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Detection of Objects Buried in the Sea Bottom with the Use of Parametric Echosounder

Eugeniusz KOZACZKA[(1),(2)], Grażyna GRELOWSKA[(1)], Sławomir KOZACZKA[(1)], Wojciech SZYMCZAK[(1)]

[(1)] *Polish Naval Academy*
Śmidowicza 69, 81-103 Gdynia, Poland; e-mail: g.grelowska@amw.gdynia.pl

[(2)] *Gdańsk University of Technology*
Narutowicza 11/12, 80-233 Gdańsk, Poland; e-mail: kozaczka@pg.gda.pl

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The paper contains results of a *in situ* research main task of which was to detect objects buried, partially or completely, in the sea bottom. Object detecting technologies employing acoustic wave sources based on nonlinear interaction of elastic waves require application of parametric sound sources. Detection of objects buried in the sea bottom with the use of classic hydroacoustic devices such as the sidescan sonar or multibeam echosounder proves ineffective. Wave frequencies used in such devices are generally larger than tens of kHz. This results in the fact that almost the whole acoustic energy is reflected from the bottom. On the other hand, parametric echosounders radiate waves with low frequency and narrow beam patterns which ensure high spatial resolution and allows to penetrate the sea bottom to depths of the order of tens of meters. This allows to detect objects that can be interesting, among other things, from archaeological or military point of view.

Keywords: sea bottom, sea bottom acoustics, buried objects.

1. Introduction

Detection of objects occurring on or under the seabed surface presents a challenge for researchers interested in exploration of the sea bottom. The problem relates to objects buried at depths of up to several tens of meters from the seabed surface. Finding such objects is the subject of interest for a wide group of professionals, including archaeologists, marine safety specialists, and the military responsible for defending coastal waters. One of the currently developing non-invasive remote sensing methods consists in the use of phenomena accompanying nonlinear propagation of elastic waves.

Hydroacoustic examination of the seabed upper layer requires systems with high directivity beams in order to minimize sediment reverberation (Galloway, Collins, 1998; Hamilton *et al.*, 1999). Parametric sonar systems meet this requirement and generate low-frequency/wide-band beams with extremely concentrated main lobes (Grelowska *et al.*, 2010; Kozaczka *et al.*, 2012a). Due to their comparatively small dimensions and weight, parametric systems can be easily mounted on ROVs (remotely operated underwater vehicles) or AUVs (autonomous underwater vehicles); for this reason, they can be used as e.g. relocalization sensors for one-shot disposal systems combating mines buried in the seabed.

There are various types of high-resolution sub-bottom profiling systems, differing mainly in energy sources and receiving elements, their specific merits and demerits, and fields of application (Walter *et al.*, 1997; Turgut, 1998; Sternlicht, Moustier, 2003). One of the most popular and widely used sub-bottom profiling systems is that utilizing air gun(s) as the energy source and a separate receiving cable for recording reflected acoustic signals. A much more accurate system, called the parametric echosounder, is based on parametric sound generation. Probably the best known solution of this type is TOPAS (Topographic Parametric Sonar manufactured by Kongsberg) that allows to penetrate sea floor up to thousands of meters and is a superior sub-bottom profiling system as far resolution is concerned but is less popular due to its high cost. There are also other mobile parametric sediment echosounder systems available that allow to carry out surveys in shallow waters. The ultimate objective of this technique is to provide a spatially detailed and resolved picture of the seafloor and the subsurface sediment structures. High resolution seismic surveys are primarily confined to the uppermost 80 meters of sediments. This is the area used by majority of typical engineering applications. It is estimated that about 80% of sub-seabed technical infrastructure is located in the upper 15 to 20 meters. Some typical major applications include reconnaissance geological surveys, minerals exploration, foundation studies for offshore platforms, detailed site surveys for engineering projects, cable and pipeline route investigations, harbor development, and environmental studies.

However, single-beam echosounders, even parametric ones, provide information on the seabed only immediately below the surveying vessel. The footprint on the seabed varies in size, depending on the water depth and the local slopes, but is generally large. Seafloor coverage will therefore be variable and rather small.

