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AUV Technology for shallow water MCM reconnaissance

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ABSTRACT
The ability to perform MCM reconnaissance missions in shallow water is important in both expeditionary MCM and in the protection of ports against maritime improvised explosive devices (MIEDs). For many years AUV systems have been viewed as offering a suitable platform for performing the required reconnaissance tasks. NURC, amongst others has been investigating system designs for meeting this need. This has included: experimentation efforts (in collaboration with NATO partners) to test the performance of existing systems and identify technological limitations; and research efforts to develop the technology necessary to better meet the military need.

This paper describes the results of these programmes, examining the extent to which current technology meets the requirement and providing a look ahead to the ongoing NURC development work and how it is addressing an integrated system for current and future shallow water reconnaissance operations.

INTRODUCTION

NURC has been involved in the development, testing and assessment of unmanned underwater system technology for MCM and port protection roles over many years. Recently this work has been concentrated in two main areas: an experimentation programme [1,2] for the testing and evaluation of AUVs; and a research and development programme focussing primarily on the development of enhanced sensors, specifically synthetic aperture sonar [3,4,5]. This paper provides a brief summary of the results from these programmes and uses insights gained from this work to generate a requirement for an AUV system which would be suitable for expeditionary MCM and port protection operations.

The performance of current technology is compared against this requirement to highlight where performance needs are met and where further development work should be concentrated.

The paper completes with a description of how the NURC Research and development programme has evolved to meet these emerging requirements.

COMPLETED WORK

As stated, the work completed to date within NURC in the area of AUVs for MCM reconnaissance can be divided into two: experimentation; and research and development.

The experimentation programme began at the end of 2003 and initially focussed around the use of COTS AUV systems for port protection. This programme of work was expanded towards the end of 2004 to include testing of COTS systems in a more generic shallow water MCM role with the programme completing in 2006. During this period a series of trials were completed as follow:

- **Rotterdam Port protection trial.** This trial assessed the ability of COTS AUVs to examine harbour basins and inner port channel areas.
- **NL03 Loch Ryan trial**. Examined the use of the NURC Ocean Explorer and REMUS vehicles to survey a 3km channel using sidescan sonars.
- **MX1**. Addressed port protection type operations in a highly cluttered environment. The trial was performed in Olpenitz using the REMUS AUV.
- **MX2.** Port protection experimentation trials performed in La Spezia using the REMUS AUV, PLUTO mine disposal vehicle and an EOD dive team.
- **MX3**. A major trial off the coast of Italy near La Spezia involving 6 different types of AUV (SeaOtter Mk1, HUGIN 1000, REMUS-100, REMUS-600, Gavia and Bluefin-9). The trial examined system performance for a range of different operations including exploratory and percentage clearance operations.
- **MX4**. Port protection type operations performed with the REMUS vehicles in the Black sea.
- **MX5**. MCM operations performed with the RMEUS vehicles in combination with other MCM forces in the Baltic as part of Operation Open Spirit.

Overall the series of experiments gathered valuable data on all aspects of AUV performance in a broad range of different conditions. Specific analysis has been performed to examine: the ability of sensors to find targets and reject clutter; the accuracy and robustness of the vehicle navigation systems; the stability in different conditions; and the data processing and networking capabilities.

In addition to experimentation, NURC have an ongoing programme of MCM research. This programme addresses the full breadth of MCM capability including basic sonar models, mine jamming / sweeping and hunting systems.

Figure 1; The HUGIN system onboard CRV LEONARDO during SWIFT

The areas of research and development which are of particular relevance to MCM AUVs are:

- the development and analysis of synthetic aperture sonar (SAS);
- performance evaluation of ATR and the development of ATR techniques;
- planning and evaluation tools for MCM operations with sidescan sonars.

Specific achievements have included:

- understanding the implications of multi-path effects for SAS [5];
- application of high performance interferometric algorithms to a SAS;
- specification of a shallow water interferometric SAS [5];
- development of a theoretical basis for setting an upper bound on classifier performance based on sensor characteristics [6];
- sea trials to obtain test data for ATR systems:
  - CITADEL (which generated comprehensive multi-aspect target sets using the Canadian DORADO system in collaboration with France and Canada);
  - SWIFT (worked with the HUGIN (figure 1) and REMUS vehicle (figure 2) systems to gather multi-range, multi-aspect sonar data in several different environments);
  - COLOSSUS (generated high resolution SAS data using the MUSCLE AUV system equipped).
- the creation of a planning and evaluation tool which uses a mixture of recorded data and simulation techniques to evaluate the performance of missions performed with sidescan sonar.

Experience gained from the experimentation and research programmes has helped to deliver improved AUV solutions, whilst also supporting the provision of a better understanding of vehicle system requirements.

THE REQUIREMENT

The modern MCM requirement is driven by two key operational requirements, namely:

- the need to be able to perform more expeditionary type operations across the world;
- to protect home ports and harbours against the effects of potential terrorist acts.

The effect of these two different roles on the system requirement for a future MCM AUV system is examined here for six key technology areas as follows:

- endurance;
- sensing;
- navigation accuracy;
- stability;
- C4I;
- launch and recovery.

