows the operator to maximize standoff distance from the threat has obvious safety advantages. There are two ways that increased standoff might be achieved. The first would involve the use of long-range effects delivered from a shore or pier location. Alternatively, an unmanned vessel could be used to deliver effects at a shorter range. Engagement might range from warning devices to entanglement or other stopping measures, to lethal response.

2.6 Assessment

Following engagement at any level, assessment must be accomplished in order to verify the effectiveness of the engagement. This could often be done with the same sensors as were used for the characterization and verification. The assessment phase shares characteristics with the characterization and identification phase. Logically then, the same sensors and systems are applicable to this part of the mission. In fact, one could use the term re-assessment after engagement.

3. Sample Vessels in Harbour Protection

Navies throughout the world are expected to rely on ever-increasing numbers of unmanned platforms in the future. A couple examples of classes of ships designed around the capability that USVs will bring are the French Swordship and the Littoral Combat Ship (LCS) under development in the USA. The USVs to be featured on these ships will build on the experiences of the Spartan Scout Advanced Capability Technology Demonstration (ACTD), which began in 2004. The initial ACTD was a joint venture between the United States and Singapore, with France joining the partnership at a later date. Two models of Spartan have been extensively tested and exercised, including operations in the Arabian Gulf. The 7-meter version features a single engine and water-jet propulsion system, while the 11-meter version has the added performance and redundancy of two engines and water-jets. Spartan was deployed to the Arabian Gulf with the USS Gettysburg in mid-2003 as a first major deployment with fleet users. Spartan contributed to the recognition of the overall maritime picture around the cruiser and carrier. The developers also received valuable feedback from the warfighting community on aspects of performance.

Further evidence of Singapore’s interest in USVs is given by their purchase of Rafael’s Protector USV. The Protector is also an important asset in the Israeli Navy’s future arsenal. This capable vessel features radar, day/night electro-optic sensors, and a weapon system based on Rafael's Mini-Typhoon remote-controlled, stabilized machine gun mounting. Two other Israeli companies are important participants in the world USV market – Elbit Systems and Aeronautics Defense Systems. In addition to the Stingray mentioned earlier, Elbit Systems produces the Silver Marlin and is a partner with Brunswick Boats in development of the Sentinel vehicle. Another company within Elbit Systems develops electro-optic sensors which are used on the vessels. In the case of the Sentinel, Brunswick provides the hull and propulsion design while Elbit supplies expertise with regard to control and sensors. Aeronautics Defense Systems was a former partner with Rafael on the Protector, but are now marketing their own vessel called the SeaStar. Like the Protector, the SeaStar and Silver Marlin are shown in company literature with a stabilized remote control gun aboard. More recently, Calzoni s.r.l have entered the market with their 7-meter U-Ranger under contract to the Italian Navy. This is a 40-knot vessel capable of deploying an imaging sonar for inspection of subsurface objects when it is operating slowly. The vessel was demonstrated in NATO Harbour Protection trials in Eckernförde Germany in 2008.

A lighter category of fast vessels can be well typified by the QinetiQ Sentry, which is built on the baseline of a personal watercraft. QinetiQ's Sentry and Elbit's Stingray are judged to be among the most mature products in this class. In both cases the featured sensors are daylight and night-time cameras.

For more than a decade the Massachusetts Institute of Technology (MIT) has been an important participant in the development of simple lightweight unmanned surface vessels. The MIT team has demonstrated a variety of missions using SCOUT (Surface Craft for Oceanographic and Undersea Testing) including obstacle avoidance, multi-vehicle cooperation in track and trail, and dynamic baseline navigation provided to cooperating undersea vehicles using underwater acoustic modems.

SeaRobotics of Palm Beach Gardens, Florida (USA) offers several commercial products in the light/slow category of vessels – trimarans, catamarans, and small monohulls – all equipped with DGPS, heading, attitude, and depth sensors. Recent customers of note include US Navy facilities in Panama City FL and Monterey CA.

In addition to the vehicles noted, there are a few suppliers for kits designed to turn any vehicle (vessel) into a USV. The Spectre from h-scientific is judged to be the most mature of these. In fact, it is based on algorithms which are used in thousands of vessels worldwide – sold under license to Raymarine for use in their autopilot units. The approach they take to remote vehicle control is that the functionality is the same as an autopilot, the only difference being the person operating the autopilot is located some distance away from the vessel. Spectre interfaces to a wide variety of vessels, single and twin engine, propeller or waterjet.

4. Practical Lessons

Work at NURC and with partnering organizations through 2008 has focused on subsurface missions which can be performed by USVs. Of the six missions outlined in section 2 of this document, three have been exercised using USVs: Baseline, Detection, and Classify/Identify (the last dependent on cuing from a fixed surveillance sonar).

Baseline surveys are readily performed with USVs that NURC has had access to. We have demonstrated success with vessels ranging from kayaks of a few meters up to seven meters of length. The capability to repeat the same tracks so that surveys can be compared from one day to the next has been demonstrated. Appropriate speed of the vessels for such work is a maximum of about 4 knots with a sidescan sonar, and slightly slower if surveying the bottom with a forward-looking multi-beam. The ability to operate at this speed with good steerage presents problems for some larger vessels, and even for jet-drives on smaller vessels. A sidescan sonar fixed firmly to the hull of the vessel makes the system more sensitive to waves and chop on the sea surface. The observed images are of good quality in sea states of 0 or 1, and degrade rapidly in sea state 2. On the other hand, a towed sonar will continue to provide good imagery in sea state 2 and possibly 3 – but towing a sonar leads to limitations of minimum water depth, and reduces manoeuvrability (increased turning radius).