The main feature of the parametric echosounder consists in generating a sounding pulse of frequency that can be set between 4 kHz and 15 kHz and occurs as a consequence of interaction of two main sounding pulses of higher frequencies, e.g. 100 kHz and 115 kHz. In the device used in the course of experiments described in this survey, the sea bottom was sounded with low frequencies sounding pulse using small-size antenna and additionally gaining narrow main lobe without side lobes.

The fields of most extensive commercial use of this technique include the oil/gas industry and the subsea engineering. High-resolution seismic/sub-bottom profiling surveys provide essential information necessary to make decisions concerning oil rig/platform site selection. Cable and pipeline route investigations need a very detailed picture of the top few tens of meters of the sediment, and sub-bottom reflection profiling method is the primary source of such information.

The technique of precise sub-bottom survey has one more application important for safety at sea. Nowadays, mass destruction weapons are frequently placed in shallow waters in a way making them very difficult to find. Detecting such objects in the sea requires the use of devices that offer possibility to penetrate sediment covering them.

This paper presents results of experimental research aimed at detection of underwater objects with the use of a device called the sub-bottom profiler. The research area was the Southern Baltic, with particular interest focused on the Gulf of Gdańsk.

Some examples of actual acoustics images obtained during the sea trials will be shown in the following together with physical interpretation.

2. *In situ* measurements

A bathymetrical measurement system with sub-bottom profiler was installed on a 10.5 m long small survey vessel. The parametric echosounder antenna was installed on the starboard and the multibeam EM3002 transducer on the port side 100 cm below water surface, with both devices fixed to special mounting arms. Additional navigation devices were tested in different locations and finally mounted in places optimal from the point of view of their functions. GPS receiver was installed in the center line of the vessel, close to the deck in order to minimize speed and position errors. The motion sensor MRU-Z was fitted near the vessel's center of gravity. After mounting the devices, measurements were made to define lever arms for each bathymetrical unit. GPS position, heading, and motion speed sensor signals were distributed to different devices used for the sea bottom investigation. Small measurement vessel with calibrated measuirng units was used during trials on Gdańsk Bay. Some interesting results of sounding and processing methods will be bring up.

The sub-bottom structure was investigated with the use of parametric echosounder SES-2000 manufactured by Innomar. This is a nonlinear transducer source which simultaneously transmits two signals with slightly different high frequencies at high sound pressures. Nonlinear interactions generate new frequencies in water, one of them being the difference frequency that has a bandwidth similar to the primary frequency. Both the primary HF signal (100 kHz) and the secondary LF signal (6 to 12 kHz) were recorded. Penetration occurred up to a few tens of meters in soft sediments. Advantages of the parametric acoustic system include:

1) small beam width at low frequencies;
2) deep penetration with high resolution of sediment layers and objects;
3) accurate depth measurements with the high frequency signal.

Data processing was carried out with the processing software ISE 2.9 which allows to edit and export layers to ASCII data, extend signal processing, convert and export data, and correct results for tide, water sound velocity, and GPS z-level.

Conditions of elastic wave propagation in the Baltic Sea depend strongly on hydrological parameters. For that reason, vertical distributions of sound speed as well as temperature and salinity were determined before measurements using STD/CTD sounder (SAIV A/S).

Echograms of the investigated area were taken during the research project devoted to detection of objects buried in the sea bottom. The purpose of this study was to observe the sea bottom structure and compare the obtained results to data given on the geological

