Proceedings of the Seventh European Conference on Underwater Acoustics, ECUA 2004
Delft, The Netherlands
5-8 July, 2004

EXPERIMENTS WITH A SHIP-MOUNTED LOW FREQUENCY SAS FOR THE DETECTION OF BURIED OBJECTS.

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In September 2002, GESMA and TNO-FEL carried out a sea trial with a low frequency (20 kHz) sonar mounted on a mine hunter. The objective of the experiments was to collect sonar echoes from proud and buried objects for subsequent synthetic aperture processing. A large data set was collected, consisting of sonar data from several SAS modes and relevant non-acoustic measurements such as sonar movement from a Motion Reference Unit, GPS data, ship navigation data and sound speed measurements. Inspection by divers, a scan of the trial areas with a high-frequency side scan sonar and bottom core analysis completed the data collection. This paper presents details of the experiments and some preliminary results. The use of a ship-mounted sonar has proven quite valuable. The ship is sufficiently stable for SAS applications and a wide variety of non-acoustic sensors is available for improving the SAS processing.

1. INTRODUCTION

Synthetic Aperture Sonar (SAS) is currently a mature technique that is most frequently applied for imaging the sea floor with high frequency sonar. An important military application therefore, is the detection and classification of sea mines. The gain in resolution compared to conventional sonar yields improved performance, in particular of shadow classification.

Nevertheless, the detection of buried mines remains one of the recognised shortfalls in current mine countermeasures capabilities [1]. Mine burial may occur in sandy sea bottoms under the influence of sand dune migration, tidal currents and occasional storms, but also in harbours, where the sediment is often soft and muddy. Buried mines are considered a serious threat due to their invisibility to normal (high frequency) mine hunting sonar, which cannot penetrate the sediment. For this purpose, much lower frequencies are needed, below about 20 kHz. At these frequencies, the azimuth (beam) resolution of conventional sonar is insufficient unless a prohibitively large array is used. SAS promises to be the technique that meets the requirement of combining low frequency with high azimuth resolution and acceptable array size. The latter aspect is particularly important when AUV's (Autonomous Underwater Vehicles) are used as a sonar platform that cannot support a large receive array.

To experimentally validate the concept of using SAS for the detection of buried mines, GESMA and TNO-FEL have set up a collaboration that aims at collecting and analysing low frequency sonar data from buried and proud objects, using a ship-mounted sonar. This paper describes the trial set up and the type of data that were collected. A second paper [2] presents results of the analysis of the collected data until now.

2. TRIAL OUTLINE

The trial was conducted during ten days in September 2002 in the waters near Brest, France. Two sheltered locations with different bottom type were selected for placing targets, see Fig. 1 left; one near Morgat in the Bay of Douarnenez, depth about 25 m, the other near Rascas in the Bay of Brest, depth about 35 m.

Each target field consisted of three metal cylinders and one fully buried dummy Manta mine. The cylinders ranged from proud and half buried to fully buried, as shown schematically in Fig. 1, right. The targets were placed by divers in the month preceding the trial. Additional to the target fields, three ship wrecks were measured at various locations in the same area.

