High resolution wideband AUV minehunting reconnaissance and surveillance sonar

Introduction

Whilst the final concept of operation employed for AUVs remains uncertain, their central role in the undersea warfare of the 21st century seems guaranteed. Major Research and Development programmes such as the UK Battlespace Access UUV (BAUUV); US Autonomous Operations Future Naval Capability (AOFNC) and NATO SACLANTCEN MCM AUV projects have been initiated to explore the envelope of AUV operational application.

Operational Requirements

Broadly speaking, these programmes have established five major areas of interest:
Reconnaissance (Intelligence, Surveillance, Reconnaissance (ISR), Ocean Survey, etc.)
Search and Survey (Rapid Environmental Assessment (REA), MCM);
Weapons platforms (ASUW, ASW, 3rd party targeting);
Logistic supply and support for special operations; and
Undersea communications and navigation infrastructure.

Understandably the initial emphasis of these programmes has been placed on core vehicle technologies such as energy systems; navigation; autonomous mission management and communications rather than the sonar.

The purpose of this paper is to explore the requirements likely to be placed on the AUV sonar sub-system for the reconnaissance and search survey missions associated with MCM.

Thales Underwater Systems (TUS) has won the majority of worldwide development contracts for state-of-the-art wideband dedicated MCM sonar systems and is currently supplying such systems to the UK, French, Dutch and Belgian Navies. The central requirement of these systems is to successfully detect and classify the latest generation of stealthy low target strength mines laid in high clutter, high noise littoral (10 m -> 100 m depth) water environments.

An identical requirement will be placed on AUVs performing MCM missions with the addition of extending capability into the Very Shallow Water (VSW) and Surf Zone (SZ) regions.

It is largely an accepted fact that the diverse spectrum of AUV mission types will necessitate a mix of AUV platform size and capability. Modularity of sensor package for each platform will ensure mission flexibility.

The diversity of environmental conditions transitioning from Deep Water (DW) through Shallow Water (SW0 to VSW and SZ leads to the difficult issue of whether the MCM problem is tackled by a single vehicle type capable of performing Detection, Classification, Identification and Marking (D,C,I,M) or a counter-measure concept where this functionality is distributed across different vehicle types which are then correspondingly smaller.

The concept of a few MCM vehicle types is attractive from the point of view of ‘mission modularity’ where the MCM AUV force mix may be optimised for the particular emphasis of that mission (i.e. more reconnaissance than intervention, etc.). This concept lends itself to smaller AUVs (< 21”) which in turn lend themselves to operation in the VSW region.

The concept of a single MCM vehicle type capable of performing D, C, I and M is attractive for missions in which the emphasis is usually on full MCM (reconnaissance - > neutralisation) and where the larger (21”), more capable sensor suite can take advantage of a relatively more benign environment such as SW -> DW. This type of sensor suite would be capable of performing high resolution, high area coverage rate bathymetry allowing the AUV to simultaneously fulfill a key battlespace access reconnaissance requirement.

In both cases the varying timelines associated with differing in-stride MCM missions will be met by scaling the numbers of AUVs involved. The clearance of a CVBG operating area may extend to 1000 nm^2 requiring 100+ AUVs for in-stride operation whilst a mine-field may be limited to ‘just’ a few nm^2 requiring far fewer units.

An important focal point for the generation of realistic AUV CONOPS is the transitional route they will take into the Fleet. One particular instance is the way in which they may be used as force multipliers for dedicated MCM assets where the AUV functionality is limited to accurate MCM reconnaissance and Route Survey. The dedicated asset can then identify and neutralise the threat with one-shot wire-guided or autonomous munitions. This CONOP could be used for instance to extend the capability of RN SANDOWN Class MCMVs optimised for DW (80 m +) operations into the SW region.

Common to all these concepts is the need for high performance detection and classification. The requirements this places on the AUV sonar will now be examined.

Key AUV sonar requirements

The key figures-of-merit for MCM will be detection probability; classification probability (low false alarm rate against both ground and in-volume threats) and rate of advance.

Whilst top-end COTS sonar systems have been shown to deliver significant detection capability over limited swathes of ± 75 m (e.g. USN Fleet MCM Exercise Kernel Blitz March 2001) the lack of classification performance and commensurately very high false alarm rate has shown them to be operationally inadequate for full active MCM. It is the operational requirement for low false alarm rate which is likely to be the true discriminator for AUV MCM effectiveness.

