USING MULTIBEAM ECHOES IN SEAFLOOR CHARACTERISATION AND CLASSIFICATION

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The method of seabed identification and classification from multibeam sonar echoes is presented. The proposed approach is based on calculation of a set of parameters of an echo envelope, similarly as in seafloor classification using single beam echosounder. These parameters are extracted for each consecutive beam allowing the estimation of their dependence on the seafloor incident angle. The relation between seabed type and calculated echo parameters and its angular dependence, is investigated. The results obtained using sonar data records from several bottom types in Gdańsk Bay water region are presented and discussed. It has been primarily justified that the proposed approach may be useful in seafloor characterisation.

INTRODUCTION

The reliable and efficient seafloor characterisation and classification is an important problem related to many fields, for instance, to hydrography, marine engineering, environmental sciences, military applications, fisheries etc. Acoustics methods of sea bottom typing have known advantages over the other methods (e.g. using geological cores, underwater TV cameras etc.) as being faster, non-invasive, versatile and more cost effective.

The seafloor characterisation methods using parameters extracted from single beam echo are well known and verified (see [1] and [2] for example). The proposed, newly developed approach relies on calculation of a set of echo parameters for each consecutive beam of multibeam sonar. Then, the parameter dependence on the seafloor incident angle is estimated and used in seafloor type classification.

This work is the continuation of [3] and [4].

MATERIALS AND METHODS

The scheme of the applied approach was shown in Fig. 1.

The set of echo envelopes corresponding to particular beams was obtained as a multibeam sonar output (the sonar had to operate in „water column" mode in order to register the beam echo waveforms, not only the bathymetry information). After detection of a bottom echo in the received signal, the above set of echo parameters was calculated for an appropriate part of each beam echo, with averaging of obtained values for the whole set of echoes of the same transmission angle (for all swaths). The seafloor was assumed to be approximately flat, therefore the transmission angle was assumed to be equal to the incidence angle φ.

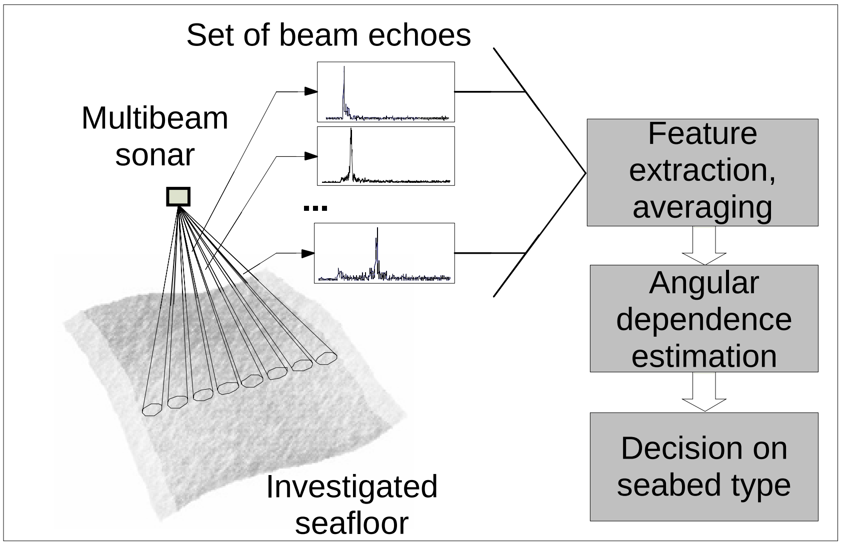

Fig.1 The used concept of multibeam echo processing for seafloor characterisation

In the investigation, the following groups echo parameters were calculated:

I. Basic parameters:
1. The echo total energy *E* calculated as a sum of squared acoustic pressure values of all echo samples.
2. The echo maximum amplitude.
3. The echo duration time (the echo length) *T*.

II. Parameters related to statistics of the echo energy:
1. Echo energy mean.
2. Echo energy standard deviation.
3. Echo energy skewness (normalised third statistical moment).

III. Parameters describing the echo geometric shape:
1. The center of gravity of an echo envelope along the time axis [2].
2. The normalised moment of inertia *I* [2] of the echo envelope, with respect to the axis containing its gravity center.
3. Fractal dimension *D* of an echo envelope, interpreted as a measure of its shape composedness. It was calculated as a box dimension approximation of a Haussdorff dimension, as described in [1].

The data used in the experimental verification of the proposed approach were acquired by the Kongsberg EM 3002 sonar in Gdańsk Bay region of the Baltic Sea in September 2007. Several sites of different seabed types were investigated, but the results are presented and discussed for 4 selected data measure points corresponding to 4 seabed types: mud, anthropogenic sand and mud, fine grained sand and coarse grained sand with stones. The information about seafloor type was taken from the geological map of the Gdańsk Bay. The sonar operating frequency was 300 kHz, the width of beams: 1.5° x 1.5°, the transmitted pulse length: 0.15 ms, the echo sampling rate: 14.3 kHz. The bottom depth was in a range approximately between 10 m and 100 m. 500 swaths from each of four seafloor types were processed. For each swath, 160 beams covered the angle sector from -65° to 65°, but only the beam echoes corresponding to angular sector from -25° to 25° were selected for further processing and parameter calculation. This was due to less complex pre-processing procedure for beams closer to normal incidence, as well as because the seafloor scattering of the acoustical signal is better known theoretically for the sounding direction more close to vertical.

RESULTS

2.1. Angular dependence of calculated echo parameter values

The obtained calculation results for selected parameters of beam echoes are presented in Fig. 2 in a form of plots of a dependence of a parameter value on a beam transmission angle for 4 bottom types.

