Gambit MCM AUV: Overview and System Performance

J N Morrison, B S Evans, T S James, K D Allen
QinetiQ,
Marine and Acoustics Centre,
Newtons Road,
Weymouth, Dorset, UK
DT2 8UR
jnmorrison@qinetiq.com

Abstract

The Marine and Acoustics Centre (MAC) at QinetiQ Bincleaves is currently pioneering MCM research and development in support of the UK MoD by undertaking a programme of work focussed on developing and demonstrating MCM surveillance and reconnaissance from an AUV. It is recognised that MCM operations impose key demands on vehicle and sensor performance levels, with recent analysis highlighting four main areas of essential capability, which form the main focus of the research programme. These areas are:

- the ability to correctly detect and classify targets;
- the ability to accurately determine the location of targets;
- the ability to cope with unexpected events, obstacles and environments, whilst still delivering the required mission level performance;
- the ability to communicate findings / provide suitable connectivity with other military assets.

To meet these needs the following major technologies have been integrated onto the vehicle platform:

- Wideband high frequency Synthetic aperture sonar (SAS) offering near photographic imagery of the seabed at long ranges;
- Non-acoustic sensors in the form of a 9-axis magnetic gradiometer for buried mine detection;
- Advanced navigation combining high-grade INS and MCM sensor data to improve the accuracy and robustness of the overall navigation solution;
- On-board computer aided detection and classification algorithms to provide a high probability of detection and low false alarm rates;
- 3-dimensional forward looking sonar;
- High data rate acoustic communications optimised for operation in shallow water;
- Vehicle autonomy for sensor optimisation, collision avoidance, communications scheduling and run-time mission re-planning;
- Network enabled capability for inclusion of the threat information into the wider battlespace picture.

Forming part of a joint UK/US collaborative programme these sensors and processing techniques are currently being integrated in a phased approach onto the Gambit AUV, a vehicle based on the Bluefin Odyssey III platform. Supporting the procurement of a future UK MCM capability, the overall aim of the Gambit AUV is to demonstrate the completion of a high performance MCM reconnaissance mission.

This paper will present an overview of vehicle, the key technology areas being addressed in the programme with examples of data gathered during sea trials.

I. INTRODUCTION

Control and denial of the underwater battlespace is one of the key objectives of the Maritime Force Commander. The UK mine warfare capability primary concern is to provide safe waters for military operations (such as amphibious assault and port break-in) by managing the threats posed from sea mines and obstacles.

The provision of timely and accurate MCM reconnaissance information in advance of the main force is seen as an important area of capability and AUV technology is considered to be a key enabler in achieving this objective. AUVs can provide a rapid and covert search and reconnaissance capability across a range of environments, particularly in the littoral. Being part of a dedicated or organic force AUVs could be interoperable with other assets whilst offering the flexibility to be deployed from a variety of sea, land and air platforms. Information gathered from potential missions supports the construction of the MCM tactical picture, facilitating subsequent mine avoidance, clearance, neutralisation or obstacle removal operations.

Although current AUV technology provides a step change in MCM capability over divers, as demonstrated by REMUS in support of operation Iraqi Freedom, the technology consistently suffers from several key capability limitations essential for effective future MCM operations. These include:

- low area search rates;
- high false alarm rates (particularly in harsh environments);
- poor levels of target classification, particularly for low target strength mines;
- insufficient navigation accuracy;
- limited capability to cope with changes in the environment;
- restricted ability to participate in a network enabled capability.

These shortfalls have resulted in surveys conducted by current AUVs identifying a large number of potential targets at a level of navigational accuracy that prevented subsequent accurate relocation and confirmation of whether the contact was truly a target or one of the many false alarms. The data provided by these systems was therefore of limited utility in support of the planning of future military operations and could lead to confusion rather than aiding of the MCM picture.

Current AUVs do, however, provide a suitable base platform for implementation of an MCM AUV system. Consequently, the technical approach being taken by the Gambit programme has been to focus upon the development of an MCM payload, which provides solutions to the key technology risk areas. As a result, the main focus of this work has been placed on the following four main areas:

- high performance sensors and processing algorithms for providing high classification and low false alarm probabilities, whilst supporting large area coverage rates;
- precision underwater navigation solutions;
- communications systems to support connectivity as part of a future network enabled force;
- provision of a true autonomous command control and mission management (CCMM) capability adapted to RN requirements.