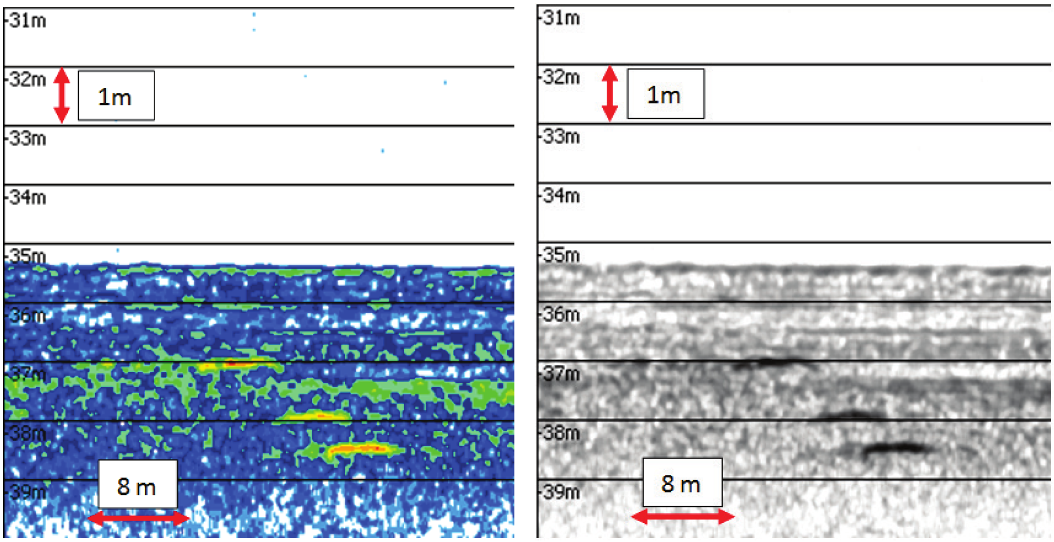


Fig. 1. Echogram with buried objects (the same echogram, but in different color scales).

map of the region (Uscinowicz, Zachowicz, 1994). Measurements were carried out along the paths crossing the Gulf of Gdańsk.

Some examples of data collected during sea bottom measurements are given in the following figures. They allow to assess the penetration properties of the equipment and determine the presence of buried objects as shown in Fig. 1.

High-resolution sediment echo-sounding allows to differentiate between sediment layers with different impedances (Wunderlich, Müller, 2003). Typically, an image is characterized by presence numerous distinct closely spaced continuous parallel horizontal reflectors. There are particularly strong major reflectors within such vertical sequence. Parametric echosounders allow to obtain information based only on perpendicular reflection from layer boundaries (Kozaczka *et al.*, 2012b). Investigations of wave propagation within individual layers have not been carried out to date. Acoustic penetration of the Gulf of Gdańsk ranged from about 5 to 40 meters depending on the seabed geoacoustic parameters.

To extract more information on the seabed structure, special post-processing software was developed. Data converted from the software dedicated to the parametric echosounder were imported to Matlab programming scripts where raw recorded signals (reflected from sediments) were processed. It allowed to present data collected during the measurements in different ways (as an envelope or typical signal). Some of them were helpful in obtaining more detailed information about the objects, especially relative strengths of the targets and their longitudinal dimensions, as in the example shown in Fig. 2.