Endurance

MCM reconnaissance performed in support of both expeditionary MCM and port protection operations is similar in that the prime purpose is to find safe areas / routes and to support the creation of safe areas/routes when mines (or MIEDs) have been laid. The US UUV Master Plan [7] states that, for expeditionary type operations, MCM reconnaissance may need to be performed for areas of between 100 and 900 Nm^2 (340 to 3100 km^2). This covers 'sea-lines of communication

(SLOCs), offshore Fleet Operating Areas (e.g., Carrier Operating Areas (COAs), Amphibious Operating Areas (AOAs)), and Littoral Penetration Areas'. Whilst this provides an overall requirement, operations over smaller areas are also likely to be beneficial. Too huge to mean much. Concentrate just on the up-threat aspects where the discreet nature of AUVs would be of greatest benefit, namely the clearance of the 'littoral penetration' area. In this case the search requirement can be reduced to nearer 32km^2 as follows:

- a transit lane (potentially up to 20km long and up to 1km in width);
- an anchorage area (at least 2km x 2km);
- 4 boat lanes (up to 5km long by 500m wide).

The area coverage for port protection missions will also be highly variable, depending on the size of the port. However, coverage areas in the region of 30 to 70km^2 would appear suitable (assuming that clearance is focussed around key areas and not the entire harbour), depending on the size of the port and the length of the required approach lane.

Figure 2; Deployment of REMUS vehicle during SWIFT

Of the two missions, the expeditionary MCM mission is the one which most drives the endurance requirement as it includes the need to be able to perform a transit into an area and still achieve a useful search after this has been completed, whilst for port protection it is likely to be possible to launch and recover the vehicle from close to the required area of interest. The minimum endurance requirement is therefore set as an ability to perform at least 40km of transit and perform a survey of 4km^2. The specific endurance required by a vehicle will obviously be driven by the performance of the sensor fit and the number of vehicles deployed. However, for a search lane spacing of 100m, this would equate to an endurance of approximately 12h, including time for vehicle launch and recovery.

Sensing

The sensing requirement is driven by the type of object that needs to be successfully detected and classified. Assuming that a successful MIED will need to be at least as large as a small mine to achieve the necessary level of effect suggests that the MCM sensor needs the ability to detect and classify objects as small as 0.5m. This performance will need to be maintained in a range of different environments, from flat sandy bottoms, through to soft mud.

Environmental effects are likely to be most severe in ports and harbours due to: the potential for greater levels of manmade clutter (due to long usage and high shipping density); and the size / shape of the port preventing more difficult areas from simply being avoided. However, these environmental effects could in part be overcome by using route survey / change detection based techniques which would be unavailable to expeditionary operations. This would enable the sensing requirement to be limited to detecting differences rather than providing a full level of classification.

The sensing operations are likely to have to be completed in the full range of water depths (8-200m for ports (including approach lanes) and 3-200m for expeditionary operations) and in high levels of turbidity (coastal waters).

Navigation

The navigation requirement is driven by two key factors as follow:

- the need to deliver location information which is of sufficient accuracy to allow targets to be safely avoided or quickly relocated and removed;
- the need to ensure that the vehicle avoids known hazards (such as dock walls).

It is generally accepted that, the error in the position of a seabed object should be less than 10m, with this distance being driven by the capability of mine-disposal systems (divers or vehicles) to quickly relocate the object.

With most search sensors having a range of at least 30m, there should be no need for a vehicle trajectory to be programmed to lie within 20m of a known obstruction (sensor positioning errors must be less than the required relocation accuracy) so the dominant requirement is the need for a 10m relocation accuracy.

The accuracy should be maintained for a distance of at least 2km (enabling the vehicle to search along the full length of a 2km box without surfacing). Ideally the vehicle should be able to remain underwater for the entire mission duration to reduce the collision risk.

Where change detection is being used, or where multi-look data is being combined to better classify a target, then an accuracy of +/-0.5m is necessary to ensure correct data matching.

Stability

The stability requirement is driven primarily by the capability of the sensors and the need to deliver high quality sensing data and as such it can only be estimated on a case-by-case basis. However, the range of conditions under which the AUV would need to maintain a stable operation can be identified as follows:

- currents of up to 3kt (although higher currents may well be encountered, it is likely that an AUV system would be able to avoid problems areas at the times when currents are highest);
- changes in salinity (especially in ports and harbours where there river outflow and rain run-off is likely).

C4I

The C4I elements of an MCM reconnaissance AUV have to meet several important requirements. The most basic need is for the vehicle to be able to deliver the necessary mission information back to the operator. This should include:

- target finds and locations;
- bottom types and maps;
- other relevant environmental information (such as sound velocity profile / currents etc.);
- a measure of search performance.

For the system to support effective networked operations this information is likely to have to be delivered in mission, within the constraints of the available communications system [8].

In addition to delivering the necessary information in-mission, the C4I system must also enable missions to be quickly and effectively programmed, supporting robust AUV performance within the expected and encountered environment. It should also be possible for plans to be easily updated in response to changing operational requirements or to differences in the perceived environment.

