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Autonomous Underwater Vehicles for Port Protection

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- Expeditionary Operations Support (EOS)
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Autonomous Underwater Vehicles for Port Protection

By Edoardo Bovio

Abstract

NATO's present capability to deal with a terrorist threat to our ports is slow, dangerous, and inefficient. Ports are a challenging area within which to conduct MCM operations due to several factors: shipping movements, very shallow water, turbidity, confined space, mine burial due to muddy/silty conditions, and high clutter density. The shortfall in NATO's ability to deal with this problem has been recognised by NATO Strategic Commanders who gave the highest priority to MCM for Force Protection and Counter-Terrorism. Recent progress in underwater robotics has been aimed at developing small, rapidly deployable Autonomous Underwater Vehicles (AUV) to achieve a large spatial sampling for both acoustic and non-acoustic measurements. The vehicles that are now commercially available, have great potential to work in conjunction with existing MCM assets and have several advantages: significantly faster search rate, reduced danger to divers, rapid deployability, and ability to carry out surveys in confined areas. The NATO Undersea Research Centre studies the performance of AUVs equipped with COTS sensors and working in conjunction with conventional assets (Mine Hunters and divers) to carry out MCM operations in ports and port approaches. To measure the effectiveness of this new technology in comparison to current practice, several experiments have been conducted in the ports of La Spezia (Italy), Strenraer (Scotland), Rotterdam (Netherlands) and Olpenitz (Germany). The paper summarizes the results and discusses the lessons learnt from the trials.

1 Introduction

The NATO Undersea Research Centre[1] (NURC) located in La Spezia, Italy, performs basic and applied research and development to fulfil NATO's operational requirements in undersea warfare. The results of the Centre's research that can be seen at sea in many ships and submarines of the Alliance, have contributed to NATO's military capabilities over the past 41 years. Unique in its international makeup, the Centre functions as the Centre functions as the "hub" in a virtual laboratory which brings great synergy to the research process and shortens timelines between research and development and military applications. The Centre's own resources are therefore multiplied by collaboration and Joint Research Projects (JRP).

In response to NATO advanced planning that anticipates significant use of Autonomous Underwater Vehicles (AUVs) for Mine Counter Measures (MCM) and Rapid Environmental Assessment (REA), the Centre and the Massachusetts Institute of Technology (MIT) initiated in 1997 a 5 years joint research project, designated GOATS (Generic Oceanographic Array Technology Systems), for the development of environmentally adaptive AUV technology applicable to MCM and REA in coastal environments. The GOATS JRP grew in membership and scope and it was joined by an international host of collaborators who shared the notion that AUVs were ready to graduate from their role as research objects to a new supporting role for advanced ocean monitoring and maritime military tactics.

Between 1997 and 2001 the GOATS JRP explored and expanded the state of the art for networks of robotic ocean observers, supporting new approaches to battlespace preparation and mine hunting. The programme included a sequence of three field experiments with the

[1] Following the change in NATO command structure, the SACLANT Undersea Research Centre has been recently renamed NATO Undersea Research Centre

participation of 14 institutions. The August 2001 GOATS Conference [1] marked the end of this JRP, but not the end of the work.

Building on the success of the GOATS JRP, the Centre initiated in 2002 a new long term programme called Battlespace Preparation (BP) with AUVs to explore and demonstrate the operational benefits and limitations of AUVs for military battlespace preparation. Similarly to the GOATS series of experiments, the programme organized multi-national, multi-disciplinary sea trials addressing the utilization of AUVs in coastal waters. The results have been reported at the Maritime Recognized Environmental Picture (MREP) Conference [2] held in La Spezia in May 2003.

In response to a request by SACLANT[2] in October 02, the Centre has initiated a short term project to evaluate the applicability of COTS AUV technology to counter terrorist mining of our ports. NATO's capability to respond to a terrorist threat to ports and harbours is characterised as slow, laborious and dangerous. Such installations are an extremely challenging area within which to conduct MCM operations due to several factors: shipping movements, very shallow water, turbidity, confined space, mine burial due to muddy/silty conditions, and very high clutter density. Due to the requirement to limit disruption to shipping, MCM operations are time critical with the added necessity of achieving close to 0% residual risk.