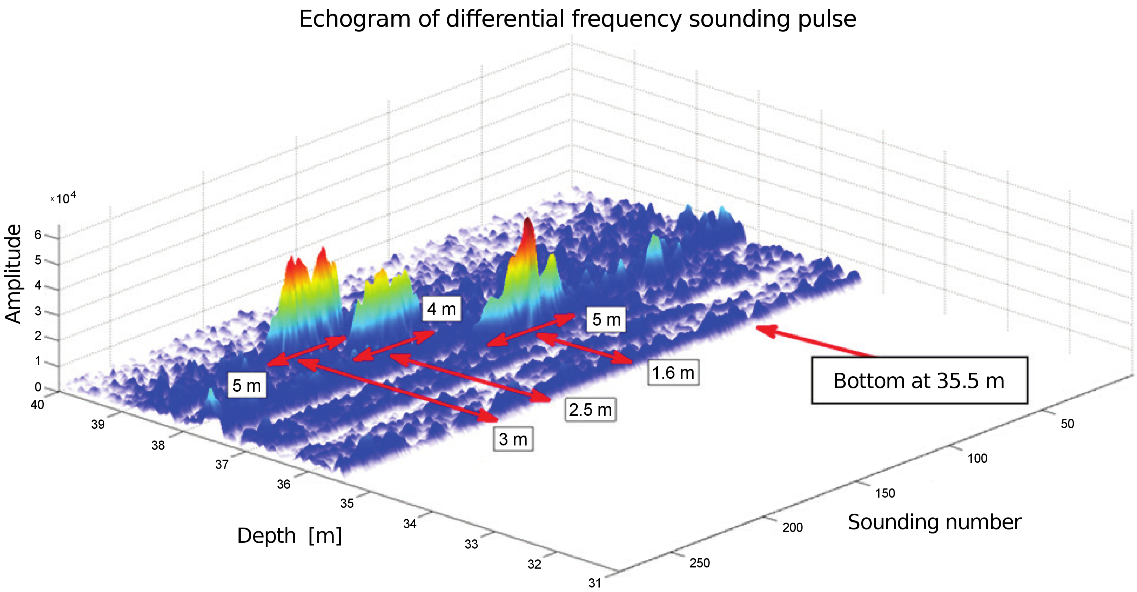
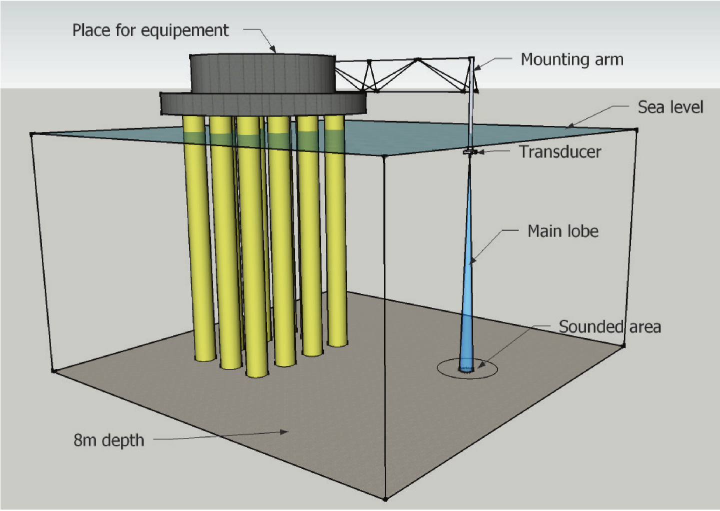


Fig. 2. Data from Fig. 1 after post-processing.

However, the problem how to differentiate remotely between objects with various shapes remains still unsolved. For this reason, measurements on a stationary range were carried out. Different types of objects of known shapes shown in Fig. 4 were used in the experiment (an object with the form close to Manta mine and steel canisters with different types of material inside). The equipment used in this experiment was the same as in the measurements carried out in the sea. The configuration of the measurement range is shown in Fig. 3. Antenna was mounted on an stable, aluminium holder. Objects were located directly under the transducer on the bottom surface and buried at different depths. All equipment used for the trials was placed



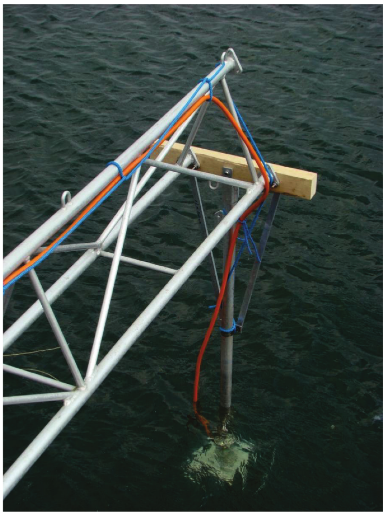


Fig. 3. Stationary range for *in situ* measurements.

