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Techniques for Detecting and Characterising Objects On and Under the Sea Bed

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Active sonar systems are usually used to locate objects in mid-water, while passive systems are used to determine the range and direction of sources of sound. Some systems can yield information about the seabed, for example a depth sounder can give a plot of depth along the travel direction, while a side scan sonar can give a two-dimensional image of the sea bed. This paper describes the application of a parametric sonar system that can generate a narrow beam with enough acoustic power to penetrate the water/sea bed interface. Subsequent acoustic scattering at deeper interfaces may yield information about the underlying sediments or the detection and ultimately the characterisation of buried objects such as lost cargo, mines, pipelines or shipwrecks.

1. Introduction

SOund Navigation And Ranging (*SONAR*) systems have been used since the First World War, originally to detect submarines. Despite eight decades of refinement and sophistication it is perhaps surprising to realise that modern *sonars* still have serious limitations. For military operations, automatic target recognition has always been a desirable feature but there remains little confidence in such techniques compared with the interpretive capabilities of a trained human operator. For surveying operations, a 'picture' of the seabed may be obtained with a side scan sonar but the resolution is a function of frequency and if fine detail is to be observed it is at the cost of reduced range. An area of sonar research that is wide open for exploitation is sub-bottom imaging. This is of interest for sediment identification and characterisation, which is important for mineral and gas exploration, pipeline surveying and many more applications. It is also important for the detection and identification of buried objects. The main aim of the research described here is to devise techniques for transmitting a narrow beam of sound into the seabed with sufficient power to detect objects buried to depths of several metres. A further aim is to excite the natural resonances of these objects so that they may be characterised in terms of size, orientation, material, whether air-filled or water-filled, and so on. Ideally, a single acoustic pulse, appropriately coded, is transmitted into the seabed so that any scattered signals may be processed to yield the 'identity' of any intercepted object. This was the aim of Loughborough University's contribution to the European Commission's MAST-III *DEO* (Detection of Embedded Objects) project.

2. Equipment and Methodology

Two complementary parametric sonar systems operated by Loughborough University (LU) and the SACLANT NATO Research Centre (SNRC) were used. LU developed a 75 kHz system that was calibrated and used on sea trials during the MAST-II *REBECCA* project [1-3], then subsequently for the present *DEO* project for static raft trials in Loch Duich, Scotland. SNRC used a 40 kHz TOPAS system in an Italian Navy dry dock and off the coast of the Mediterranean island of Elba. The main characteristics of both systems are summarised in Table 1, although only the LU system is described further here. The objectives of the LU tasks were:

- To achieve real time control of the transmission direction of a parametric array, allowing preferential sea-bed incident angles, optimised signal returns from objects, and dynamic correction of any platform instability;
- To determine the best mode of deployment for easier interpretation of data obtained during trials;
- To obtain 'acoustic snapshots' of signals scattered from an object at different orientations to the parametric array, to record them for theoretical analysis, and to identify any spectral differences ('spectral colouring') between the transmitted and received signals as a means of characterising the object.

The methodology was to investigate the relationship between the electrical signals applied to the parametric array and the corresponding received signals after reflection and scattering from an object that may be partially or completely buried and which may be randomly orientated with respect to the array's propagation direction. The objectives were principally concerned with signal generation and signal retrieval using the existing parametric array and associated electronics, which have been described in detail elsewhere [1-3].

3. Trials

Two open-water trials were carried out in Loch Duich, Scotland in collaboration with TNO-FEL, The Netherlands, whose receiver system is only briefly described here. A raft and other facilities of the Scottish Office, Fisheries Research Service (FRS) were deployed for these trials. The first trial, during May 1997, involved the detection in a free field of scattered signals from a target, initially air-filled, then flooded with sea water.