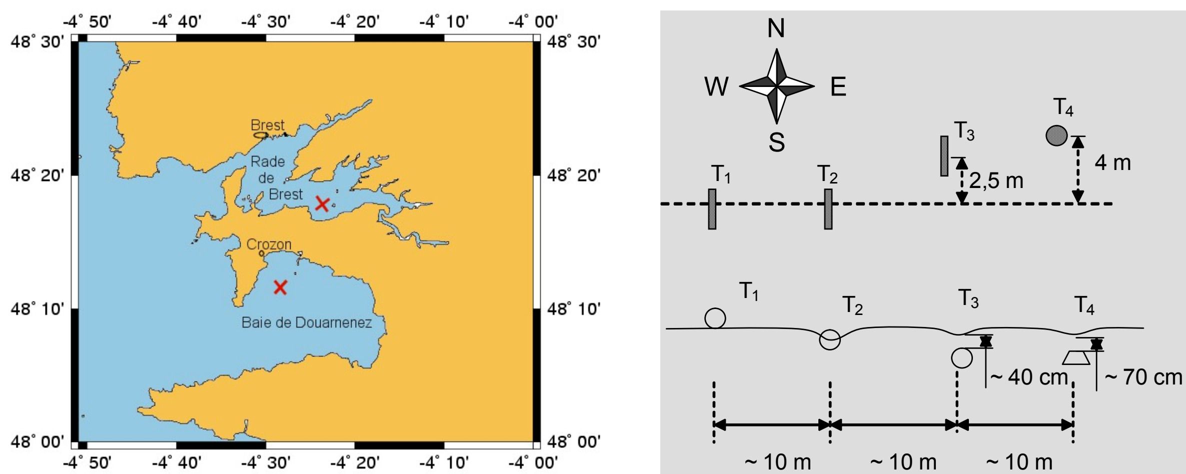

Fig. 1: Left: The two target field locations, marked by red crosses. Right: Orientation, approximate burial depth and spacing of the targets.

Before the trial, bottom coring was carried out at both trial locations and the cores were analysed ashore. Results of the analysis are presented in Table 1 and Table 2. It appeared that the Morgat sediment is much more homogeneous (sand) than that in Rascas, which could also be observed during visual inspection. In Rascas, a dense layer of shells ('crepidules') covered the somewhat muddy sea floor.

The trial ship was the mine hunter HNLMS (Her Netherlands Majesty's Ship) Hellevoetsluis, made available by the Royal Netherlands Navy (RNLN). This ship is equipped with a PAP (a remotely operated vehicle for inspection with an underwater camera), array stabilisation system for the mine hunting sonars, two echo sounders, DGPS navigation and autopilot, and divers were on board for visual inspection of target burial. With the help of the RNLN maintenance service (SEWACO), a GESMA sonar was installed on the ship instead of the detection sonar. The ship's classification sonar was kept operational. For manoeuvring, and especially during track following, active rudder and bow thrusters were sometimes used.

Table 1. Sediment analysis in Rascas area

	Sample 1	**Sample 2**
Rock, stones	0%	3.4 %
Gravel	12.65 %	14.7 %
Sand	10.85 %	30.3 %
Fine sand	46.7 %	38.9 %
Mud (silt, clay)	29.8 %	12.7 %

Table 2. Sediment analysis in Morgat area

	Sample 1	**Sample 2**
Rock, stones	0 %	0 %
Gravel	0.9 %	0.4 %
Sand	37.5 %	56.7 %
Fine sand	61.4 %	42.8 %
Mud (silt, clay)	0.2 %	0.1 %

During the trial, the environment was further monitored by measuring the sound speed profile at regular intervals, using a Digibar Pro sound velocity probe. An almost flat profile of about 1513 m/s was measured throughout the trial. The weather conditions were favourable during most of the time, resulting in very little ship movement.

After completion of the trial, the areas were inspected by a French mine hunter and scanned with a high-resolution side scan sonar (DUBM41).

3. EQUIPMENT CONFIGURATION

Prior to the trial, a 48-element sonar receive array of 80 cm length and an ITC 3001 transmitter provided by GESMA were tuned, calibrated and equipped with an IXSea Octans Motion Reference Unit (MRU). The MRU measures three rotations and three accelerations and was placed on the sonar housing to obtain a minimum lever arm between point of measurement and receiver midpoint. This configuration, as shown in Fig. 2, was mounted with a fixed 32° tilt angle on the sonar hoisting and stabilisation system of the ship. The choice of tilt angle was a compromise between swath width (small tilt) and sediment penetration (tilt larger than critical angle).