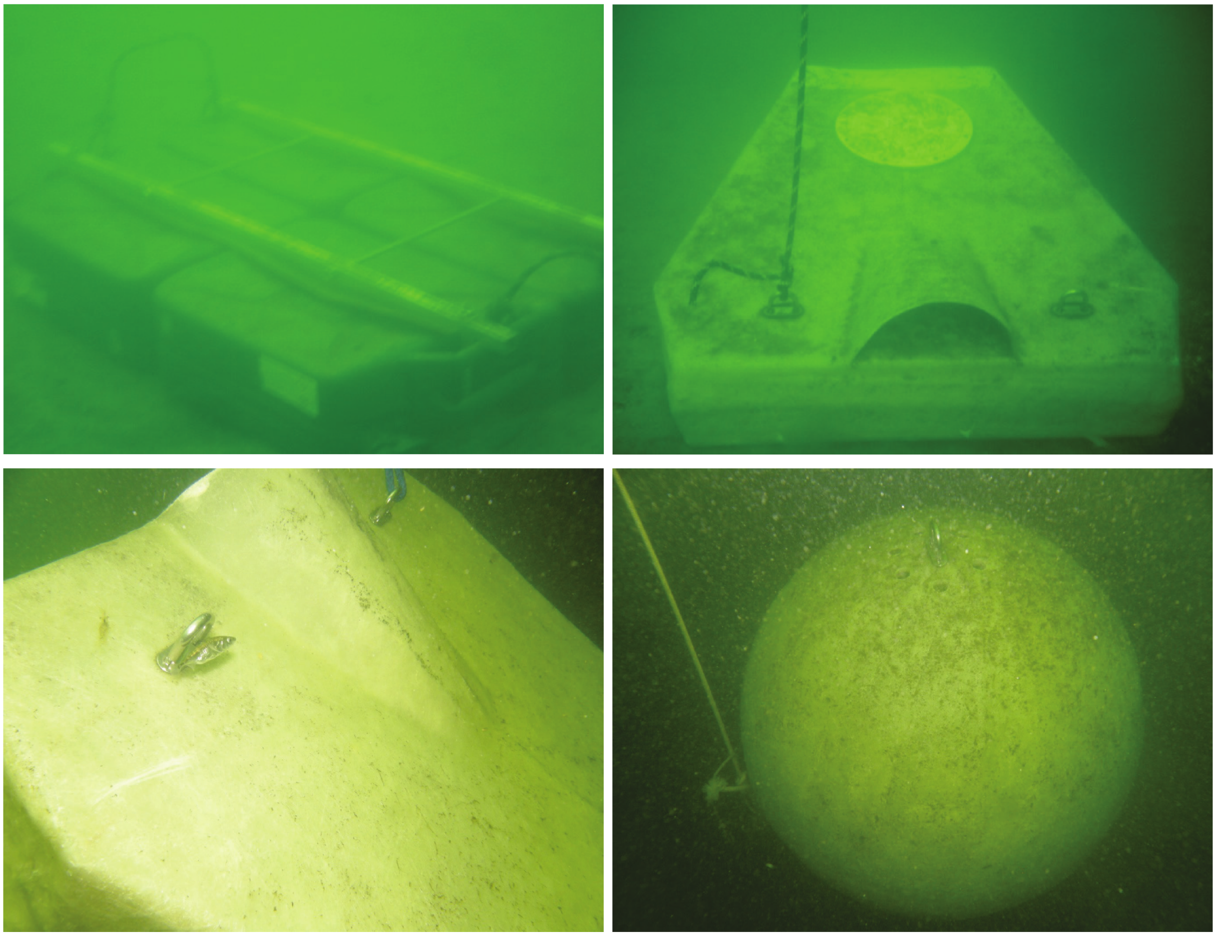


Fig. 4. Objects used as targets.

on a concrete base and powered via a long power cable plugged in ashore.

In the course of the experiment, echoes obtained from the bottom free of any objects were compared to data with an object or objects covered with the sediment and buried. Examples of the results are shown in Figs. 5 and 6. Results of sounding are shown as a comparison between the clear bottom image and the same area with objects placed on or under the seabed surface. In Fig. 5, first 440 pings correspond to the clear bottom, and the second part of visualization (pings numbered 441 to 1000) represents the object (a group of canisters filled with dry sand) placed on the bottom. Figure 6 can be interpreted the same way but there is a difference in location of canisters that are buried and covered with a 5 cm deep layer of seabed material.

3. Conclusions

Echograms of Southern Baltic bottom and sub-bottom obtained by means of parametric echosounder confirm usefulness of the device that allows to determine remotely the structure of the upper part of sea bottom and locate object buried in the seabed.

However, we cannot differentiate remotely between several different materials of sediments. This task requires a lot of experimental work in the course of which the acoustically obtained echograms should be attributed to sedimentary structures determined from sediment cores.

