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SAS PROCESSING RESULTS FOR THE DETECTION OF BURIED OBJECTS WITH A SHIP-MOUNTED SONAR

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In September 2002, TNO-FEL and GESMA carried out a sea experiment with a low frequency (20 kHz) sonar mounted on a mine hunter. To our knowledge, it is the first time the synthetic aperture sonar technique has been implemented on board an operational mine hunter for the purpose of buried mines detection. The collected data set is mainly made up of sonar runs in several SAS geometries (side scan, squinted, spotlight and tomographic configuration). This paper presents preliminary results that have been obtained after synthetic aperture processing of the sonar data, with or without using additional non-acoustic data for motion correction and geo-referencing. It is concluded that targets that are not too deeply buried can be detected. In addition, the technique has also been evaluated on non-military data for the purpose of surveying shipwrecks.

1. INTRODUCTION

Nowadays, buried mines are considered a serious threat against harbor zone activity and maritime traffic, especially in muddy and sandy environments [1]. The detection of buried mines is a recognized shortfall in current mine countermeasure capabilities. Substantial progress has been made in the development of high frequency SAS (Synthetic Aperture Sonar) algorithms for mine hunting and bathymetric purposes [2][3][4].

Those types of sonar are expected to be integrated into AUVs (Autonomous Underwater Vehicle)[5][6]. However, using SAS to improve target detection and resolution of bottom penetrating sonar has not yet been widely investigated [7][8][9]. Preliminary experiments: BMC'99 (Buried Mines Classification–1999 experiment) and MIDSAS'00 (Mines Detection with SAS–2000 experiment) [9], involving GESMA, have proved that the technique is feasible in the LF (low frequency) case. However, these two experiments were made on a rail with very tight accuracy requirements. We still had to prove the feasibility on a more realistic platform and on richer types of bottom. In this new experiment, even if the UUV (Unmanned Underwater Vehicle) is the targeted operational platform, a surface ship was preferred for the ease of navigation and data acquisition. The expected larger platform movements compared to a UUV are measured with an INU (Inertial Navigation Unit) and can be compensated.

2. EXPERIMENT DESCRIPTION

The main objective of the trial was to collect low-frequency sonar echoes from proud and buried targets and all related information that was required for the subsequent analysis of the data. For this objective, a GESMA sonar was mounted on the mine hunter, HNLMS Hellevoetsluis, provided by the Royal Netherlands Navy (RNLN) [13]. The ship is about 50 m long and weighs 500 tons. For mine-hunting, and during experiments, active rudders and bow–thrusters have been used. Auto-pilot helped to keep the track. The sonar track has been recorded with a Motion Reference Unit (MRU) and differential GPS (Global Positioning System). Precise knowledge of the burial status of the mine-like targets (buried, half-buried or proud), their position and orientation has been determined from diving operations before, during and after the trial using divers and a Remotely Operated Vehicle (ROV). High frequency (HF) sonar surveys and sediment coring have also been done.

(a) (b)

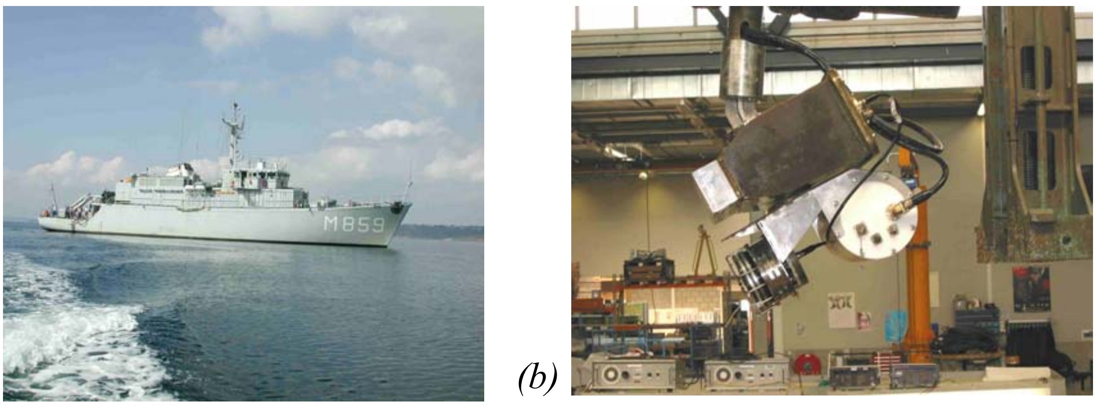

Fig.1: Photo of the mine hunter HNLMS Hellevoetsluis (a) and of the GESMA low frequency Synthetic Aperture Sonar (b).