The target was a thin-walled, galvanised steel cylinder with flat end-caps, 1m long and 0.25m diameter with a 6mm wall thickness. This was suspended from a separate target raft 76m downrange of the parametric array, close to mid-water at 15-20m depth, and the target aspect angle was controlled in the horizontal plane by a stepper motor. The TNO 20-element hydrophone array was placed between the array and target, either horizontally or vertically deployed, allowing measurement of both direct and back-scattered parametric signals, as shown in Figs 1 and 2. The centre of the hydrophone array, when deployed horizontally, was 56m from the source. The source was deployed at a depth of 16m below the FRS raft, allowing transmission in the horizontal plane. Fine adjustment of the acoustic beam could then be made by using a pan-and-tilt facility in the vertical plane or by electronic beam steering in the horizontal plane. The target raft was held in place between two horizontally tensioned wires attached firmly to the FRS raft, as also shown in the figures.

Transmitter and target control electronics were operated from the mains-powered FRS raft moored approximately 300m from the shore. Recordings of secondary frequency signals, both direct and scattered, were made with the 20-element hydrophone array. Signals were transmitted ashore for processing via a sea-bed cable to the TNO base. Three single-element, 25mm-diameter ball hydrophones (with receiving sensitivities of -202 dB re 1 V/μPa at 75kHz) were also used. These allowed the monitoring of direct and target-scattered signals at both primary and secondary frequencies. An additional low frequency (1-10 kHz) hydrophone was also used. Initial deployment was approximately 4-8m from the target along the transmission axis of the parametric source, allowing the capture of both direct and scattered signals, i.e. to and from the target. An additional hydrophone placed close to the target itself was used to aid transmitter-target alignment. Transmitter and receiver logging systems were synchronised using a GPS receiver for post-correlation of transmission and received data. Additional transmit signal data and target angle information was sent ashore via a fibre optic link for display at the TNO base. Fibre-optic and cable links also allowed transmitter–receiver communications and synchronisation. The system is shown in Fig. 3.

The second trial, during July 1998, was also carried out in collaboration with TNO. The aim here was to insonify the same target when it was lying on the sea bed at a number of different orientations. To achieve this, it was necessary to rig up a lifting arrangement so that the target cylinder could be raised above the sebed, rotated, then lowered again. To monitor each orientation angle a magnetic compass was attached to a rod connecting it to a TV camera that was deployed above the target. This assembly was raised above the target area during insonification of the target. It should be evident that for this trial the parametric array was directed down towards the seabed, rather than horizontally.

4. Measurements and preliminary data

For the first trial, the target was rotated continuously, with its axis horizontal, so that it presented a range of aspect angles to the parametric array, and recordings of both primary and secondary frequency signals for both incident and scattered data were made. For the second trial, only eight discrete aspect angles was possible. Various secondary frequency signal types were used including: (i) sine wave signals in the range 1-10 kHz; (ii) 'chirp' signals from 2-10 kHz; (iii) Ricker pulses centred on 5-7 kHz; and (iv) sector-scan signals at 5 kHz.

Acoustic signals reflected and scattered from the target were detected by the single-element hydrophones linked to an integrated PC-based data capture system. This system allowed data capture on up to sixteen parallel channels of a 16 ms snap-shot time window. A 250 kHz (16 bit) sample rate was used to allow the capture of signals with frequencies up to 100 kHz, thus suitable for both primary (70-80 kHz) and secondary (1-13 kHz) frequency signals. External memory could be reconfigured under software control to allow data capture over an increased time window of up to 256 ms for a single channel. All data was archived directly to hard disk for later analysis. In addition, 'real time' displays of time and frequency domain signals were provided on the PC monitor. The data capture system was fully integrated with the transmitter signal synthesis system, providing a high degree of signal monitoring during transmission. Other signal processing electronic systems include pre-amplification, filtering and envelope detection. Sampled acoustic signals were recorded on a PC hard disc and a digital oscilloscope capture system.

Incident and back-scattered signals were recorded using secondary frequencies in the range 1-10 kHz for various target orientations. Comparisons of incident and scattered signals at both primary and secondary frequencies were made for sine wave, chirp and Ricker pulses.