Status of key AUV sonar technologies

Many of the key sonar technologies required for successful AUV based MCM are already fairly mature. The high bandwidth transducers, low power miniaturised ASIC receivers and high bandwidth multiple channel signal processing are currently available with relevant form factors. The synthetic aperture processing is at a mature research phase and is being 'fine-tuned' for product specific application. Automatic detection algorithms are available. Automatic classification algorithms are less mature and considered medium risk. Likewise concurrent mapping for long range high accuracy navigation is not yet available and is considered a medium risk.

Benefits of high bandwidth systems

The benefits of high bandwidth systems for new generation dedicated forward looking systems are well known in terms of:

i) the resulting centimetric range resolution – used as the basis for long range echo based classification where synthetic aperture shadow contrast may not be available – and
ii) the excellent reverberation suppression for low target strength detection.

As has been stated previously, detection performance alone is insufficient for effective MCM. It is essential to deliver this performance in parallel with high classification probability for low false alarm rates.

This high performance classification will be provided by synthetic aperture (SA) processing – a research area in which TUS is collaborating with University College London (UCL) – an established source of expertise in the implementation of such techniques to Radar.

The key problem for successful application of SA processing is that relating to sub-wavelength motion compensation of the array. This problem has been solved and demonstrated in both rail and UUV based experiments. The latter refers to a three year collaborative programme involving TUS, DERA (Qinetiq) and BAE SYSTEMS. This programme involved the integration of the TUS wideband sonar onto a torpedo-like vehicle. To our knowledge this is the most capable wideband sonar so far integrated to a UUV.

The key to this success has been a micro-navigation system based on Displaced Phase Centre (DPC) techniques, Image based autofocus and INS phase measurement systems.

The high bandwidths have allowed more accurate micro-navigation through provision of greatly increased numbers of independent samples used within the DPC technique. The high relative bandwidths have also been shown to be a key figure of merit for interferometric SA processing.

Displaced Phase Centre (DPC) SA micro-navigation

The Nyquist spatial sampling criterion dictates the real array used to form the synthetic aperture moves no more than 50% of its length between pings. The DPC technique relies upon the formation of redundant phase centres from ping n to n+1. Cross-correlation of the hydrophone time sequences in this overlap region provides a means for the measurement of along track surge, and across track sway by finding the spatial position of the correlation curve peak and associated range lag respectively.

TUS / UCL have shown this technique to provide extremely accurate micro-navigation for surge and sway errors. Yaw errors may also be extracted but these require higher overlaps still. The main disadvantage is the impact of the spatial oversampling on the rate-of-advance.

Autofocus SA micro-navigation

To maximise the azimuth gain achieved from the SA formation and to improve rate-of-advance, TUS / UCL have concentrated on achieving high performance image based auto-focus. A variety of schemes were investigated but by far the most promising is the Phase Gradient Autofocus (PGA) technique. Further technical details will be discussed in the presentation including the use of PGA on sea-bed scenes where there are no dominant scatterers and targets exhibiting large range migration through multiple range cells.

Figure 1a shows the effects of SA formation in the presence of a small 1 m pitch sinusoidal navigation error (10 mm pk-pk) introduced deterministically during rail based experiments conducted by Qinetiq/GESMA in Brest Harbour during 1999. Figure 1b shows the result of applying the TUS/UCL DPC algorithms to this data set. The focussing results in the clear presence of a spherical and cylindrical target casting well defined shadows. Figure 1c shows the result of applying PGA alone to the data set.

Figure 2 shows a target image from the UUV Pathfinder trial with all combinations of micro-navigation system applied. It is clear that the combination of PGA to the DPC results in enhanced gain. In this instance corresponding to an azimuth resolution gain of around 25.

The ability of the PGA autofocus technique to extract sway and yaw errors is further discussed in the presentation.

Constraints and Design Aims of an AUV MCM Sonar

Size, power and cost are important design drivers for these systems. These must be satisfied whilst delivering the detection and classification performance necessary for effective MCM.

The electrical power constraints will depend upon mission duration, vehicle size and sensor utilization. Typically the aim will be to produce a sonar system including processing requiring less than 300 W.

The array length is a critical design parameter and for synthetic aperture processing defines area coverage rate through the Nyquist sampling criterion.