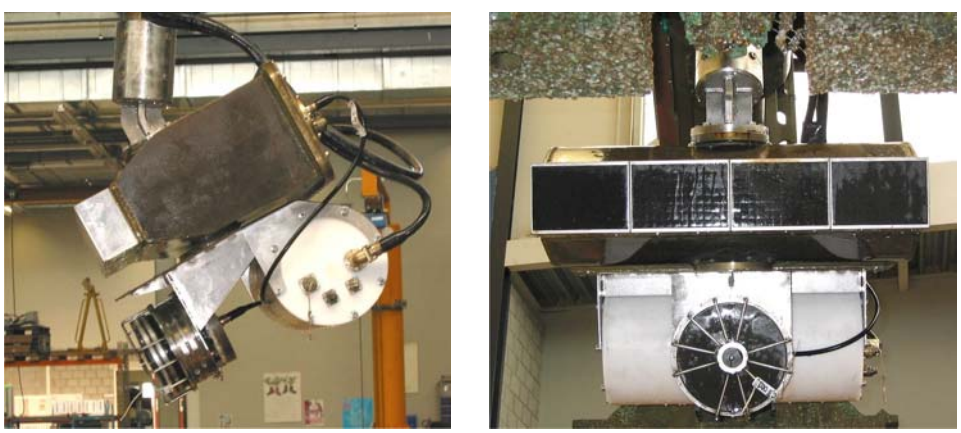

Fig. 2: Side (left image) and front (right image) view of the sonar configuration, with circular transmitter ITC3001, receive array consisting of 4 modules of 12 elements each, and (in the white container) the IXSea Octans Motion Reference Unit. The tilt angle is fixed at 32°.

The transmitter beamwidth was 28° at 15 kHz in a conical beam, which effectively puts a limit on the maximum SAS integration length. The sonar operated in the 14-25 kHz frequency band, where various pulse types (LFM, CW) could be generated. The sonar signals were digitised to 16-bit data, recorded in RAM during a run, and stored on hard disk and DLT-tape afterwards. The sample frequency was either 100 kHz or 75 kHz, depending on the required range bracket (the number of samples per ping was fixed). Synchronous with the sonar data, non-acoustic data were recorded from the MRU, DGPS and ship's autopilot. These data were recorded for geo-referencing and motion correction in the SAS processing.

4. EXPERIMENTS

Many different runs were carried out at each target field location. Variations were made in track direction and SAS mode. Track directions were chosen both parallel and perpendicular to the target fields and at different ranges. Most tracks collected 700 pings at 5 Hz ping rate and ship speed 2 knots. Hence the track length was about 140 m. Used SAS-modes were:

- *Side-looking* = standard SAS mode, similar to side-scan.
- *Squinted forward* = sonar aimed slightly forward (up to 45°), operationally relevant in previously unsurveyed areas.
- *Spotlight* = adjusting the sonar heading to point to the target while the ship sails by (target is "in the spotlight" all the time). This method allows a much larger synthetic aperture, because the transmitter beamwidth is no longer limiting. However, only a small area, the "spot", is imaged and motion compensation is more critical.
- *Multi-pass* = using the tide to pass the targets several times along the same track at a different height. This is to investigate the feasibility of repeat-pass interferometry.
- *Circular* = sailing around a target to allow tomographic reconstruction.

The wrecks were surveyed only in side-looking mode. Additionally, noise recordings were made without sonar transmissions to get an estimate of the ambient noise level. The ship speed was varied during these measurements.

In separate runs, echo sounder signals were recorded to allow making a bathymetry map of each location and for potential acoustic bottom classification.

5. PRELIMINARY RESULTS

This chapter shows results for one (arbitrary) eastward run in the Morgat area, parallel to the target field. Fig. 3 shows the recorded GPS track of the ship in blue dots and the target locations in red crosses. Obviously, the track is not entirely straight, which calls for motion correction prior to SAS processing.

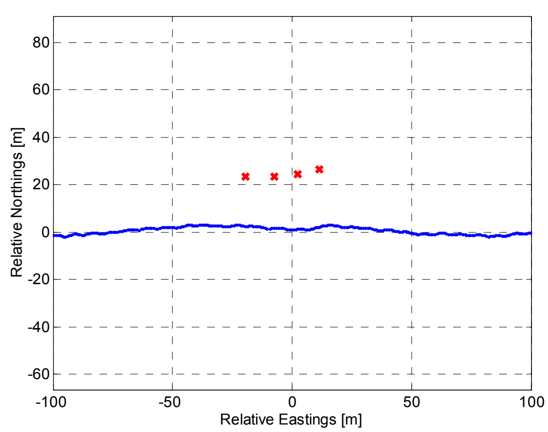

Fig. 3: Measured ship's track from GPS and target locations, Morgat target field.