Launch and recovery

Launch and recovery (figure 3) is a key element of any AUV operation. Any launch and recovery operation should enable vehicles to be recovered during both daylight and night time hours and should maintain performance in a broad range of different sea states (particularly for recovery where local changes in the weather may lead to a degradation in conditions by the end of a long mission).

It is therefore proposed that the launch and recovery requirement is set to enable day and night operations up to sea state 4.

Figure 3; Launch of the MUSCLE AUV from CRV Leonardo in May 2006

AUV TECHNOLOGY ANALYSIS

The results of the NURC testing and development work have been used to analyse the extent to which current (and near-term future) technology is able to meet operational needs for each of the key requirement areas. The analysis has also been expanded to identify where there are existing technology gaps and where there is a need for further trials data to be gathered to provide a definitive analysis.

Endurance

A lack of endurance always used to be the main limitation for AUV systems. The advent of the Lithium-Ion and Lithium-Polymer batteries significantly reduced this problem. Delivering 5-8 times more energy than the equivalent mass of lead acid batteries, AUVs are now achieving endurance levels in the region of 12h (depending on sensor fit). At present most systems are not used to deliver this full capability as the method of operation (and probably system confidence) are leading to much shorter missions being used. However, with very long (36h+) missions being delivered within the oil industry it would seem only a matter of time and experience before similar duration MCM missions are performed.

Although Lithium battery technology has delivered the necessary endurance, there are still reservations, mainly in terms of longevity. Whilst far less sensitive to the charge / discharge regime than NiCAD batteries, lithium batteries do age due to the electrolyte slowly dissolving the positive plate [9]. This causes an increase in the internal resistance of the battery and leads to a permanent loss in the amount of energy which can be delivered. The severity depends on storage conditions (mainly temperature and charge level) and can vary from as little as 2% per year to as much as 65% [9].

Overall AUV endurance has reached a suitable level for MCM reconnaissance type operations to be performed, provided batteries are properly cared for and replaced. Further improvements in energy storage technology would still, obviously, be of benefit, both in terms of greater endurance and reduced system mass and size.

Sensors

The main technology deployed on MCM AUV systems is sidescan sonar, although side-looking synthetic aperture sonar (SAS) is also becoming more common. Tests with the 900/1800kHz Marinesonics sidescan fitted to NURC's REMUS vehicles have demonstrated the ability of current sensing technology to produce good images of seabed targets, as shown in figure 4.

These results have been confirmed with tests using other AUVs fitted with a range of different sensor types.

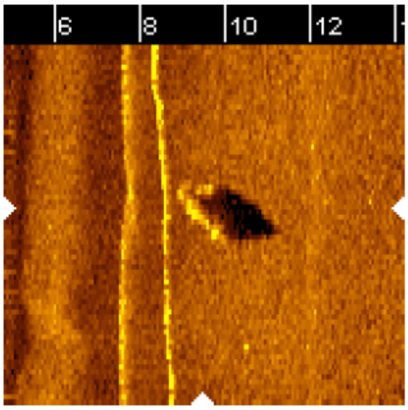

Figure 4; REMUS image of a cylindrical target at a range of 10m

However, as the size of the object being viewed is reduced, the quality of the image can rapidly degrade, as shown in figures 5 and 6.

The first of these figures shows a half buried cylinder viewed from broadside. Whilst the highlight is relatively unaffected, the quality of the shadow is significantly reduced.

If the viewing angle is then changed to end-fire, then a further reduction in performance can be seen as the size of the target is further reduced. In this case, both highlight and shadow are affected and the resulting image becomes increasingly difficult to correctly classify, even though the target is large.

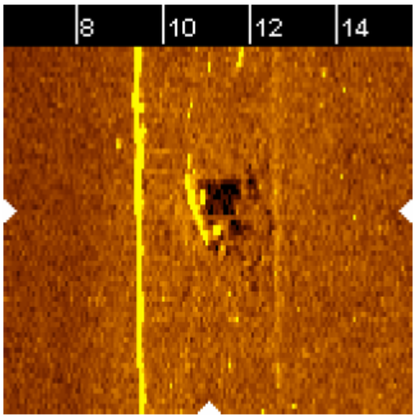

Figure 5; REMUS image of a half buried cylindrical target at a range of 11m

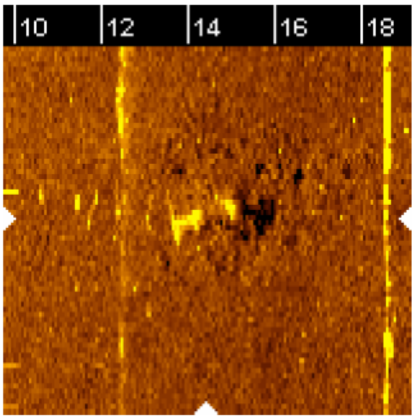

Figure 6; REMUS image of a half buried cylindrical (endfire) target at a range of 14m

Attempts have been made to reduce these effects by increasing the resolution of the sensing system, either by the use of increasing sensor frequency (such as the 1800kHz system from MarineSonics), or by increasing the array length.

