A POTENTIAL ALGORITHM FOR TARGET CLASSIFICATION IN BISTATIC SONAR GEOMETRIES

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The recent evolution in oceanographic sensing and platforms, including the availability of Autonomous Underwater Vehicles (AUVs), is encouraging the investigation of new high-resolution sonar concepts based on multistatic geometries. The rationale behind this concept is that multistatic systems, in particular if the geometry can be adapted with the experiment, can be located in the regions where the scattered signal is carrying the most information. The work described in this paper is a follow-up of the research carried out by the authors as part of the European Union project SITAR (Seafloor Imaging and Toxicity: Assessment of Risks caused by buried waste), in which a Multiple Aspect Scattering measurement technique has been investigated with the aim of imaging buried objects of small dimensions. Within SITAR, a very rich data set has been acquired in the tank facilities of the University of Bath. The data set consisted in scattered signals from a set of targets, ensonified with a high frequency source (238 kHz) as a function of grazing, scattering and bistatic angle. Moreover, the targets were proud on the surface, semi-buried or flush-buried in different kinds of seabed sediments. The SITAR data set has been processed by a suite of algorithms, inspired from spectral distances often used in speech processing, with the aim of determining some characteristics that may allow the automatic classification of the object. Within this process, significant relative differences in the received signal power at bistatic angles different from the azimuthal (180°) angle have been systematically observed. This experimental finding is reported here as a potential basis for an automatic classifier, particularly advantageous because of the simplicity in the data processing requirements.

1 Introduction

Within the last years a consistent number of contributions have been presented in the scientific literature, concerning the problem of classification of objects either buried or proud on the seafloor (see for instance [1 - 3] and references therein). The major driving force behind this research direction is the problem of mine detection [4], although similar approaches can be efficiently employed in other underwater applications, such as marine

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archaeology [5] or toxic waste mapping [6]. One particularly interesting aspect of this research line has emerged with the increasingly popular use of Autonomous Underwater Vehicles (AUVs) as transmitting and/or receiving platforms of a multistatic acoustic scattering system: AUV characteristics make feasible and affordable the deployment of adaptive systems in which the source/receiver(s) configuration can be re-arranged rapidly as a function of the received signal themselves [7 - 8] . The possibility of geometrical adaptation of the system configuration makes even more interesting the investigation of multistatic scattering and related detection/classification methods. Unfortunately, high frequency scattering from the seabed is a rather complex process: there is still a lack of physical models capable of convincingly reproducing the field data collected at sea without strong assumptions on the system geometry and/or the environmental conditions. Within this context, laboratory experiments of acoustic scattering in controlled conditions are of great relevance: data from such experiments can be used to validate/refute model predictions, and can provide hints for favourable at-sea deployable configurations [9].

In this paper, we report some of the results obtained from the analysis of a data set collected in the laboratory tank test facilities of the University of Bath [10], as part of its activities in the European Union project *SITAR* [6]. A subset of the data collected has been processed in a number of ways to bring into evidence some systematic differences that may be exploited in an automatic target classification procedure [11]. Distance measures among signals adapted from speech analysis have been employed [12 - 13]. The results reported here show how the scattered power received from different targets as a function of the grazing and the bistatic angle exhibits pronounced differences at bistatic angles different from the azimuthal (180°) angle, even if the difference is negligible at 180° bistatic angle. The fact that diversity emerges with variation of the bistatic angle confirms the richness of information obtained through a multistatic configuration (either synthetic or real) and it can be exploited in an automatic classification algorithm.

Section 2 will describe the experimental procedure employed and the portion of the SITAR dataset used. In Section 3 the distance between signal powers as a function of grazing and bistatic angles is reported for two cylindrical targets of similar dimensions but different fillings (fluid- and air-filled). These results are discussed in Section 4.

2 Experimental set-up

The bistatic scattering data have been acquired using the tank facilities of the University of Bath, U.K. Different kinds of sediment, as well as different targets, have been used to perform the experiments [9-11]. During the experiments, the water level of the tank (controlled by an electric pump) has been kept constant, 1.45 m above the sediment surface. Four steel trays, 30 cm deep, fill the bottom of the tank and contain different kinds of sediment (silt, sand, fine and coarse gravel). These sediments were thoroughly degassed and have not been disturbed for several years, to ensure good stability and homogeneity.