Work on the Gambit programme is primarily concerned with de-risking, in a phased approach, these key AUV technologies for MCM, assessing and demonstrating the performance achievable by an MCM AUV and the subsequent impact on operational capability. Forming part of a UK/US collaboration under the ‘UUVs for MCM’ project agreement (PA) the main goal will lead to the ability to undertake a reconnaissance mission with an AUV that will detect, classify and accurately locate the position of mines and underwater obstacles with increased coverage rates.

II. SYSTEM OVERVIEW

The Gambit AUV is a modular platform consisting of a tail section based on a proven Bluefin Odyssey III propulsion unit, a custom designed main payload module containing the MCM sonar and two nose configurations selectable depending on the sensor configuration being evaluated (see Figs. 1 and 2). The vehicle length varies between 3.5 m and 4.5 m respectively for the short and long nose configurations. The shorter nose simply provides a fairing for the basic vehicle, whilst the longer nose supports the integration of forward looking collision avoidance sonar, magnetic gradiometer and low light camera. The overall dry weight is 550 kg.

The tail section primarily contains: the main electronics housing (MEH) containing the main vehicle computer (MVC) which primarily supports dynamic control, guidance and navigation functions; and a power control and conditioning board used to switch on / off the vehicle sensors and the on-board battery supplies. In addition, the MEH is fitted with a baseline navigation suite consisting of a GPS, doppler velocity log (DVL), heading reference system and depth sensor.

The main MCM payload is fitted in the centre section of the vehicle. The main components fitted within this section include: the synthetic aperture sonar (SAS) processor and associated data storage (250 GBytes); the SAS power amplifier and electronics; a payload processor; a high grade inertial navigation system (INS); the magnetic gradiometer processor; a forward looking sonar; a video data recorder; an acoustic modem and power conditioning systems. The sonar transmitter and receivers are rigidly attached to the pressure vessel via a mechanical band clamp to ensure alignment between the sonar and INS.

Fig.1 Gambit (short nose)

Fig.2 Gambit (long nose)

A major driver in the overall layout of the payload section was the requirement to integrate the MCM sonar transmitter and receiver transducers. This is a single sided system (mounted on the port side of Gambit) consisting of a main 1.8m long, 128 channel receive array fitted underneath the vehicle, a wide band transmitter fitted directly above the centre of this receive array and a top interferometric receiver, consisting of 64 channels, for generation of bathymetric data. All arrays are wideband and manufactured from 1:3 ceramic composite.

Battery packs located beneath the pressure vessel provide sufficient power to the payload and vehicle for a 5-hour mission. An ethernet network throughout the vehicle supports distribution of data and precise time.

III. TECHNOLOGY REVIEW

A. Sensors

This programme is addressing the development and integration of two sensor technologies on the Gambit MCM AUV system. The primary sensor being produced is single sided wideband side-looking interferometric sonar. This will utilise both conventional beamforming and echo-classification algorithms as well as a SAS processing capability. The wideband nature of the system provides the required range and range-resolution, whilst the SAS technology offers high levels of azimuth resolution, even at longer ranges thus providing a robust input to image classification algorithms.

Once fully developed the system should be capable of providing a least a 400m swathe (and potentially a 1000m capability) with an across and along track resolution of 2.5cm across the full sonar range. This level of performance would enable a 1000m wide operational channel to be covered in a single pass of the AUV. Further information on the sonar can be found in the paper titled 'Robust wideband synthetic aperture sonar processing on an AUV platform' also being presented at this conference.

The second technology is a 9-axis magnetic gradiometer, see Fig. 3. This consists of an array of 6 fluxgate magnetometers mounted on a rigid 50cm baseline. Through application of novel signal processing and sensor balancing techniques gradient information measured from these sensors can be used to detect, provide relative 3-d positioning information and classify target dipoles within the sensor's field of view in real time. The sonar sensor has the ability to cover wide areas of seabed classifying the majority of targets with a high level of probability. The magnetometer provides an added level of classification, albeit at a much shorter range, which can be effective in areas where the search area has been confined and high clutter or mine burial is likely.