Whilst both of these work well at shorter ranges, performance is still range limited, as shown by the sequence of images in figures 7, 8 and 9 where the same target is viewed at several different ranges.

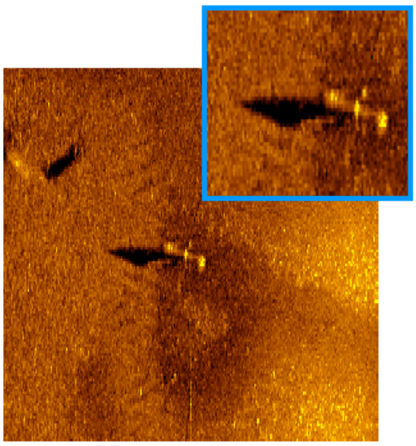

Figure 7; REMUS image of a cylindrical target at a range of 20m (with zoomed inset)

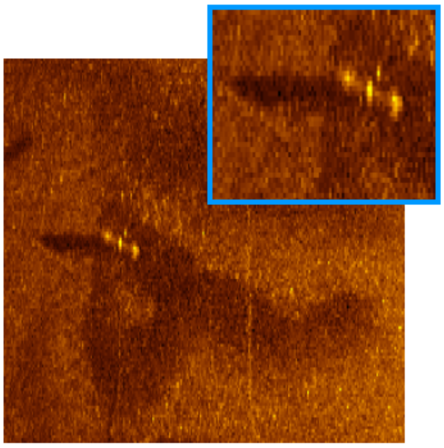

Figure 8; REMUS image of a cylindrical target at a range of 30m (with zoomed inset)

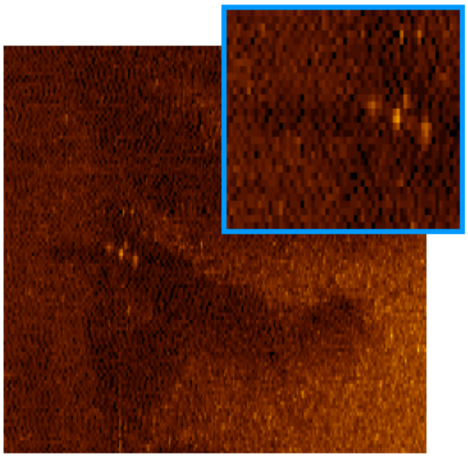

Figure 9; REMUS image of a cylindrical target at a range of 40m (with zoomed inset)

The images clearly demonstrate the problem of reducing resolution and contrast which occur with conventional systems.

For the last 10 years NURC (amongst others) has been researching the used of synthetic aperture sonar (SAS) to overcome these effects. The NURC research has resulted in a system specifically designed for achieving long range (>150m) even in shallow waters [5].

A realisation of this system has been produced by Thales Underwater Systems as the MUSCLE AUV.

Images obtained from the MUSCLE SAS are provided at figures 10 to 12[1].

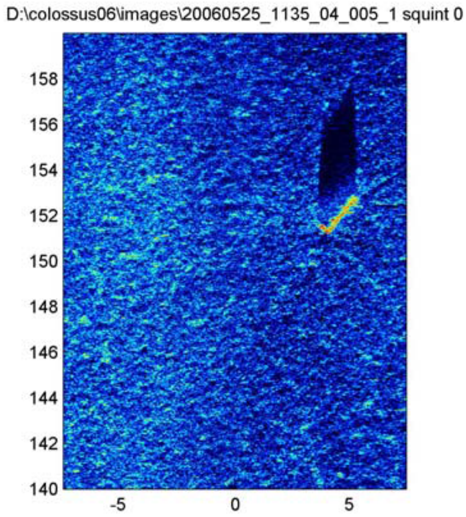

Figure 10; MUSCLE SAS image of a cylinder at a range of 152m in 20m water depth

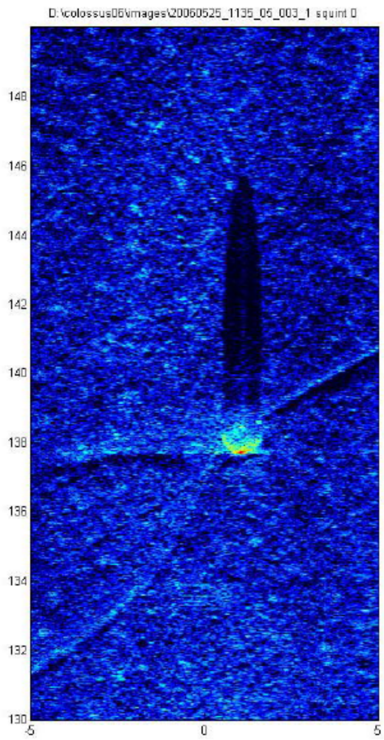

Figure 11; MUSCLE SAS image of a sphere at a range of 138m in 20m water depth

[1] The sonar data for the MUSCLE AUV system shown in figures 10 to 12 is the joint property of NURC and Thales Underwater Systems