The SITAR Project imposed some restrictions on the characteristics of the targets. In fact one of its aims was to developed new methods for the detection and classification of human made objects like barrels of toxic and/or munitions waste. According to the project specifications, a scaling factor of 10:1 was used in the design of the experiment and cylindrical shaped targets have been chosen. Figure 1 and 2 show, respectively, the longitudinal section of the tank and the top view of the experimental set-up, together with the definition of grazing, scattering and azimuthal angle. All targets have been used proud, half buried and flush buried. Table 1 shows the characteristics of the targets.

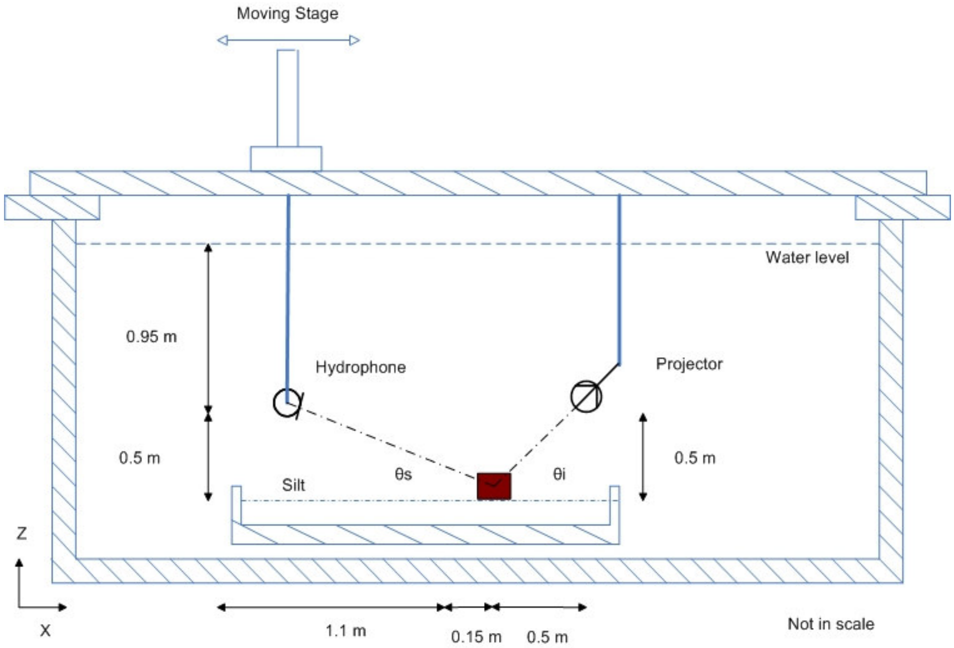

Figure 1. Longitudinal section of the tank used for the experiments; θ_s is the scattering angle, θ_i is the grazing angle. Both receiving hydrophone and acoustic projector can be moved to achieve the configuration desired in terms of grazing and scattering angles.

Table 1. Characteristics of some of the targets used in the experiments [4].

Target	Characteristics	Dimensions Diam x Length	Other
T_1	Sealed aluminum tin	67 mm x 100 mm	Fluid filled
T_2	Stainless-steel cylinder	58 mm x 104 mm	Air filled Sidewall thickness 3 mm End cap thickness 2 mm
T_3	Solid aluminum cylinder	51 mm x 81 mm	
T_4	Solid steel cylinder	70 mm x 80 mm	
T_5	Solid brass ring	105 mm x 75 mm	Wall thickness 7.5 mm