2 Experimental program

The recent availability of small, rapidly deployable, relatively inexpensive AUVs equipped with a range of acoustic, optical, and magnetic sensors for shallow water operations, can contribute significantly to improving the capability of conventional assets. The use of AUVs in conjunction with Mine Countermeasure Vessels (MCMVs) and divers has several advantages: significantly faster search rate, reduced danger to divers, and ability to carry out sonar searches in confined and very shallow areas. Of particular interest is the capability to ship overnight small AUVs anywhere a crisis might occur and to place the appropriate sensors (sonar, optical, magnetic) in close proximity of mines without risking human lives. The limited cost of COTS AUV (compared with traditional MCM assets) allows deploying fleets of specialized vehicles to achieve large area coverage.

Between 2002 and 2005 the Centre has successfully conducted experiments in the ports of La Spezia, Straenraer, Rotterdam and Olpenitz to assess the value of AUVs for MCM ops in our ports and to compare their performance with that of existing assets. The results of this work, documented in [3], [4], [5] and [7] are summarized in this paper. The experience gained during the exercises helped developing a concept of operation and issuing preliminary guidance for the tactical use of AUVs in counter terrorism MCM operations in ports and harbours [6].

The two AUVs used to conduct the experiments, the REMUS and the Ocean Explorer, are briefly described below. Both Centre's ships, Alliance and Leonardo have been extensively used during the experiments.

2.1 REMUS

The REMUS, COTS AUV (Figure 1) developed by the Woods Hole Oceanographic Institution and manufactured by Hydroid, is designed to carry out reconnaissance missions in shallow and very shallow water. The REMUS weighs 36 kg and is deployable by hand. It is 1.58 m long

[2] Supreme Allied Command Atlantic, now renamed Supreme Allied Command Transformation (SACT)

with a 0.19 m diameter, operating between 3 and 5 kts with an endurance of 20 hours (60 nm) and 9 hours (45 nm), respectively. The endurance specification is based on fully charged lithium ion batteries. The REMUS vehicle used during the trials was equipped with a 900 kHz side-scan sonar (SSS) for the detection and classification of objects on the seabed. It also had sensors to measure water temperature, salinity, underwater visibility (optical backscatter) and water depth. The maximum depth rating of the REMUS is 100 m.

The logistical requirements to transport the REMUS system are minimal. The REMUS is transported in a container 1.78 m × 0.41 m × 0.38 m. The total weight including the vehicle is 67 kg. The auxiliary equipment (e.g. transponders, computers, etc) is transported in a similar container weighing 62 kg. The vehicle and auxiliary equipment can be shipped via commercial air cargo, but special procedures apply to the lithium ion battery package. The REMUS system also includes the Ranger system that allows the vehicle to be acoustically tracked and controlled in real time from a small boat by means of simple commands (abort mission, come home).

Figure 1 : REMUS vehicle with system components: Notebook, Ranger, handheld GPS, two navigation transponders.

The vehicle can navigate in three modes: acoustic long baseline (LBL), dead reckoning (DR) and acoustic ultra-short baseline (USBL). In the LBL mode, two or more acoustic transponders are moored to the seabed and positioned (i.e. by divers using handheld GPS). The REMUS interrogates two transponders concurrently and determines its range to each. Knowing the position of the transponders, the vehicle calculates its position by triangulation. If more than two transponders are present, the vehicle will use the pair that gives the best angle of cut. The maximum range capability of the transponder system is approximately 2000 m. Quoted accuracy is 10 m, which excludes the error associated with the transponder measured positions. The vehicle updates its position by DR between position fixes at approximately 5 s intervals. In the DR mode, the vehicle uses speed and heading to compute its position. Speed is calculated using propeller RPM and acoustic Doppler signals. Heading is determined using a magnetic compass and yaw rate sensor. Quoted accuracy is 40 m per 1000 m travelled, provided that the vehicle is within 20 m of the seabed to ensure that Doppler data is obtainable. When the navigation error exceeds a threshold, the vehicle can be programmed to return to the surface for a GPS fix. The USLB mode is used for homing in on an acoustic transponder during vehicle recovery or docking. It uses a four-channel hydrophone located in the nose cone. Maximum range is about 1500 m.

Transit and search plans are prepared on a rugged notebook PC and the commands required to perform the mission are uploaded into the vehicle via serial port. On completion of the mission, the vehicle, sensor and side-scan sonar data are downloaded to a PC via an Ethernet link for post-mission analysis. Side scan data are tagged with time and position so that the position of contacts on the seabed can be determined.