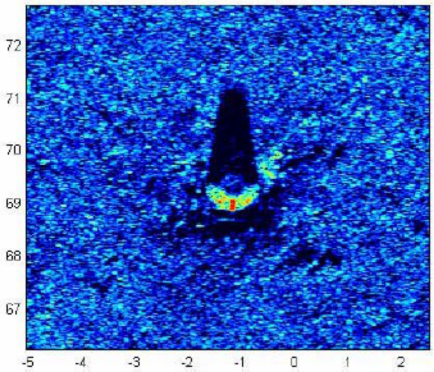

Figure 12; MUSCLE SAS image of a truncated cone shape at a range of 69m in 20m water depth

For this system both the echo resolution and contrast are maintained at all ranges (shadow resolution falls with range due to noise effects) until the sonar noise starts to dominate.

This increased level of performance is of course not achieved for free. Greater levels of processing are required to generate the SAS images and the overall sonar system is significantly more complex, power hungry and expensive than sidescan equivalents (especially the small and relatively cheap REMUS system which was used to produce the sonar images presented earlier in this paper).

The theoretical resolution of the MUSCLE SAS and approximations of the 900 and 1800kHz sidescan sonars (based on a single, unfocussed element) from the NURC's REMUS systems have been developed as shown in figure 13.

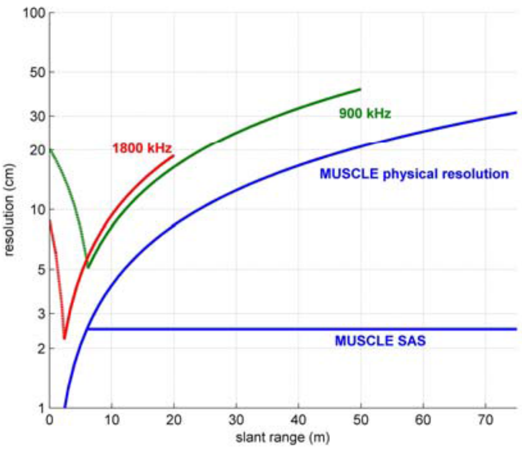

Figure 13; Theoretical comparison of the MUSCLE SAS resolution with that of approximations of the 900 / 1800kHz sonar mounted on NURC's REMUS vehicles

It can be seen that the use of synthetic aperture should provide significantly better resolution than the high resolution sidescan sensors at all but the closest ranges, with the SAS theoretically capable of achieving a resolution of 25mm over the entire effective range. In practice images produced to date have provided a 50mm along track and 16mm across track resolution, with further improvements being expected.

If we apply either the rate distortion bound [6] or the Johnson criteria [10] to the required 0.5m target, then we can show that an effective resolution of 62.5mm would be required to support the correct classification the target (although this will also be affected by contrast). The 50mm resolution already achieved by the SAS is therefore already likely to be sufficient (especially with the level of contrast being achieved). The theoretically modelled 900kHz and 1800kHz systems should similarly support a high level of classification, but only over short ranges (less than 10m).

In summary, more modern sensors are delivering enhancements in both contrast and resolution. This results in better defined images of large targets and the ability to adequately image smaller objects of interest, with sidescan and SAS delivering images at a resolution that is likely to support effective target classification. Modern SAS in particular are demonstrating levels of performance which should offer a high level of operational capability.

Navigation

Current AUV navigation systems can broadly be divided down into two main types, namely:

- aided inertial navigation systems (AINS)
- dead reckoning combined with acoustic long baseline (LBL) navigation.

NURC has examined the performance of these different types of navigation system has been examined over several years using three basic techniques:

- measuring the size of the 'jump' between predicted position and GPS position when the vehicle returns to the surface (easy to measure but measurement affected by GPS error);
- measuring the error between detected target location and laid target location (requires precise deployment of targets, ideally utilising a combined approach based on RTK-GPS and acoustic positioning);
- measuring the spread in location positions for multiple passes over the same set of targets.

The first two techniques provide a measure of absolute navigation accuracy, but are affected by vehicle GPS error and the target deployment accuracy respectively. The third technique only provides a measure of relative accuracy / repeatability, but is not susceptible to GPS or target deployment accuracy effects.

Tests on AINS based systems have included an assessment of systems based around 0.1 to 0.01deg/hr grade inertial units. The performance of these units have been examined for both long (up to 15km) straight-line transits and ladder searches within a more constrained area. In all cases tests were performed in shallow water where DVL bottom lock was maintained at all times.

AINS based around high grade inertial units have been observed to achieve navigation errors of less than 0.2% of distance travelled during long transits (equating to position errors of less than 20m after 10000m underwater). Errors during ladder searches are lower, with an error growth of typically less than 0.02% of distance travelled.

A typical target relocation plot for a multi-lane ladder search is provided at figure 14. The left hand plot shows the error with respect to the target deployment position, whilst the right hand plot shows the error with respect to the mean detected position. The data shown on the chart was gathered from two different missions (each is plotted in a different colour) and clearly shows both the low drift rate from the small spread of detections during the mission (the data points from each separate survey were gathered over the period of 2 – 3h) and the effects of the initial GPS fix in terms of the difference in average location between the two groups (approximately 3m for the example given).