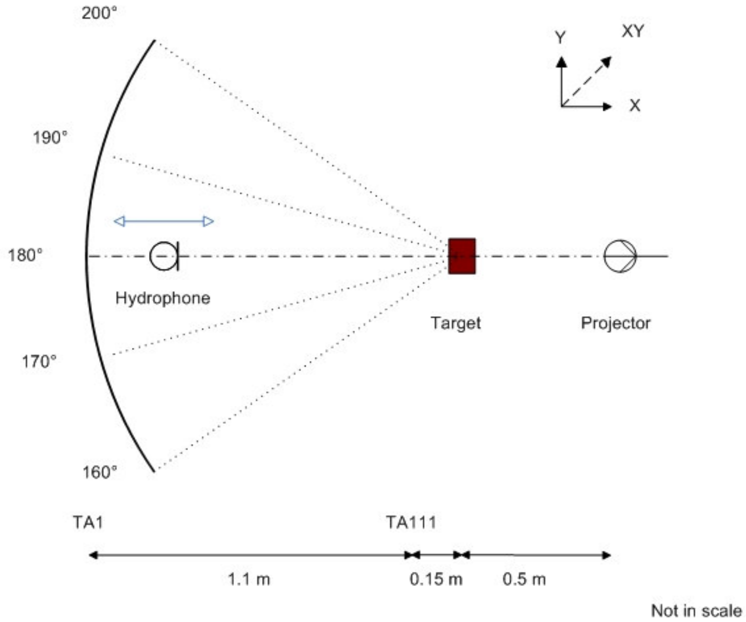

Figure 2. Top view of the experimental set-up. The receiving hydrophone can be positioned along the arc depicted as a continuous line at bistatic angles from 160° to 200°, at 10° steps. The configuration with a 180° bistatic angle is the configuration at azimuthal bistatic angle, or in-plane scattering, since the acoustic ray always travels in the plane defined by projector, target and receiver. TA*X* refers to the hydrophone position.

According to the function of the different devices, it is possible to separate the experimental set-up into three main sections:

1. Transmission of the acoustic pulse.
2. Reception and pre-processing of the scattered signal.
3. Storage of the signal.

The core of the transmission section is the acoustic projector, an active piezoelectric PZT5A characterized by a very narrow beam width (10°), and calibrated before starting the experiments. A track-supporting system allowed the projector to move along the longitudinal axes of the tank. The tilt angle of the transducer could be set to any value by an apposite mechanism. A single sinusoidal pulse with an amplitude of 20.43 V and a frequency of 238 kHz, has been used as acoustic source. A Bruel & Kjaer omnidirectional hydrophone has been used to receive the scattered signal. After an analogue pre-processing stage (bandpass filtering, amplification, anti-aliasing), the output of the hydrophone was connected to a Lecroy LT-264 digital oscilloscope. The whole experimental set-up (signal transmission, source/receiver position, etc.) was controlled and monitored by a LabView™ programme resident on a PC connected to the experimental instrumentation by a GPIB bus. The received waveforms were averaged over 100 sweeps at a time, in order to improve the signal to noise ratio, and then stored digitally.

3 Results

This section describes some results with data collected with the previous experimental set-up. As mentioned in the introduction, a set of different methodologies has been applied to the data in order to experimentally determine if some distance measure among signals could be employed in order to discriminate from one target to the other. The class of possible distance measures explored has been adapted from those most commonly used in speech processing applications. They consist in a set of frequency domain norms applied to the Fourier transform $S(f)$ of the signal $s(t)$, as the L_q norm:

$$d_q(s) = [\int |S(f)|^q df]^{1/q} \quad (1)$$

or the Log Spectral Deviation among two signals $x(t)$ and $s(t)$:

$$d_q(x,s) = [\int |\log X(f) - \log S(f)|^q df]^{1/q} \quad (2)$$

A comprehensive report of the many results obtained can be found in [11]. In the following some examples are shown using the Log L_2 norm of the signals plotted as a function of the scattering angle, with fixed grazing and bistatic angle. The Log L_2 norm of a signal $x(t)$ is easily computed, since it is simply the Log of the signal power, which in turn equals the value of the autocorrelation function at the origin:

$$\text{Log } P_x = \text{Log } [R_{xx}(0)] = \text{Log} \int |X(t)|^2 dt = \text{Log} \int |X(f)|^2 df \quad (3)$$