2.2 Ocean Explorer

The Ocean Explorer (OEX), procured from Florida Atlantic University (FAU), is a modular vehicle, featuring a PC-104 Pentium executing the supervisory control structure, interfaced to a distributed communication and control network based on the open LONTalk network protocol, a modular power system and a modular payload capability. The modular design results in a field reconfigurable vehicle, well suited to experimental work. The vehicle consists of an aft propulsion/control/navigation section, a payload section and a forward nose cone. Located in the aft section are the propulsion engine, the control surface motors, the navigation sensors, the control computer, the RF and acoustic communication systems, and the battery packs.

The navigation relies on a standard suite of sensors (tri-axial flux gate compass, precision rate gyros and accelerometers, Doppler Velocity Logger) that provide both relative and geodetic positional information. The modular design facilitates the inclusion of a variety of geodetic navigational instruments including a DGPS, long baseline (LBL), and ultra-short base line (USBL) acoustic tracking systems. A GPS/RF tow float has been developed at the Centre.

The payload section contains the mission sensors and is attached to the aft portion by a bayonet mechanism that allows for quick payload changes. Elements in the payload are simply additional nodes on the LONTalk network and are integrated with the tail section with a power conductor and a control line. The nose section contains a video camera, a flashing strobe, the emergency drop weight and the vehicle recovery line device.

The depth rating of the vehicle is 300 m and its endurance with standard batteries is 50 km at 3 kn. During operations OEX can be tracked acoustically via USBL and communicates via the acoustic modem. The Centre currently operates the OEX with two side scan sonar payloads: a dual frequency (150 and 600 kHz Marine Sonic sonar) and a 12kHz two dimensional array (one side only). The first payload is used to assess the value of AUVs for REA and MCM applications, the second is used for studying the effectiveness of synthetic aperture sonar for the detection and classification of buried mines. More payloads are planned, the first being a state of the art interferometric side scan sonar capable of providing co-registered imaging and bathymetry of the seafloor.

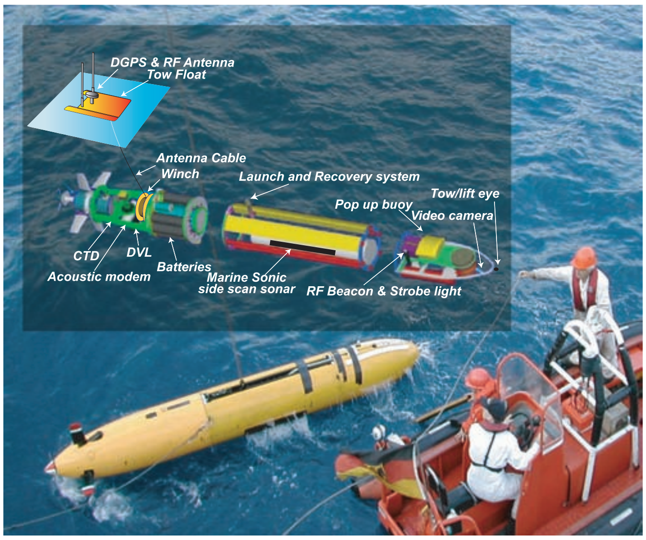

Figure 2 : The Ocean Explorer (OEX), procured from Florida Atlantic University, is a modular vehicle well suited to experimental work. The GPS/RF tow float has been developed at NURC

2.3 Initial demonstration to NATO Naval Group 3 (NG3)

In the fall of 2002, in response to SACLANT request, the Centre organized in cooperation with the US Office of Naval Research (ONR) and the Italian Navy an initial demonstration to NATO Group 3 (NG3) of the potential role of COTS AUVs for MCM operations in port and harbours. REMUS and OEX surveyed a very shallow water area in the port of La Spezia and detected all targets laid by the Italian Navy. The experiment demonstrated the capability of AUVs to detect mine like targets in ports where mine hunters could not operate.

2.4 Cinque Terre 03 (CT03) Exercise

CT03 demonstrated the use of MCMVs, AUVs and EOD[3] divers to counter terrorist mining of La Spezia and Carrara harbours. The Italian Navy provided ITS Alpino, two MCMVs (Crotone and Gaeta) and one EOD team embarked on ITS Pedretti; the French Navy provided the MCMV Persée. The mine hunters, assisted by the OEX and EOD divers cleared four routes to La Spezia and Carrara and two anchorage areas.

CT03 demonstrated the ability of the OEX to detect and classify all targets with a localization accuracy that allowed a mine hunter to quickly and efficiently re-acquire the targets for further identification and prosecution.