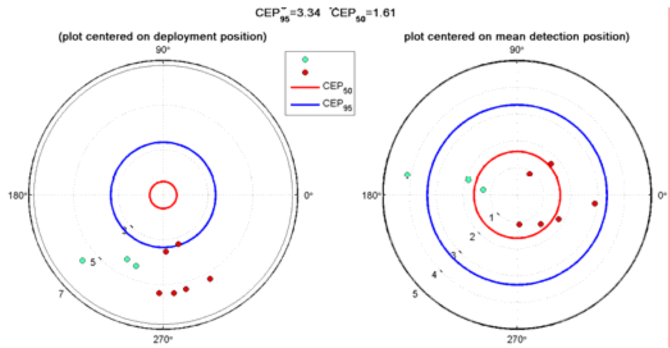

Figure 14; High grade AINS target relocation accuracy

A similar plot is obtained from systems based around 0.1deg/hr, as shown in figure 15. Here the data was obtained from a single mission, so the spread in location is caused purely by the drift rate of the inertial system. Analysis indicated that the drift rate of the AINS based around the lower grade inertial unit was approximately 0.2% of distance travelled.

Whilst the rate of error growth is greater than that of the higher grade unit, the accuracy levels are still good, with errors of less than 4m for a mission length of ~45minutes.

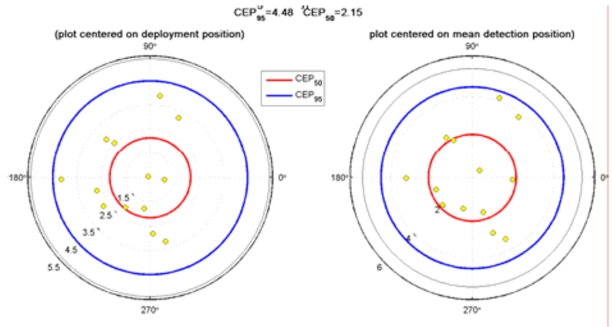

Figure 15; Lower grade AINS target relocation accuracy

Assessment of the performance of DR + LBL based navigation system was constrained to ladder-type searches within a constrained area, since the finite range of the LBL beacons makes this navigation system less suited to long transits. Figure 16 shows the typical relocation performance of the system. It can be seen that relocations can be consistently achieved to within 10m, although there are occasionally outliers.

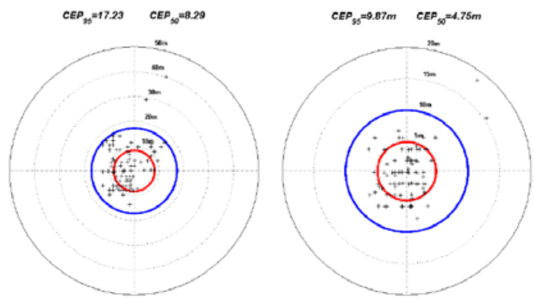

Figure 16; DR + LBL target relocation accuracy

The performance of this type of navigation system is however sensitive to the environment. For example, both bathymetry and sound velocity profile (or combinations of the two) can result in significantly greater navigation errors by interrupting the acoustic path between the vehicle and one or both transponders. Experience has shown that when communications with both transponders is lost then the location error can exceed 30m.

Navigation solutions are therefore available and effective for shallow water MCM operations where DVL bottom lock can be achieved from the surface and (for LBL based systems) the beacons can be deployed reasonably effectively.

Both systems are able to support the required 10m survey accuracy requirement within a confined area. The AINS system can also meet the transit requirement (with only a small number of GPS fixes).

Neither system is able to reliably produce data which can be used for direct change detection (i.e. an accuracy of +/-0.5m). NURC has recently developed a fast contact matching [11] which addresses this deficit by using the contact location information to align data from different surveys. This algorithm is best suited to the correction of inertial data (where it has been shown to reduce relative error to less than 0.5m) but can also be used for DR + LBL data.

A properly integrated AINS provides a reliable, self contained navigation capability. DR + LBL based navigation systems are cheaper and produce an effective level of performance when properly deployed for the environment. The system is not however as flexible as the AINS systems as it requires the deployment of supporting beacons.

Stability

The range of typical stability levels for AUV systems is provided in figures 17 and 18 for heading and roll performance respectively. Each curve represents a different AUV.