Fig. 4 shows the primary and secondary frequency components of both the direct and scattered signal received at a single hydrophone for a 1 kHz sine wave signal incident at an end cap of the target cylinder, when water-filled. Fig. 5 shows the corresponding picture for a Ricker pulse, after processing with a band pass filter. A large number of such signals have been recorded and a preliminary analysis indicates spectral difference between the incident and scattered signals (not illustrated) that should allow target identification.

5. Conclusions

The first sea trial of the DEO project by the LU and TNO-FEL partners was carried out in Loch Duich, Scotland and required the insonification, with a 75 kHz parametric sonar system, of a water-filled target cylinder that was rotated in the free field. A second trial was also carried out at the same site, with the same water-filled target lying on the seabed at parametric array. The capture of back-scattered signals for later analysis was successful and it was found possible to recognise spectral discrete orientations with respect to the differences between the incident and scattered signals, indicating excitation of the target's various resonance frequencies. Since these frequencies are related to the target's dimensions and composition, this approach shows promise of leading eventually to a degree of identification and characterisation of objects embedded in and under the seabed.

6. Acknowledgements

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Reference

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	Loughborough University	SACLANTCEN
Primary frequency (kHz)	75	40
Secondary frequency (kHz)	1-13	1-10
Source Level (dB/1 μPa / 1m)	243	240
Primary beamwidth(degrees)	3.0	2.5
Secondary beamwidth (degrees)	2.5 – 8	≥ 2.5
Angular coverage (degrees)	36	80

Table 1 Comparison of Loughborough University and SACLANTCEN systems

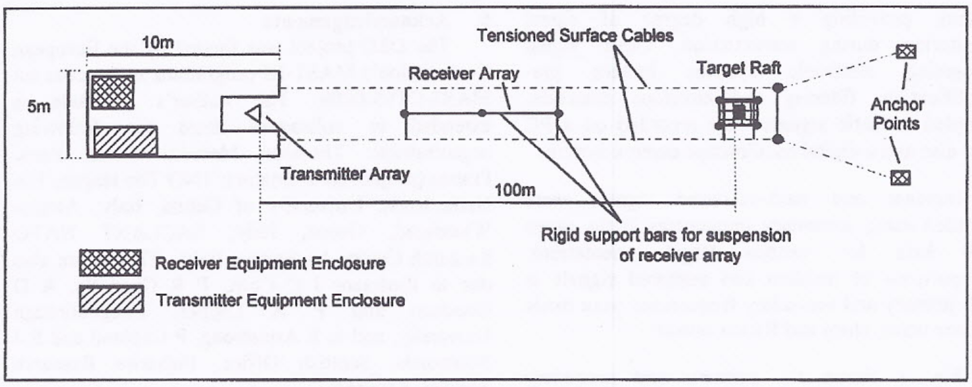

Fig. 1 Plan view transmitter-receiver-target deployment (horizontal array)