Note that, differently from the Log spectral deviation, in the Log L_2 norm of equation (3), the Log operation is applied after the averaging in frequency, and not at each frequency. In order to compare the norm as obtained from different targets, expression (3) has been normalized by the power of the scattering signals as obtained from the seabed when no targets are present; moreover, the numerical values in the following are expressed in dB. That is, each value in the following for any signal $x(t)$ is computed as:

$$\Delta P = 10\text{Log } P_X - 10\text{Log } P_S \quad (8)$$

Log P_S being the Log L_2 norm of the signal $s(t)$ obtained when no objects are present. Consider that each signal $x(t)$, $s(t)$ is obtained as the time-domain average of 100 sweeps. In the following the results obtained with the targets T_1 (fluid filled aluminum tin can) and T_2 (stainless steel air-filled cylinder) are compared in a configuration with a grazing angle always equal to 45°, varying scattering angles (2.5° interval), and at two different bistatic angles: 180° (in-plane scattering in the azimuthal direction) and 200° (off-plane scattering). The first example is reported in Figure 3; the seabed here was silt, and the two targets were oriented with their longitudinal axis parallel to the *X* axis (see Figure 2 for axis orientation convention) and proud over the seabed. It can be observed that, in the case of in-plane scattering (Φ_S = 180°) the difference between the Log L_2 norm of both signals is negligible (< 3dB) for any value of the scattering angle. On the contrary, when off-plane scattering is considered (Φ_S = 200°), for scattering angles between 40° and 65°, there is a systematic difference of the order of 5 dB. In Figure 4 the results from the same configuration are reported with the difference that now the cylinder's longitudinal axis is oriented along the *Y* axis. Again, differences among the response of the two targets become clearly visible only when off-plane scattering is considered (Φ_S = 200°).

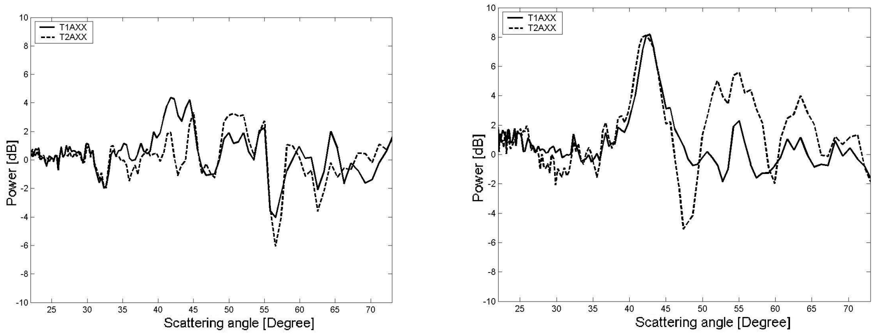

Figure 3. Power (dB) vs. scattering angle for targets T_1 (continuous line) and T_2 (dotted line). The power is normalized with respect to the seabed response without targets. Both targets are proud on silt sediment, their longitudinal axis oriented in the *X* direction (see Figure 2), grazing angle $\theta_i = 45°$, bistatic angle $\Phi_S = 180°$ (left) and $\Phi_S = 200°$ (right).

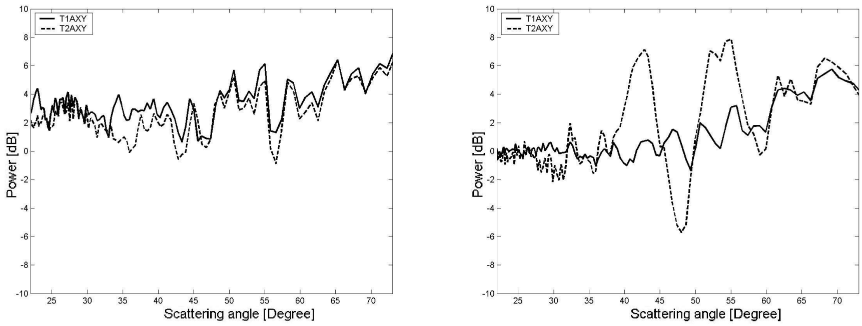

Figure 4. As in Figure 3, but with both targets having their longitudinal axis oriented in the *Y* direction (see Figure 2),grazing angle $\theta_i = 45°$, bistatic angle $\Phi_S = 180°$ (left) and $\Phi_S = 200°$ (right).