The number of receiver channels is a linear cost and complexity driver for the sensor. The channel density will determine the azimuth field of view and hence the ultimate effective cross-track resolution of the SA sensor. This resolution will determine the detection and classification probability of the sensor. Larger azimuth fields of view will also be essential for providing multi-aspect images of targets both in shadow and echo features.

High bandwidth is highly desirable for reverberation suppression, high range resolution, accurate in-volume height finding and robust SA micro-navigation. High fractional bandwidth is also desirable for high accuracy bathymetry.

TUS has developed high bandwidth 1-3 composite transducer designs together with high bandwidth, low power, miniaturized ASICS specifically for AUV applications. This technology allows practical design of high channel density, high bandwidth systems. The expertise TUS has acquired in all our current wideband contracts allows for effective re-use of advanced wideband signal and data processing techniques such as CAD and multi-ping integration.

TUS is currently developing AUV sonar sensors based on these wideband technologies capable of delivering high detection and classification performance against VLTS threats with swathes of ± 300 m and resolutions better than (1 cm x 5 cm).

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THALES UNDERWATER SYSTEMS

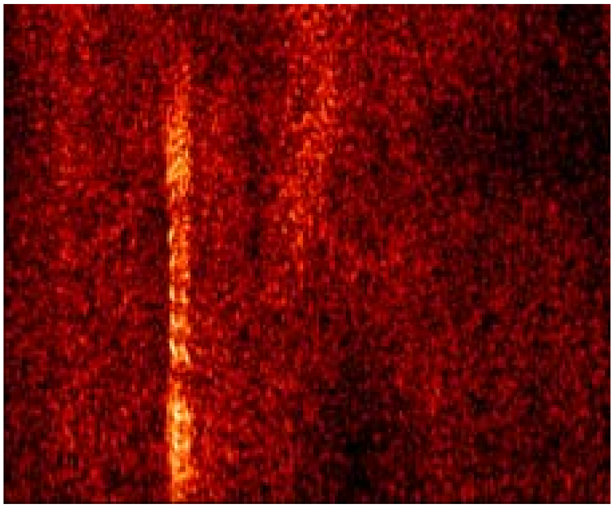

Figure 1a Synthetic Aperture formation in presence of 10 mm pk-pk sinusoidal error (Rail based data courtesy QinetiQ)