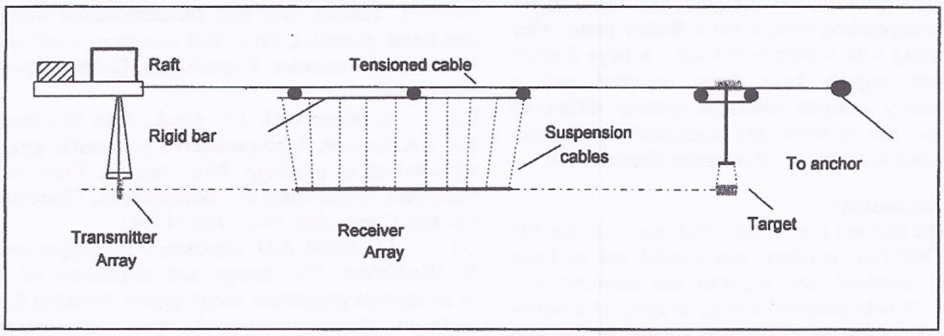

Fig. 2 Side view of deployment

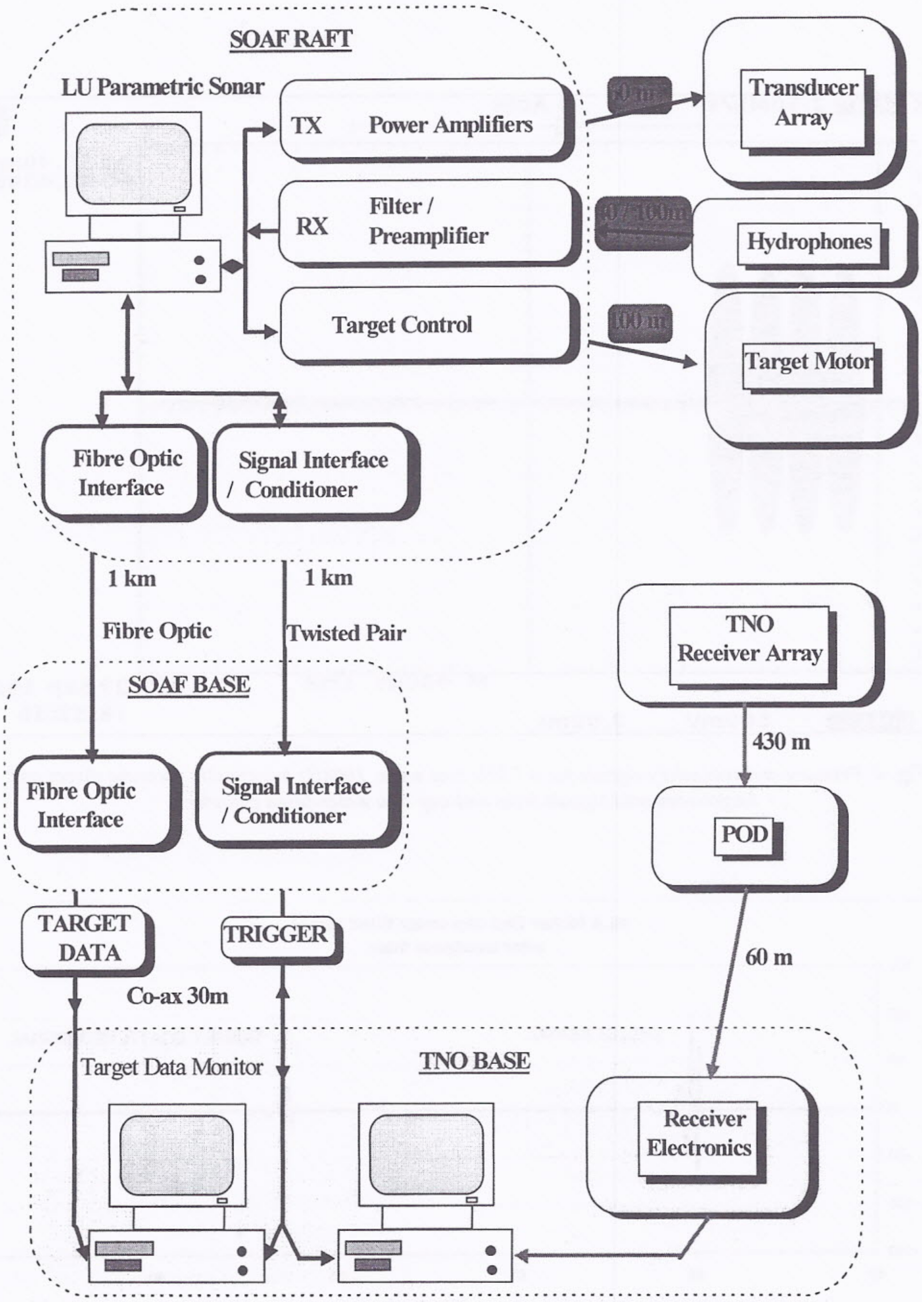

Fig. 3 Complete transmitter-receiver system for DEO project trial on Loch Duich

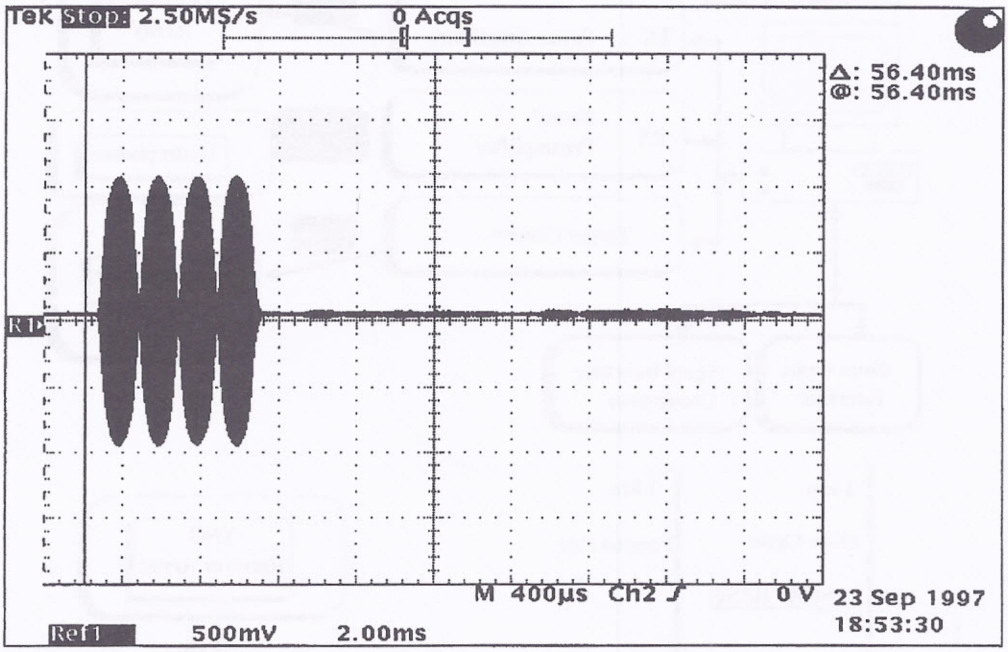