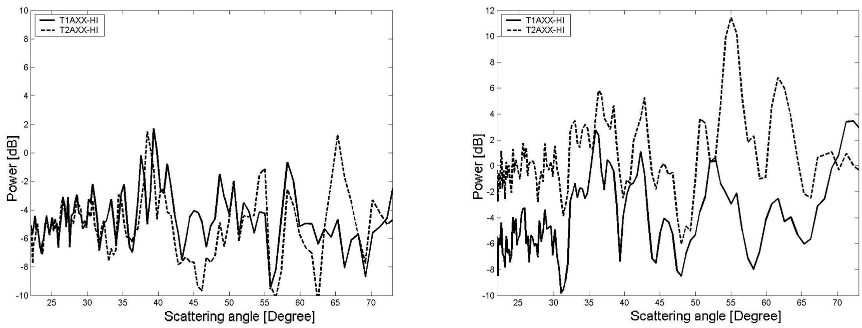

Figure 5. Power (dB) vs. scattering angle for targets T_1 (continuous line) and T_2 (dotted line). The power is normalized with respect to the seabed response without targets. Both targets are half buried on silt sediment, their longitudinal axis oriented in the *X* direction (see Figure 2), grazing angle $\theta_i = 45°$, bistatic angle $\Phi_S = 180°$ (left) and $\Phi_S = 200°$ (right) .

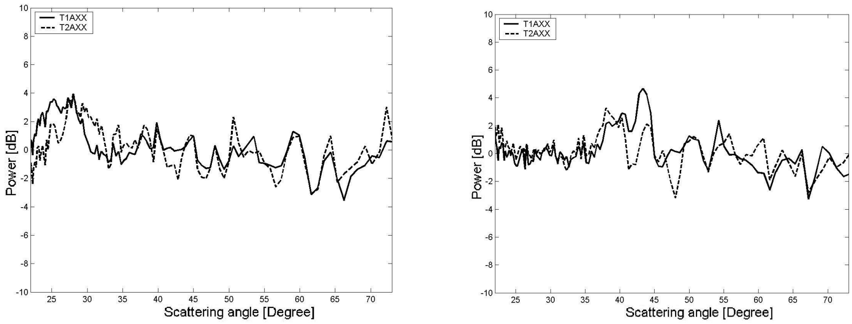

Figure 6. Power (dB) vs. scattering angle for targets T_1 (continuous line) and T_2 (dotted line). The power is normalized with respect to the seabed response without targets. Both targets are proud on gravel sediment, their longitudinal axis oriented in the *X* direction (see Figure 2),grazing angle θ_i = 45°, bistatic angle $\Phi_S = 180°$ (left) and $\Phi_S = 200°$ (right).

The same pattern has been observed when the two targets have been partially buried (gently pushed into the silt) - see Figure 5. With respect to the previous case, the difference between signal powers now becomes relevant for scattering angles above 50°. While the above results have been observed quite systematically on targets resting over silt, when the same configurations have been repeated with the same targets over the gravel bottom, the results have been negative (see for instance Figure 6): the difference in response from the two targets both for the in-plane and the off-plane scattering case are less than 3 dB, and not likely to be observed in a realistic, at sea, situation.

4 Discussion and conclusions

These results are typical examples of those reported more fully in [11]. They are an experimental indication (or confirmation, since the same observation has already been made several times in the literature, with theoretical, computational and experimental arguments) (e.g. [9]) that the 3-D acoustic field scattering does indeed provide additional information that can be successfully exploited in target classification. In addition to previous studies, the results reported show that sometimes even the bistatic configuration may not be sufficient, and that multistatic configurations should be preferred. In particular, the differences in normalized power of the scattered signals are most evident when plotted as a function of the scattering angle, and when departing from the in-plane scattering configuration. The role played by the sea bottom is also non-negligible: the results reported are significant for target detection only in the case of silt sediment (remember, however, that the experiment is scaled: with wavelengths of an order of magnitude larger, the silt grain size scales to that of a sandy bottom). When the gravel bottom has been employed, scattering processes seem so dominated by the bottom that there is no appreciable difference in the response from different targets, at least with the dimensions employed in the experiment.

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