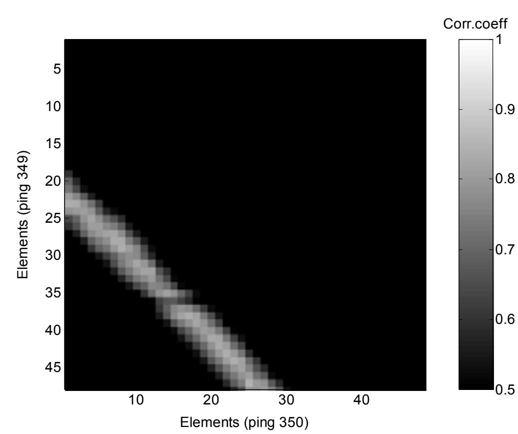

Fig. 4: Cross-correlations of overlapping array elements in two consecutive pings.

The DPCA (Displaced Phase Centres Antenna) method [3] has been applied to estimate sonar movements from the acoustic signals themselves. DPCA is an *auto focusing*, or *micro navigation*, method that yields estimates of sonar surge, sway and -optionally- yaw, using the cross-correlations of overlapping array elements between consecutive pings. It complements the MRU measurements. The performance of DPCA depends on the magnitude of the correlation coefficients [4]. To check this, the matrix of element cross-correlations between consecutive pings was computed. Fig. 4 shows this matrix for two specific ping numbers.

Fig. 5 shows two graphs of surge (speed variations) from DPC and sway (sideways sonar movements) estimated with DPCA and Image Correlation Autofocus (ICA, see below).

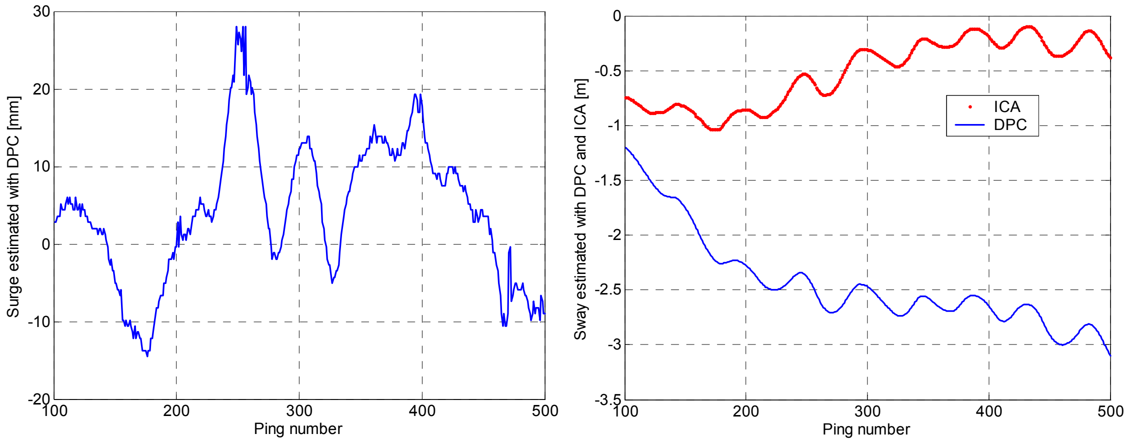

Fig. 5: Surge (left) and sway (right) estimated from the acoustic data using DPC and ICA.

It can be seen from the figures that the ship movements are indeed quite small. Nevertheless, the movements are large enough to have a severely degrading effect on SAS image quality if left uncompensated.

The other correlation based auto focusing method that was employed is ICA [5]. The imaging result that was achieved with this method is slightly better than with DPCA. We show the side-scan image (one beam per ping) and the SAS result with ICA in Fig. 6.