Detection of stationary objects on the seafloor has been readily demonstrated as part of the baseline and follow-up surveys described in the preceding paragraph. Vessel kinematic information combined with GPS reports can provide accurate localization of subsurface objects. Proof of this detection and localization capability (sufficient to return and view the object with a different sensor) was provided through a very simple interface which allowed the user to click on an object on a live sidescan display, and the vessel would return to that position so that the object could be viewed with the forward-looking sonar. Such tasking for a slow-moving contact was scheduled to be part of our experimentation in November 2008 in Eckernförde, but hardware problems with the sidescan sonar processor aboard the USV precluded a complete test of that capability.

Classification and identification of contacts with cuing from a surveillance sonar is the task NURC has studied closest. The contact of interest is a diver making a stealthy approach to a high-value asset in a harbour. Even though the divers' speed is in the neighbourhood of one knot, detection with fixed surveillance sonars is possible only at ranges which will provide on the order of 10-15 minutes to respond to such a threat.

A key enabler in NURC's work with unmanned systems is the use of a scalable and hierarchical software architecture. In particular, the use of MOOS (Multi-Objective Operating Suite)), a publish and subscribe architecture for control and monitoring of one or more mobile assets, and IvP Helm, an extension of MOOS which acts as skipper of an unmanned vessel, and is able to dynamically modify its behaviour to meet multiple simultaneous objectives. Using such an arrangement, the higher-level mission objectives can be defined independently of the particular vessel on which they will later be implemented. For example, a mission might be tested in simulation one day, on a kayak the next, and a RHBI with full-scale and capability payloads the next day.

Optimal parameters for classification sonars were studied in 2007 experimentation [10,14,15], and response tasking (tasking and routing of the vessel to the point of intercept) was studied separately in the analysis of that experiment [6]. Important recommendations from [14] are repeated below:

1. Commercially available imaging sonars typically resolve the diver body (arms, leg,

head, torso) at ranges and depths significantly less than 25 m. Close approach is therefore required.

2. The maximum range scale setting for an imaging sonar (without zoom), for use in response against underwater intruders, is about 36 m for body imaging and 110 m for bubble imaging (less stringent).

3. The horizontal beam width for body imaging should ideally be about $\delta\varphi=0.358$ degrees.

4. The response platform must be manoeuvrable at low speeds, with speed control to within a precision of 0.5 knots.

5. In side-looking images, blurring of the diver highlight and shadow by the diver's motion of arms and legs is to be expected. Diver recognition may therefore require more operator familiarity with the sonar than for forward looking sonar.

6. Real-time steering of the look angle of a forward-looking sonar was found to be more problematic than helpful. A fixed sonar mount capable of easy periodic adjustment of the look angle, mainly to account for water depth, is advisable.

7. Motion compensation of the sonar head is apparently not required owing to the short observation ranges required for diver body imaging.

8. Flow drag on a forward-looking sonar head can be significant at high response transit speeds, possibly destabilizing a small vehicle. Means for retracting the sonar head should be considered.

9. The injection of bubbles by the propulsion of the response craft should be minimized to avoid masking of the underwater scene from sonar view, especially along the line of sight between the diver detection sonar and the sonar contact, and across the imaging sonar transducer when the response craft reverses on occasion to maintain position relative to a moving contact. Propeller drive is therefore recommended above

jet drive.

10. The diver body recognition task so far remains a manual task performed by a human operator. Automation of body recognition is not expected any time soon.

11. Sonar size is an issue. A large sonar head will produce significant drag. Some sonars have a large dry end for installation on the response boat, which may be an issue for smaller boats and unmanned boats.

Demonstration of similar classification of contacts using surface sensors (day or night-time cameras) has been conducted at NATO experiments in 2007 and 2008. Detailed analysis and operational recommendations for such operations, however, have not been conducted.

5. Future directions

Further work now underway aims to extend the demonstrated capability against subsurface contacts to surface contacts. Such work will involve multiple vehicles in cooperation to accomplish the mission. Additional measures must be taken to avoid collisions with other vessels (cooperative or otherwise) and fixed objects which will be found in an operationally relevant environment. The basis for such accomplishments builds directly from earlier work described in the preceding section. Important tools already in use are the MOOS and IvP Helm.

Sensors appropriate for identification and relative positioning from surface objects and other vessels are under investigation. These include radar in various frequency bands, acoustic, IR, and LIDAR.

The short-term end state envisioned as a result of this work is a harbour protection vessel which largely drives itself to the best locations for monitoring, classifying and deterring threatening activity in a harbour, with minimal operator workload. The operator will be left free to provide high-level tasking and assess sensor data which comes back on the network link.

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Author(s)

Pastore, T.J., Kessel, R.T.

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Issuing Organization

NURC
Viale San Bartolomeo 400, 19126 La Spezia, Italy

[From N. America:
NURC
(New York) APO AE 09613-5000]

Tel: +39 0187 527 361
Fax:+39 0187 527 700

E-mail: library@nurc.nato.int