An important advantage of the presented high-resolution sub-seabed survey method would be the possibility to identify objects posing a threat in some cir-

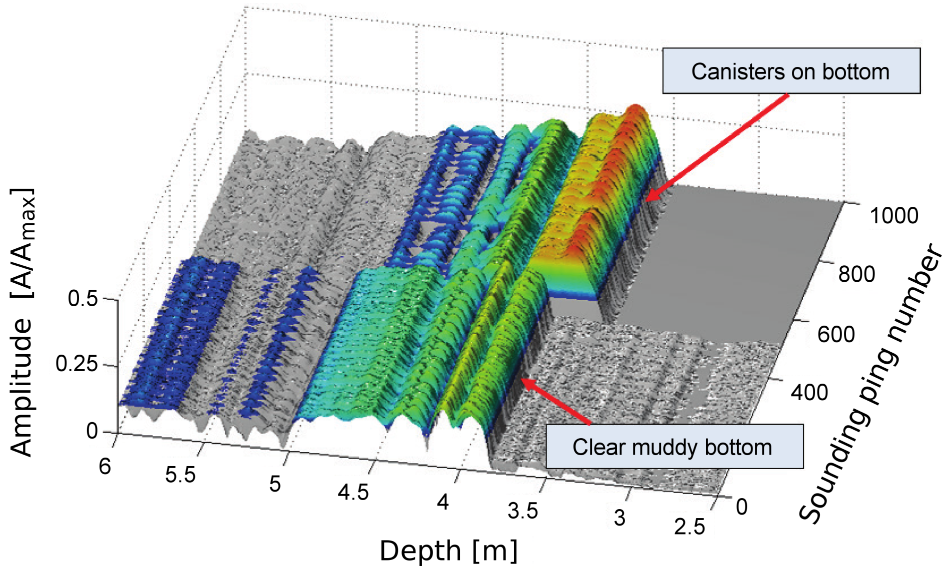


Fig. 5. A comparison of echograms: bottom clear and canisters on the seabed.

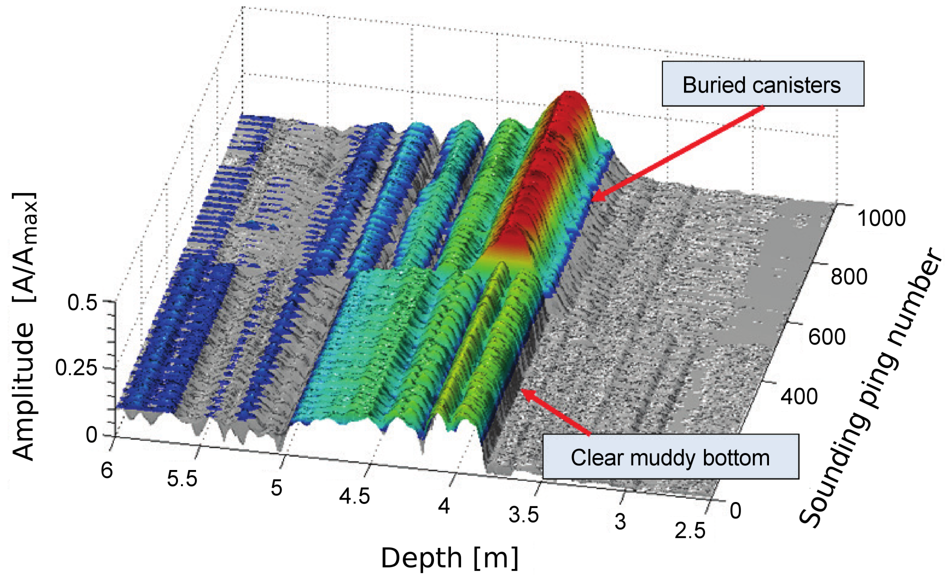


Fig. 6. A comparison of echograms: bottom clear and canisters buried in the seabed.

cumstances. Remote assessment of the type of buried objects needs a lot of experimental investigation and creation of a database of acoustical characteristics corresponding to different targets.

Acknowledgment

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