The low-frequency sonar is similar to the system previously deployed by GESMA in 1999 on the underwater rail facility in the bay of Brest, France, and in 2000, in Singapore harbor [9]. The receiving antenna has been built from acoustic devices designed by GESMA (PJ40). The used transmitter was a bought off-the-shelf transmitter (ITC3001). Both devices were calibrated in 2002. After mine-field preparation on two sites, respectively in the bay of Brest and in the bay of Douarnenez (Morgat), all the equipment has been installed on board the mine-hunter. Main part of the trial has been planned over a 10 days period, between Monday

September 16th and Wednesday 25th 2002. The HNLMS Hellevoetsluis detection sonar was removed and replaced with the experimental device. We have to note that the sonar platform is stabilized in roll and pitch. Due to technical constraints, the tilt angle was fixed at 32° from the horizontal. The sonar height from the seabed was recorded all along the experiment with the ship echo sounder.The azimuth of the sonar was controlled with the detector console. The classifier sonar was still operational during the trial. The wet-end part of the LF sonar is composed of the receive and transmit arrays in the front of a bronze container containing the electronic components. An Octans Motion Reference Unit is fixed inside a cylindrical box (see figure 1b). The receiver is composed with four PJ40 modules to form a 48 elements, 80 cm linear array. After amplification by a user controlled gain, each channel is synchronously digitized in a 16 bits ADC and recorded directly on carrier frequency. Sampling frequency was either 75kHz or 100kHz, for an operating frequency band of [15-25kHz]. Six locations were chosen to have a characteristic panel of configurations. Two areas with dedicated laid targets, in the same configuration but with two types of bottom. One sandy (in the bay of Douarnenez (France)) and one muddy (in bay of Brest). Unfortunately the muddy area was more reverberant due to a compact layer of shellfish on the bottom. A third area was surveyed where was laid buried targets back in 1992 ! Then three wrecks were surveyed, included one partly buried in sand.

3. RESULTS

The results presented in this section are preliminary. Conventional algorithms were used. First the Displaced Phase Center (DPC) motion compensation algorithm [2] is applied. Up to now, only sway and surge were corrected. Then an image was constructed with corrected hydrophone locations. Fast Factorized Back Projection (FFBP) [11] was chosen as a beamformer for its adaptability to various antenna geometries.

3.1. Results on mine-like targets (Morgat area : sandy bottom)

Mine-like objects (cylinders) have been laid by a team of divers using a dedicated ship. The burial steps are : alignment of the targets on the seabed with a rope, removal of sediment under the targets with a water jet, measurement of the burial depth, refilling the hole left over the targets with a pump equipped with a Venturi system. The sand used to fill the holes (where the mines are laying) is taken from adjacent zones within a distance of 4-5 meters. Unfortunately this work creates some additional holes and trenches in the seabed. Holes were observed on top of the buried targets after the sand consolidated. Three targets are seen, figure 2, in the field of the sonar. They correspond to three water-filled cylinders (T_1, T_2, T_3: ∅ 550 mm, length= 1000 mm) with flat end-cap. They have a North/ South orientation. T_2 and T_3 are 5° out of this direction. All the mines are linked together with a 10 m long and 20 mm diameter rope. They are aligned in the West-East direction except for T_3 which presents a 2.5 m offset from this axis. T_1 is proud. T_2 is 2/3 buried and was observed to be inside a 3 m diameter and 50 cm deep hole. T_3 is fully buried with 40-50 cm of sand on top of the mine on the south end and 3 cm on the north end. The water depth was estimated at 28 m. The reverberation level was said to be medium (50% sand and 50% fine sand). A fourth target T_4 (stealthy mine shape) was also fully buried but is not yet observable in the processed data (outside the field of the sonar).