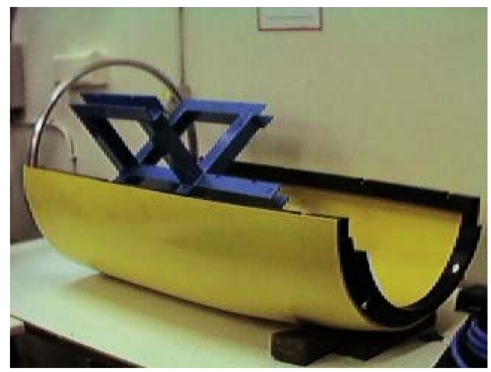

Fig.3 Magnetic gradiometer array

B. Navigation

Precision navigation is essential to AUV reconnaissance and subsequent mine disposal operations, with poor performance making the data gathered from these vehicles unreliable and unsuitable for further exploitation. To date this has been a major shortfall in vehicle technology. This programme is therefore addressing the development and demonstration of navigation technology which:

- minimises reliance on GPS (due to the need for regular surface manoeuvres) and acoustic positioning systems (due to their limited operational range);
- maximises underwater navigation accuracy throughout long missions;
- minimises navigation system cost and power requirements.

AUV navigation is predominantly based around an INS where the performance is characterised by the time dependent drift (normally expressed in m/hr or % distance travelled) in the accuracy of the position estimates it provides. Traditionally INS information is combined with: velocity aiding from the DVL to bound the errors in the horizontal channel; depth information from a pressure sensor to stabilise the vertical channel, and with position resets from either GPS or acoustic positioning systems.

In principle, the INS performance cannot be better than the DVL scale factor (e.g. in the region of 0.2% of distance travelled). It is very difficult to get beyond this unless the INS accelerometer errors can be calibrated out using higher resolution measurements than are achievable with a DVL. With the availability of an advanced MCM payload there is potential to achieve this by aiding the INS with outputs from the sonar, further improving the overall navigation system performance.

This is achieved by utilising information on the successive overlap of sonar pings to continuously measure a line of sight vector to a region of seabed. Correlation techniques are then used to track and measure the displacement of this area of seabed (along and across track) relative to the sonar array. It is estimated that the level of performance achievable with sonar will be significantly greater than the current performance of a DVL, as used on many commercial AUVs, allowing for an overall improvement in navigation performance.

This program is therefore developing filter architectures that will combine data from MCM and INS sensors to produce a high accuracy, robust and autonomous navigation solution. This work will consider a range of inertial sensor grades including low grade, high grade and mirco-engineered machined (MEMs) inertial technology already fitted to Gambit enabling an indicator of price/performance to be obtained.

C. Autonomy

Current AUVs mainly undertake pre-planned missions generated manually by the operator. The level of autonomy is limited to ladder searches based on pre-programmed mission statements (mainly consisting of position, speed, height and depth demands). This gives the system a limited capability to react to changes in the environment or information acquired as the mission progresses.

To be effective in future covert littoral reconnaissance missions, an MCM AUV is likely to require the ability to: react to changes in the environment by adapting and optimising sensor payload performance; adjust behaviours to maximise the prevailing navigation accuracy; adjust mission performance based on the detection and classification of targets; avoid obstacles, whilst maintaining area coverage; adapt search strategy to different seabed types; and schedule communications to meet overall mission requirements.

To date the programme has addressed the development of a future CCMM system and a version of the CCMM specific to MCM mission requirements has been successfully implemented and run in simulation. On-going work is focussed on integrating the CCMM with the low-level software on Gambit, with primary effort concentrated on testing and system validation. In addition, the functionality of CCMM is being increased, initially in simulation, to cover the broader range of MCM requirements, which includes application of computer aided detection/classification (CAD/CAC) algorithms scheduled to be demonstrated towards the end of the research programme.

D. Communications

The ability to exchange information between the AUV and other assets during a mission is an important capability for an MCM vehicle. A high performance data communications link supports the immediate transfer of information on the mine threat back to the command, providing a mechanism for an increase in overall MCM tempo and participation within a network enabled battlespace.

The Gambit project exploits high performance acoustic communications technology pulled through from a corporate research programme (CRP) then developed and successfully demonstrated under an applied research funding (ARP) undertaken by QinetiQ Winfrith. The aims of the research programme are to demonstrate the integration of this system into Gambit and to assess the capability of this technology to support an MCM reconnaissance mission.

The acoustic communications system fitted to the Gambit AUV is optimised for operation in shallow water environments, providing a low data rate bi-directional, and a high data rate up-link between the vehicle and surface vessel. The first of the in-water tests were conducted using the low data rate system with a lower specification transmitter than that integrated onto Gambit. These tests demonstrated reliable data exchange at ranges of up to 6 km in water depths of only 20m. Use of the higher performance transmitter should provide a 20–30% increase in range. On-going work is focussed on the integration of the communications with the CCMM identifying the frequency and nature of the data exchange required for MCM.