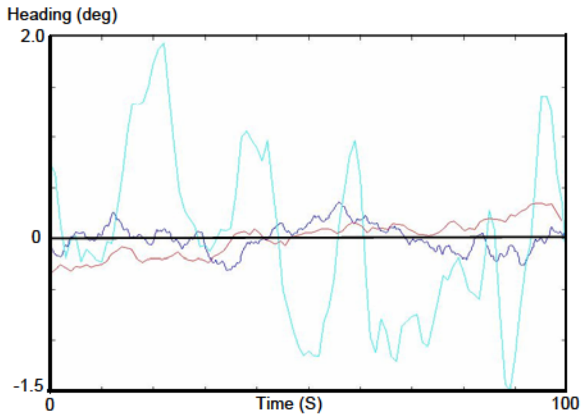

Figure 17; Heading performance for different AUV systems

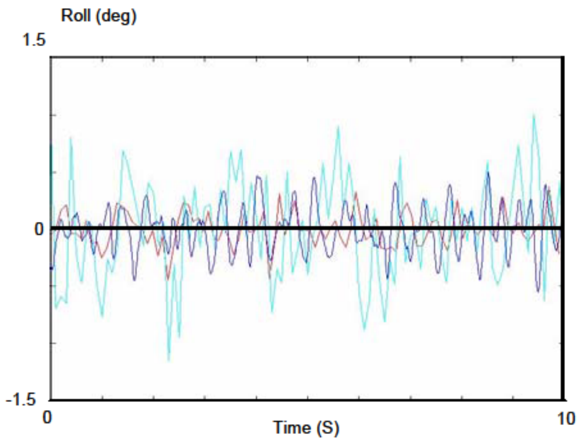

Figure 18; Roll performance of different AUV systems

It can be seen that there is significant variation between systems. This is especially true for heading performance where the standard deviation can vary between 0.2 and 1.4 degrees depending upon the system.

Changes in the environment, especially bottom roughness, waves and local currents have been seen to have some affects on stability. However, these have been difficult to quantify as the environment has been relatively benign in even the more challenging tests.

In general, provided the AUV is properly trimmed for the conditions and the control system has been adequately tuned, then current systems appear to be able to provide adequate levels of stability. Further work is required to confirm performance in more challenging conditions.

C4I

The majority of current MCM AUV systems deliver mission data only after the vehicle has been recovered and data downloaded from the disk. This is primarily due to a lack of effective automated processing which performs effectively onboard the vehicle. This limitation is starting to be overcome, with some systems (notably REMUS and Gambit [12]) including on-board ATR which enables contact reports to be communicated in-mission. Whilst high levels of performance can be achieved by ATR (generally achieved where the test conditions are a close analogue to those present when ATR training data was collected), the performance often degrades with changing environment or even aspect [13], as shown in figure 19.

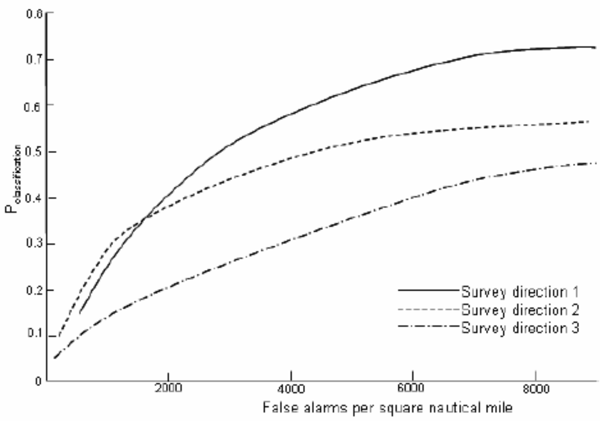

Figure 19; The effects of heading performance on a simple classifier

Without a truly robust and effective ATR capability the information transmitted by the AUV is therefore of limited benefit. Without robustness (or at least a measure of quality), ATR results cannot be trusted and will need to be subject to operator interpretation before they are used. This could potentially be overcome by using adaptive ATR that support in mission re-training of the ATR, possibly by sending targeted snapshots back to an operator for confirmatory classification.

The situation is similar with automatic bottom segmentation / classification systems. Techniques exist, but are applied in post processing and often require a level of operator involvement.

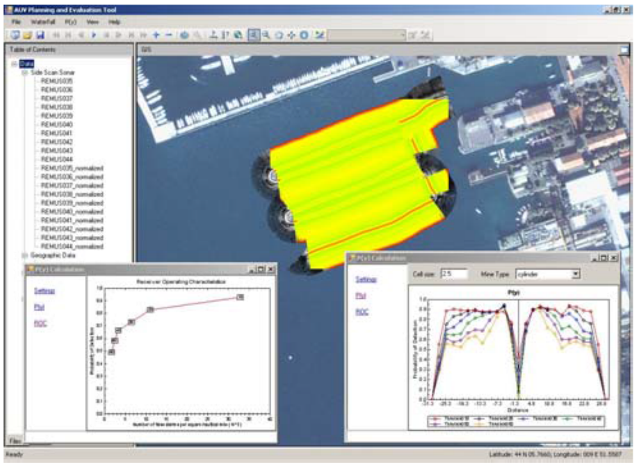

Figure 20; The NURC Planning and Evaluation tool

The final area of information delivery was the measurement of AUV search performance. NURC has recently produced the first release of a planning and evaluation tool (PET) (see figure 20) to fulfil this need [13,14]. This tool uses a novel approach for the evaluation of missions that is based on recorded side-scan sonar data. The tool can now be used to generate ROC curves, P(y) curves, coverage maps, clearance predictions and optimised AUV tracks. Further development and testing is still required, however the tool has the potential to deliver the required evaluation of search performance.