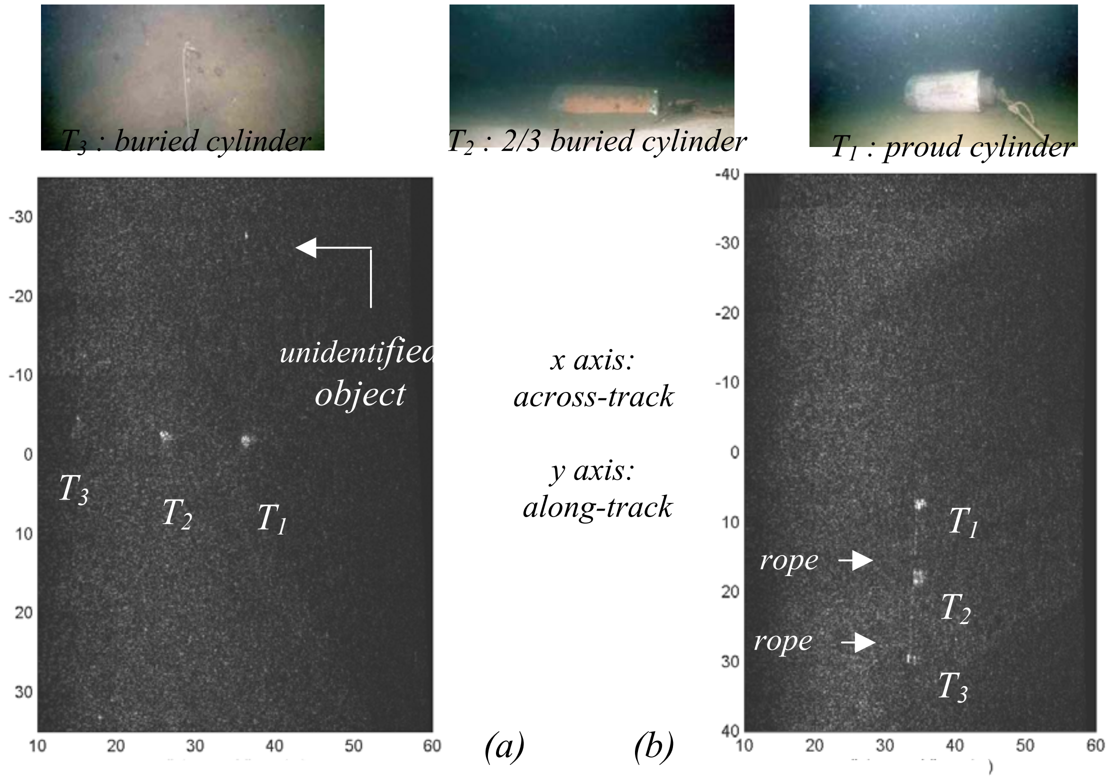

Figure 2 – Low frequency SAS results (Morgat area - sandy bottom) - ship heading 000° (a) & ship heading 270° (b) - T_1 is proud. T_2 is 2/3 buried, T_3 is fully buried

The estimated achieved resolution (by size analysis of prominent points) is about 20 cm / 25 cm in azimuth with a processing gain of about 30 at 50 m range. The synthetic aperture length is about 13 m at this range for a 0.8 m physical array. There is still a margin of improvement as the transmit beamwidth is 30° wide and should allow an azimuth resolution of 8 cm at 17 kHz. We assume that this discrepancy is mainly due to intrinsic limitations of DPC especially without yaw identification. We think that more sophisticated autofocus algorithms could increase the performance. However, even with this image quality, buried target T_3 and partly buried target T_2 are well detected. Comparison is made, figure 3, with an image of the area obtained with a high frequency side-scan sonar (about 750 kHz). Due to the high frequency response of the seabed and a high level of details, it is not obvious to find the mines on the high frequency image, except for the proud mine T_1 which shadow interpretation is obvious. To the opposite, looking at the low frequency image, the detection is obvious as the background has been “washed up” with the low frequencies.

4. RESULTS ON WRECKS

The “Swansea-Vale” steamship, figure (4a), sunk in 1918. The wreck is located in front of Camaret on a sandy bottom. Its size is 80 m length x 12 m width x 5 m draught. The holds are broken open and collapsed most of the way to the seabed. Amidships is reasonably intact and upright, with boilers and engines still in place. The stern is also upright with big holes. The seabed is flat and sandy with a lot of shells and strips of maerl, a calcified seaweed. The “ Meuse” wreck, figure (4b), is located in the middle of the Bay of Douarnenez. The size of this French Aviso is 78 m length x 9 m width x 3,4 m draught. The wreck is lying down on one side and is severely damaged. Propellers and shafts are nevertheless still visible. In this area, the bottom is sandy and the water depth is 25 m. The last wreck, called "Pen-Hir", figure (4c), is almost degraded. It has a 75 m length, 15 m width and 5 m draught. Just some fragments are lying on the sandy seabed: the two boilers, engine, a pile of chains, some scraps of hull plates. Some others are said to be buried but they are not yet distinguishable.

5. SUMMARY AND CONCLUSION

This paper describes the first results obtained after processing data from a low frequency synthetic aperture sonar experiment. A more detailed description of the experiment is made in [12]. To our knowledge, it is a first time this technique has been implemented on board an operational mine hunter for the purpose of buried mines detection. Results have been shown on proud, partly buried and shallowly buried cylinders but also on shipwrecks. Work is still in progress for upgrading image quality by improved autofocus algorithm and merging navigation data. First processing shows the high quality of the data recorded. Further analysis is planned such as tomographic imaging processing on proud and buried targets, HF and LF data fusion on mines and wrecks data (HF data are taken from high frequency sonar surveys), image improvement with echo analysis techniques and false alarms reduction techniques.