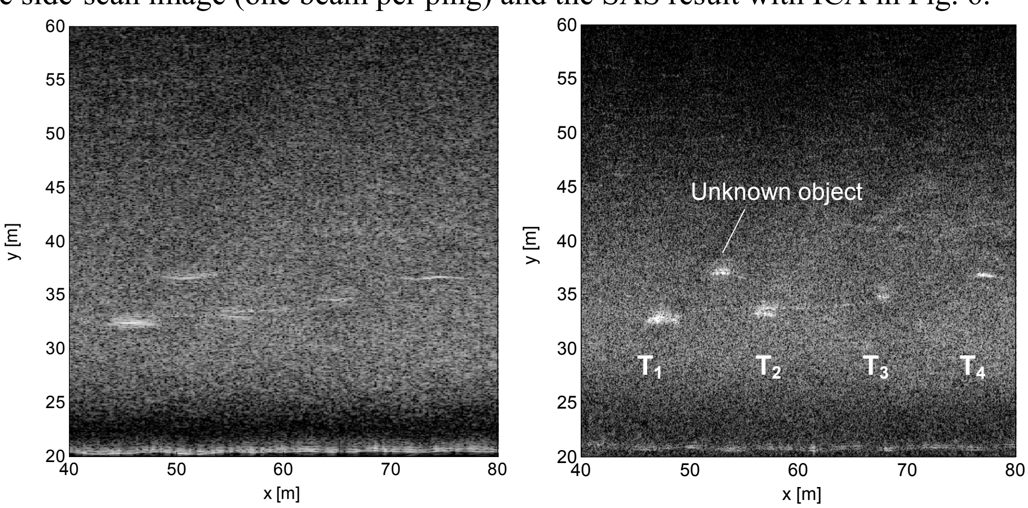

Fig. 6: Left: Side scan image for comparison. Right: SAS image, using Stolt migration and Image Correlation Autofocus. T_4 was temporarily marked with a reflector, hence the bright spot. The fifth reflection (between and little above T1 and T2) is as yet unidentified.

Finally, Fig. 7 shows the corresponding, heavily filtered, measurements from the Octans MRU. The roll angles are about −32° due to the sonar tilt angle, the heading corresponds with the ship's heading. Up to now, the MRU measurements have not been used for motion correction, but they will be in the near future.

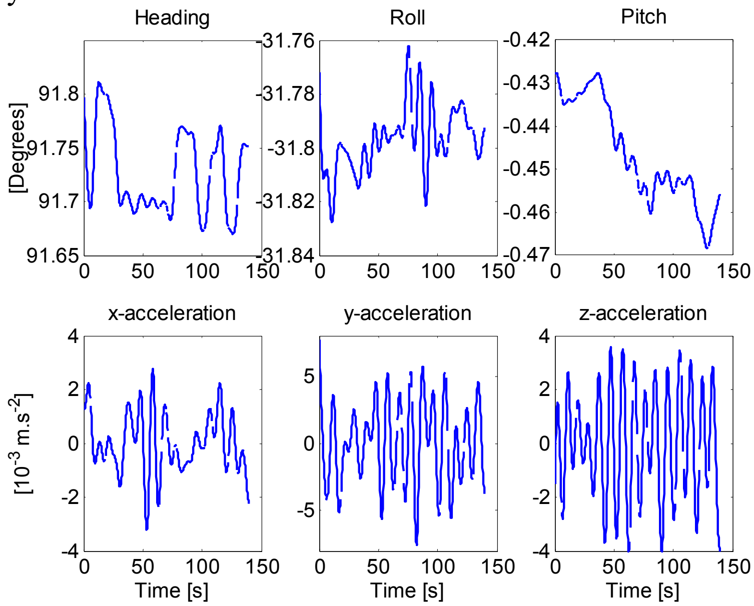

Fig. 7: Smoothed MRU measurements: rotations on top, accelerations in the bottom row.

6. CONCLUSIONS

An extensive data set of both acoustic data from proud and buried targets and non-acoustic navigation and environmental data has been collected using a mine hunter as a trial ship. The data set forms a valuable basis for subsequent analysis. Preliminary analysis shows that the buried cylinder can be detected. It can be concluded that SAS is a suitable method for ship mounted side looking sonar systems. More extensive processing will be carried out to improve the imaging quality and buried target detection performance of the SAS algorithms.

7. ACKNOWLEDGEMENTS

The authors would like to thank the Royal Netherlands Navy for their assistance in preparing and carrying out the trial and for making the ship available. We also would like to thank the French navy for their assistance with side-scan surveys and target inspection.

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