AUV mission planning software has developed noticeably in recent years. At present missions are effectively pre-programmed, with the vehicle track being fully planned prior to launch of the system.

Some systems (again notably REMUS and Gambit [12]) include a level of on-board re-planning that enables the system to automatically inspect targets detected during the mission, and it is possible to perform simple re-direction of some vehicles via a communications link in mission. At present however, further work will be required before a fully adaptive mission planning capability is available that enables vehicles to react to both target finds and alterations in the environment. Further extension will be required to cover automated planning / re-planning for vehicle groups.

Overall the currently available level of C4I is sufficient to support single vehicle operations, including some in-mission adaptation. Further develops are however required to provide a truly effective networked capability.

Launch and recovery

Trials with different AUVs from the Centre Research Vessels has demonstrated how difficult launch and recovery can be as sea state increases. Work is ongoing within industry to develop AUV launch and recovery mechanisms that can be integrated onto different vessels. Most systems (including HUGIN, GEOSUB and REMUS 6000) are using floats released from the vehicle to enable a line to be connected between vehicle and recovering ship, with the vehicle then being lifted aboard using either A-frame, crane or ramp. Launch and recovery performance in SS4-5 is claimed, depending upon ship.

The majority of NURC experience has involved small boat work to attach recovery lines, although the SWIFT trial with the HUGIN system demonstrated the benefits and greater robustness provided by the more developed method of recovery, enabling trials to be performed in sea states in which it would have been difficult to recover the vehicle using small boats and the standard NURC crane.

Overall, launch and recovery systems are now being developed that enable operation in more challenging sea states. The suitability of the various techniques to different surface platforms will need to be determined, but, there appears to have been sufficient development of the launch and recovery solutions such that it is likely that appropriate specialised solutions can be produced to meet individual platform integration needs.

DEVELOPMENT REQUIREMENTS

AUVs are meeting many of the requirements set for performing effective mine reconnaissance missions in support of MCM. Further development requirements are mainly concentrated around the related abilities of systems to network effectively and adapt robustly to circumstances. Key elements which need to be addressed to provide this capability are:

- tools to enable mission performance to be understood and reduce data to a level that can be easily transmitted. Three key items:
    - effective ATR that maintains performance in changing environments and against different target types;
    - automatic bottom type evaluation (to support intelligent planning and provide environmental feedback);
    - mission evaluation in order to be able to report achievement against objectives in a manner which can be used by other MCM forces, plus

enable search results to be combined with those from other systems to properly estimate clearance level. Also an essential pre-requisite for in-mission re-planning, as it can enable a vehicle to deliver mission requirements.

- Then need mission specific decision making capability:
    - rapid planning / autonomy that can be used to adapt to conditions, deliver the required mission; adaptive ATR etc.
    - also adaptive planning for strange groups.

NURC is working to better understand the overall scope of the problem and associated solutions. The proposed solution is shown in figure 21.

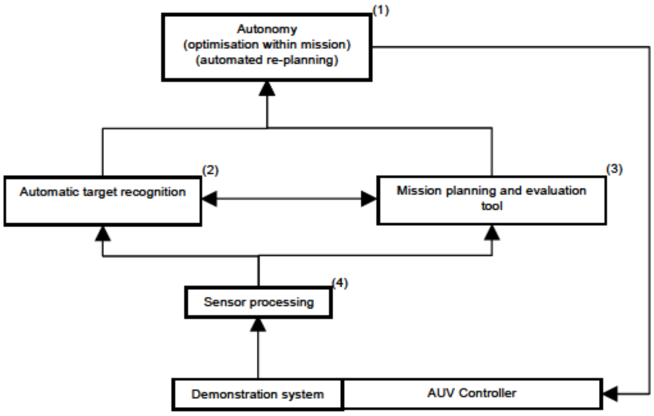

Figure 21; The NURC MCM AUV autonomous control system

It can be seen that there are 4 major processing elements. Firstly, there is the decision making software which is required to support mission planning and re-planning for both single and systems and co-operative groups. This work is particularly addressing technologies which can be used to support groups of dissimilar vehicles.

The second element is ATR which forms a major focus within the current research project. The study is addressing the use and benefits of true high resolution (in both range and azimuth).

Planning and evaluation tool. Measure of performance, plus planning algorithms. A key element. First release out to NATO.

Final area being examined is robust real-time SAS processing. Techniques for real-time sidescan processing have been around for many years. Real time SAS systems are also starting to be produced, however, robust real-time processing for long range high resolution SAS is far less mature. This project has been supporting a range of developments examining both FPGA and PC based technologies and adapting the Centre's expertise in SAS processing software to deliver faster algorithms, with results from these studies becoming available during 2007.

CONCLUSIONS

AUVs are starting to provide a level of capability which can be of benefit to MCM operations. Many of the problems which held back AUV performance in early years have been overcome with current systems delivering ever more robust levels of capability. Developments are still required to improve the automation of the processing chain in order to allow AUVs to deliver their full potential and operate effectively as part of a networked MCM force.

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