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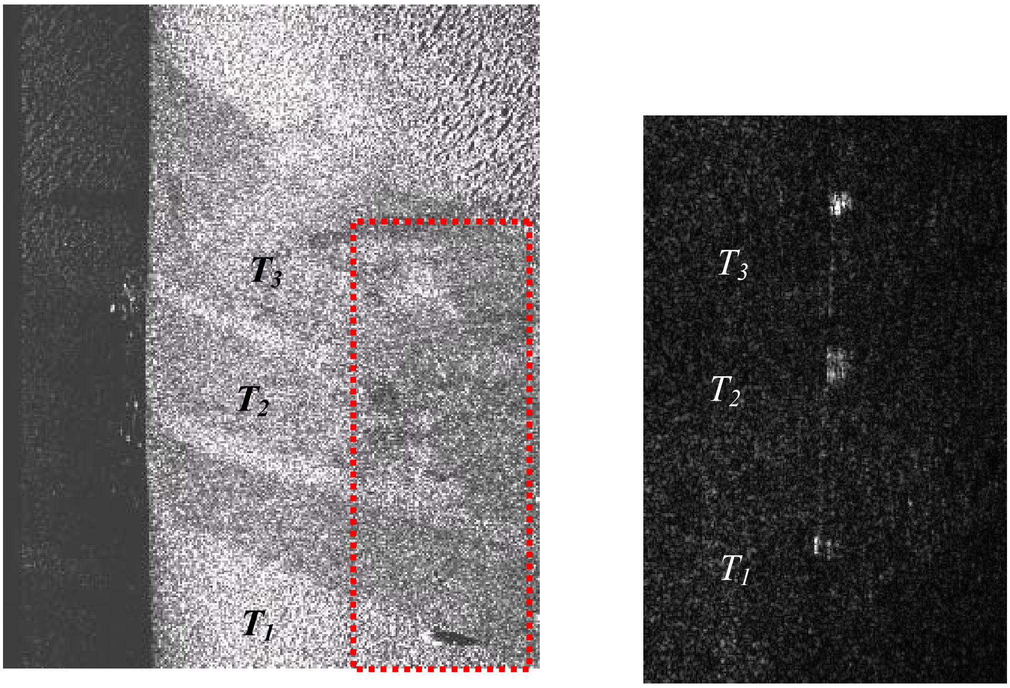
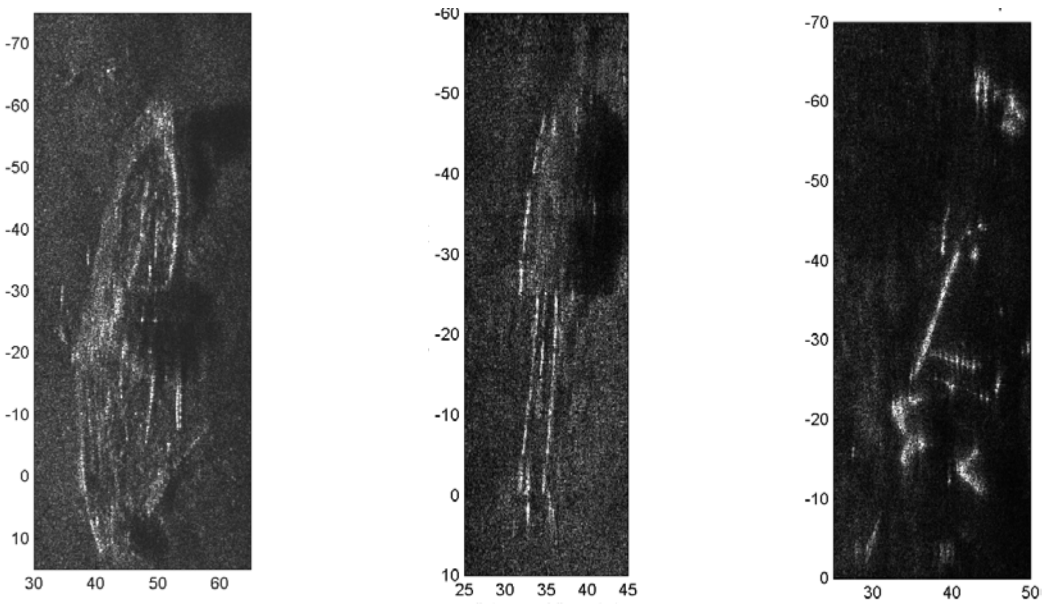


(a)

(b)

Figure 3 – HF and LF comparison (Morgat area - sandy bottom - ship heading 270°) (a) – with a high frequency sonar (750 kHz), (b) – with a low frequency synthetic aperture sonar (20 kHz) T_1 is proud. T_2 is 2/3 buried, T_3 is fully buried



(a) *(b)* *(c)*

Figure 4 – Low frequency SAS images of Swansea-vale wreck (a), Meuse wreck (b) and Pen Hir debris (c) - (xaxis = across-track, y axis = along-track)