2.5 Northern Light 03 (NL03) Exercise

REMUS and OEX participated in NL03 as part of a Limited Objective Experiment (LOE) to demonstrate the use of AUVs to survey harbors in response to a simulated terrorist threat. The experiment took place in the inner part of Loch Ryan, Scotland where Stena Lines operates ferries between Stranraer and Belfast.

Two REMUS from the Coastal Systems Station (CSS), Panama City, FL were brought to Stranraer the day before the beginning of the exercise. Two experts from CSS accompanied the REMUS to teach five EOD divers how to plan, conduct and analyze REMUS missions. The five divers were attached to the Royal Navy Fleet Diving Group Two (FDU2) in Portsmouth, England.

The OEX with all equipment necessary to operate the vehicle, including the inflatable Zodiac, was stored in a container that was transported from La Spezia by truck. The OEX, operated by the Centre AUV team, and the REMUS, operated by the FDU2 divers, surveyed the channel and successfully detected and classified all targets.

2.6 Experiment in La Spezia port and demonstration to NATO Assistant Secretary

The capabilities of AUVs for port protection were demonstrated in spring 2004 to NATO Assistant Secretary for Defence Investments and to Italian Navy in the port of La Spezia.

REMUS was launched and retrieved from an ITN RHIB to cover the channel and the anchorage areas with orthogonal lines in order to obtain multiple aspect insonification of all targets. The data acquired by the REMUS were downloaded and analysed at the end of each mission and a standard HTML report was produced. ITN EOD divers prosecuted the objects classified as mine like to perform visual identification.

[3] Explosive Ordinance Disposal

2.7 Experiment in Rotterdam port

SACT decided in 2003 to put more emphasis on experimentation in order to accelerate the change in NATO and to reduce procurement and development cycles. Due to the success of the experiments conducted by NURC, Minehunting AUVs were selected as one of the important and promising experimentation projects. It was decided to demonstrate their capabilities in the port of Rotterdam that was chosen because of its relevance to the world economy.

The areas where REMUS operated have the typical port bottom conditions with some mud and silt as well as burial of up to 50 cm. Due to the regular dredging the clutter density was not as high as in tide free ports where dredging is not necessary (e.g. La Spezia). During the missions the exercise area was closed to commercial traffic by the Rotterdam Port Authority who provided one of their vessels to reroute the traffic.

3 Discussion

The experimental program demonstrated that off the shelf AUV technology, used in conjunction with EOD divers, and, if feasible, MCMVs, is capable of significantly improving the speed, efficiency, and safety of operations aimed at countering a terrorist mining threat to NATO's ports. The present diver based search tactics, whilst fitting the requirement to be comprehensive, are unacceptably slow. The addition of AUVs effectively addresses the recognized shortfall by reducing the time required to clear a port. A gain of at least one order of magnitude in time was demonstrated in all experiments. Good detection and classification of proud targets is achieved by high resolution, short range side scan sonars of the REMUS vehicles as shown in Figure 3, or alternatively by synthetic aperture sonar techniques which also allow higher area coverage rate per unit system.

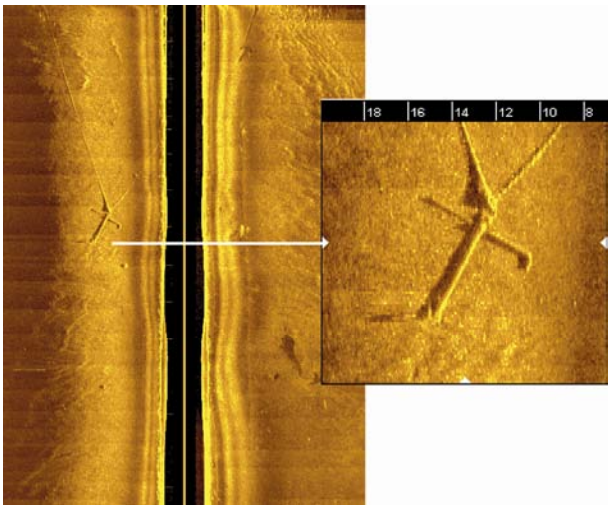

Figure 3 : Image of an anchor in very shallow water

However the difficulty in finding and classifying targets in presence of burial and the limited classification efficiency achieved in highly cluttered areas suggest that the problem of protecting our ports is not completely solved.