Fig. 4 Primary and secondary signals for a 1 kHz sine wave, 100kHz bandwidth, showing direct and target-scattered signals from end-cap of a water-filled cylinder.

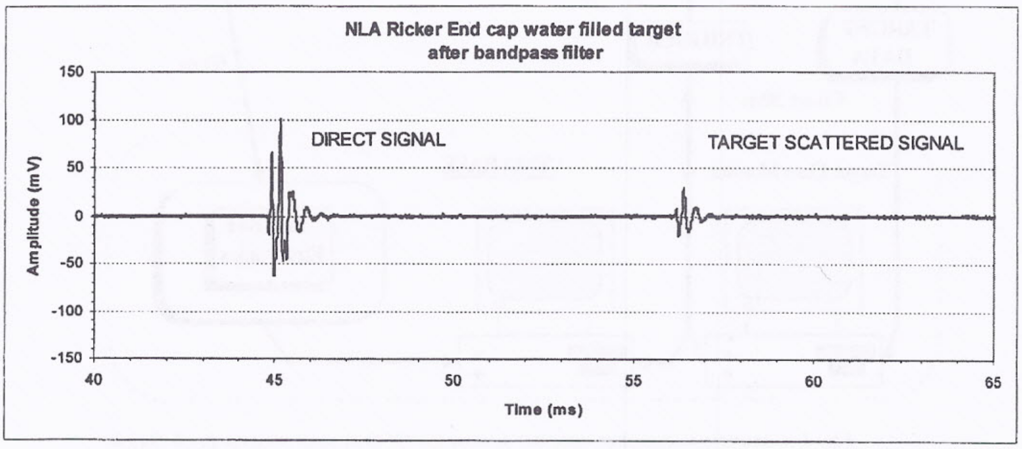

Fig. 5 Ricker pulse, band-passed secondary frequency, showing direct and target-scattered signals