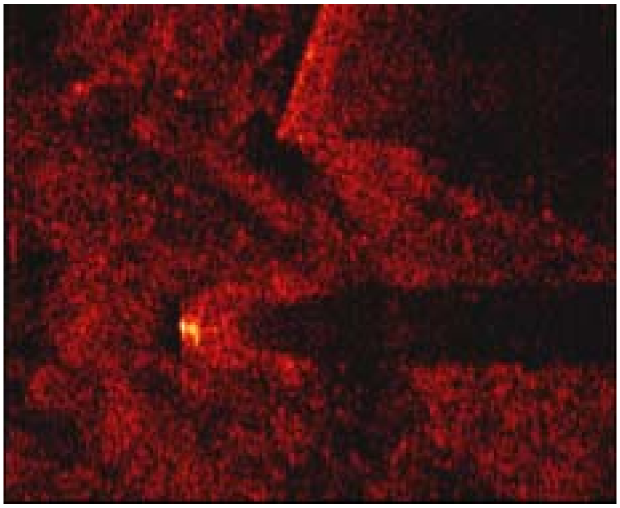

Figure 1b Focussing using DPC

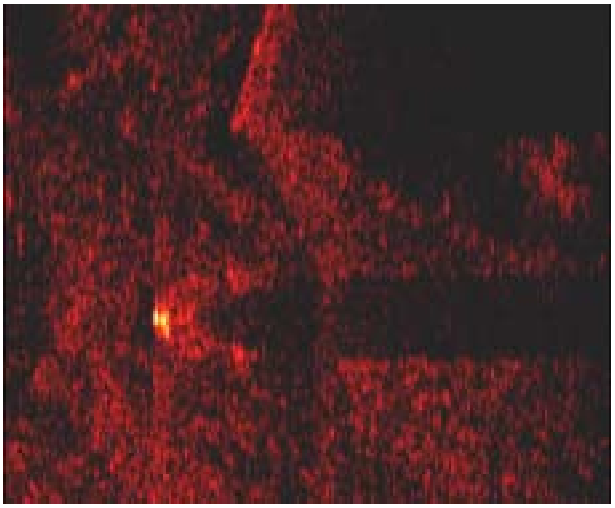

Figure 1c Focussing using PGA

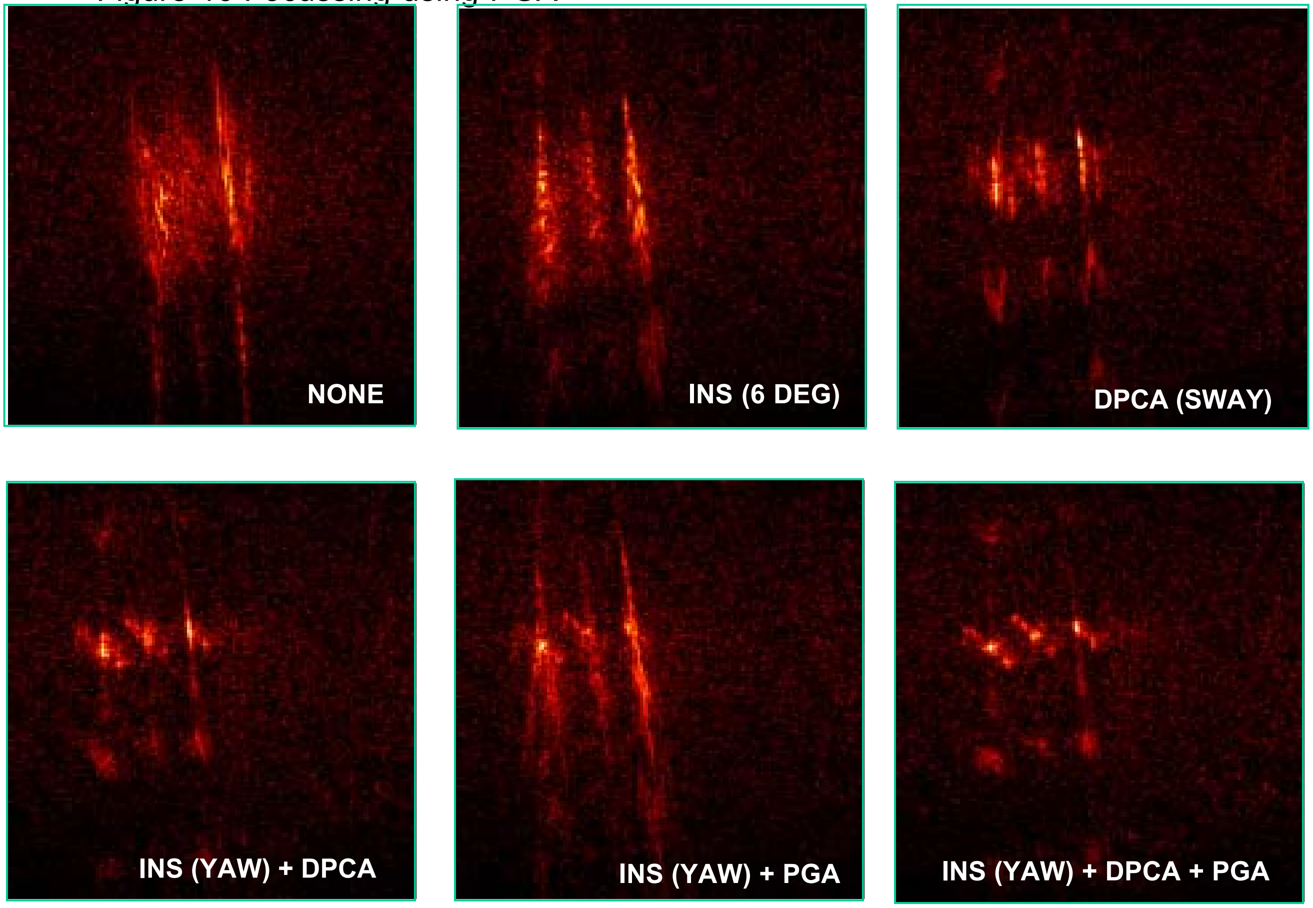

Figure 2 UUV based data set from target at 105 m; SA length = 25 m; Resolution 30 mm