The most significant problem demonstrated by the experimental work is the inability of high frequency side scan sonar to counter targets buried in the sea floor. The detection and classification of targets is based on the analysis of the acoustic shadow cast by the object. As the high frequency sound does not penetrate the sediment, an object completely buried in the bottom is not detected. Sometimes a feature visible on the sonar image (e.g. scour pit, trench, etc) can indicate the presence of a buried object. An object partially buried in the mud is detected but its shadow may be highly distorted and classification could be difficult. See for example the different images of a cylinder shown in Figure 4.

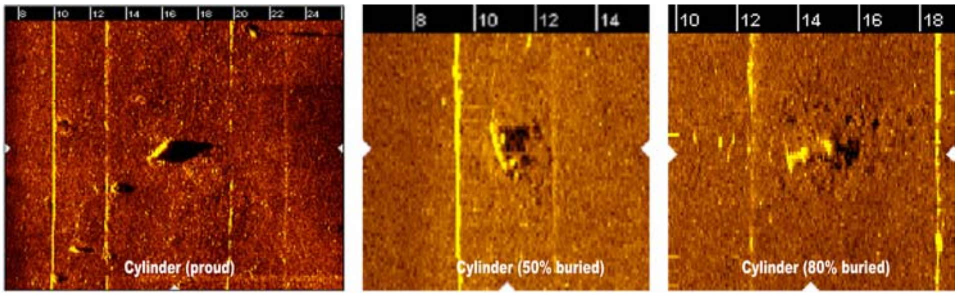

Figure 4 : Images of cylindrical target showing the increasing classification difficulty due to burial

When the target is proud on a flat sea floor (left), it casts a shadow typical of a cylindrical object and can be classified based on physical dimensions (length, width, height) that can be easily measured from the image. However when the target is partially buried the shadow is not representative of a cylindrical object. In the middle image it is possible to measure only its length and the distance between the lifting eyebolts. In the right image only the two eyebolts are visible and the distorted shadow does not convey any information.

The bottom of ports and harbours can be littered with all kind of man made objects and the clutter density is orders of magnitude higher than normally encountered in traditional MCM operations. In highly cluttered areas like the one shown in Figure 5, even easy target (bottom left) could be easily undetected or wrongly classified by operators. Even more difficult would be the case of other targets shown on the bottom with increasing order of complexity. Improvised Explosive Devices (IED) are particularly difficult to detect because their shape cannot be easily associated with that of known mines

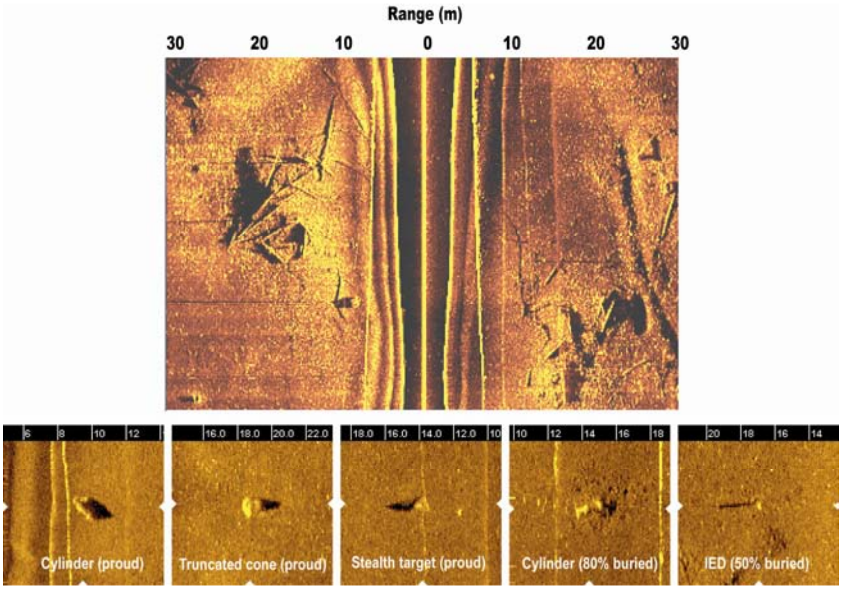

Figure 5 : In highly cluttered areas (top) , typical targets shown below in increasing order of difficulty can be missed.

The necessity to have a quick reaction in cases of crisis and the difficult (i.e. highly cluttered) environment where operations will have to be performed, requires that surveys of our ports be carried regularly with the highest possible positioning accuracy (less than 5m error) in order to have accurately geo-referenced data bases. Efficient algorithms for change detection will ensure a rapid assessment that a new object is present.