This technology has also been applied to rapidly deployed sensors (RDS) providing an underwater network enabled capability, which would provide Gambit with connectivity to the underwater battlespace.

IV. Results

To date the Gambit vehicle has completed over 30 missions local to QinetiQ within Portland Harbour, UK. The completion of these missions has:

- demonstrated the successful integration of the MCM sonar on-board Gambit;
- demonstrated the initial performance of the sonar against various targets and at various operating ranges;
- provided data essential for the development of SAS algorithms;
- provided data essential for the development of navigation solutions combining INS and MCM information;
- provided information on vehicle stability and the resultant impact on MCM sensor performance;
- supported the testing and evaluation of the acoustic communications system at various ranges.

More recently, the vehicle took part within a Joint Maritime Command exercise (JMC) in Loch Ewe, Scotland operating from the Royal Navy MCM vessel HMS Penzance, Fig. 4. The aims of this trial were to evaluate the performance of key vehicle sub-systems and sensors while exposing this type of system to the Navy. The trial was a success with a number of missions conducted from Penzance against a target minefield. The key achievements for the trial include:

- first complete operation of an AUV from an HM Ship;
- completion of high quality MCM reconnaissance missions;
- demonstration of high quality SAS images providing classification information which negated the need for further inspection (see Figs. 5 and 6);
- used automatic mission planning software;

- overall the Gambit system started to demonstrate the potential of future MCM AUV systems in a military environment.

Fig.4 Gambit Launch from RN ship

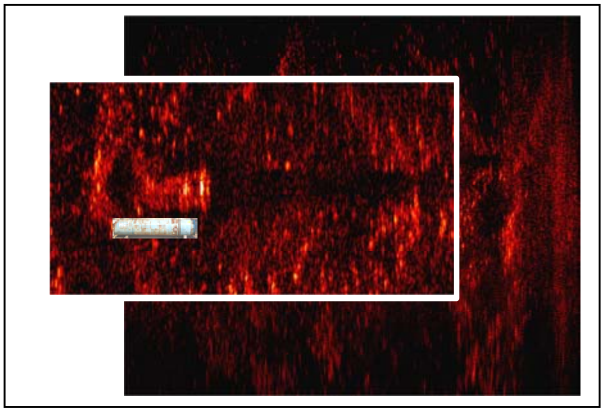

Fig. 5 AMk 12 mine at 80m range

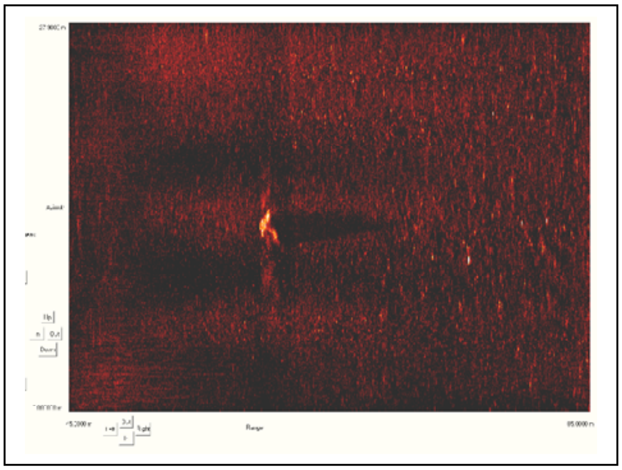

Fig.6. Rock target at 75m range

V. Conclusions

This programme of research has turned a commercial-off-the-shelf (COTS) vehicle into the basis of a highly capable MCM AUV, Gambit. This capability has been recently demonstrated by the successful operation of the vehicle from a Royal Navy MCM vessel acquiring high quality SAS images over a target minefield.

Providing a platform for research and development the Gambit AUV now forms the basis to actively undertake the development and testing of sensor, navigation, communications and autonomy technology through the remainder of the programme allowing for a gradual increase in MCM capability with further system improvements being practically demonstrated during sea trials in representative environments.

Acknowledgements

The authors would like to acknowledge all those involved in making this project possible to include: the UK MoD for funding this research; the high resolution sonar team for their work on the sonar; the Office of Naval Research (ONR) for providing the funding for the loan of the Gambit AUV to the UK MoD; Bluefin Robotics for the construction and supply of the vehicle.