The ability of COTS AUVs to perform many times the same mission with an high degree of repeatability will improve the performance of change detection algorithms as demonstrated in Figure 6. REMUS images obtained in the same area with five months interval are very similar and make it easy to spot the new target present in the second mission.

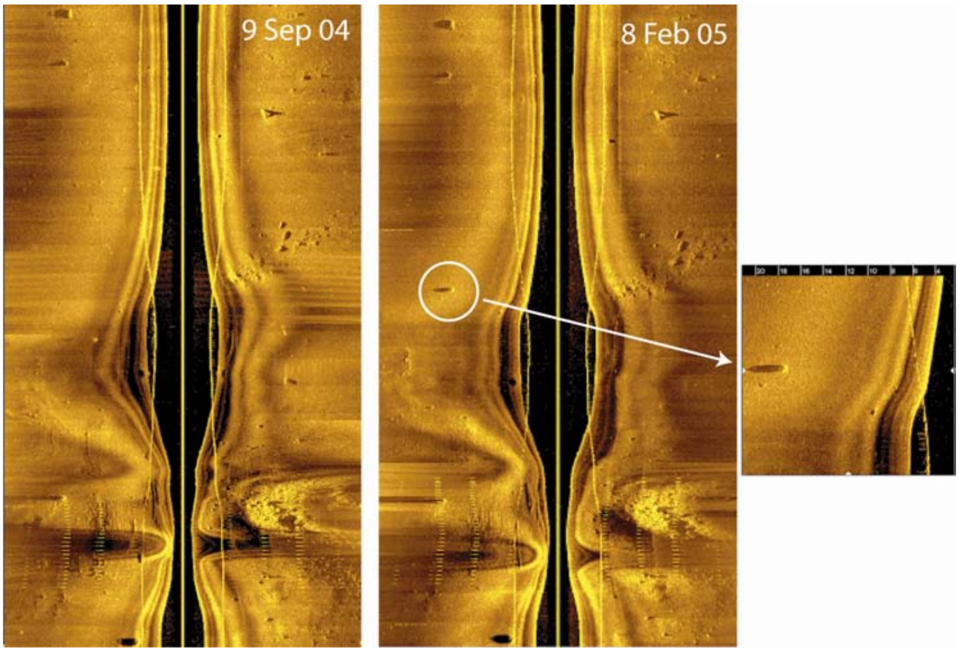

Figure 6 : In highly cluttered areas repeated surveys can help identifying new targets

4 Conclusions

The successful trials in the ports of Strenraer [3], La Spezia [Rothenbach 4], Rotterdam [5] and Olpenitz [7] allowed the following conclusions to be drawn:

- Commercially available AUVs such as the REMUS can perform efficient surveys in ports and harbours to detect and classify objects on the seafloor. When used in conjunction with existing assets (MCMV and EOD divers), the AUVs can significantly speed up clearance operations. A gain of at least one order of magnitude in time was demonstrated in all experiments.
- REMUS missions can be easily planned and executed to achieve the high positioning accuracy required for mine re-acquisition by divers. However, confined areas may impose restrictions on the optimal placing of LBL transponders and may impact the navigational accuracy of the REMUS. In addition, obstacles and obstructions (e.g. piers, navigation buoys, moorings, etc) may limit the manoeuvres of the vehicle.
- Other navigation techniques (e.g. GPS and INS) should be used to overcome the problems experienced with LBL transponders in confined spaces.
- Partially buried mines are difficult to classify with high frequency side-scan sonar. However, they are detectable and require special considerations: for example, multiple sonar images at different aspects can improve the classification performance. Completely buried mines would be undetectable with current high frequency sonars.

- Improvised explosive devices (IED) are difficult to detect, especially in a high clutter environment, typical of commercial ports
- Precise vehicle navigation is required in highly cluttered areas in order to group correctly images of the same target collected at different aspects.
- Surveys of sensitive areas in ports and harbours should be conducted regularly and contact information should be kept in precisely geo-referenced databases to be used in conjunction with automatic change detection algorithms. Consideration must be given to the periodic removal of debris and objects on the seabed.
- Future studies should focus on sensors to classify mines buried in soft mud. These could include low frequency sonar that can penetrate the sediment, magnetic sensors that can detect metallic components of the mines and chemical sniffers that can detect traces of explosives.

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