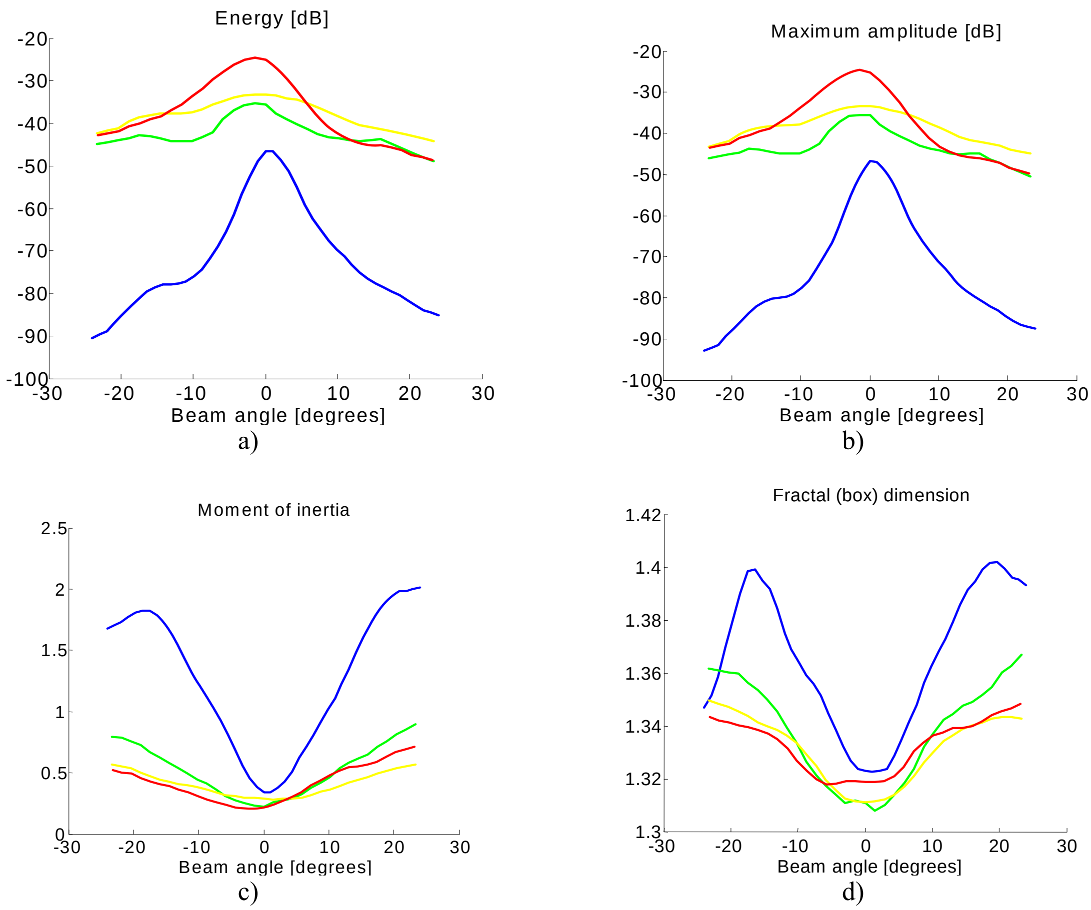

Fig.2 Dependence of selected calculated echo parameter mean values on a beam transmission angle for 4 bottom types: mud (blue), anthropogenic sand and mud (green), fine grained sand (yellow) and coarse grained sand with stones (red)

The total echo energy (Fig. 2a) has in general greater value for harder (sandy) than for softer (muddy) seabed. In all cases, its value decrease with the increase of the incident angle, what is generally in line with theoretical predictions, with the results obtained previously and also with those obtained by other authors ([5] for instance). The separation of mud from other bottom types using the echo energy value and its angular dependence is very easy, while the separation of other seabed types may be more difficult.

The parameters like the maximum amplitude (Fig. 2b) or those describing the statistics of the echo values were strongly correlated with the echo total energy and did not introduce the additional significant information.

The obtained angular dependence of the echo moment of inertia (Fig. 2c) has a very regular shape in all bottom cases. It is visible, that for example, the quantity defined as the average slope of the angular dependence of this parameter maybe useful in seabed classification. The increase of the echo moment of inertia value for higher angle of incidence is related to the echo length increase (see the previous paragraph) and the more uniform distribution of energy in an echo for angles more different from 0°.

The results obtained for fractal dimension of an echo envelope (Fig. 2d) are, to some extent, quite similar to those for moment of inertia. The increase of the fractal dimension value for higher angles of incidence may be explained by the increase of amount of the incoherent scattering, what results in more complex, irregular shape of the echo waveform. But there are differences in this effect for particular bottom types, so this parameter and its angular dependence also may be useful in seabed classification.

2.2. Quantitative features of the parameter angular dependence and their application in seafloor classification

As it was preliminarily shown in the previous subsection, the information retrieved from an angular dependence of multibeam echo parameters, may be useful in seafloor characterisation and classification. One of the approaches possible to be applied here could rely on the quantitative description of some selected features of this angular dependence. For instance, it could be the range of a parameter value, or the approximated slope of the angular dependence, within the specified angular sector. The latter has been selected for the preliminary testing of this approach. Using the same multibeam data records as in the previous subsection, the following quantities have been calculated for each sounding (swath):

- the approximated slope of the angular dependence of the beam echo moment of inertia $I(\varphi)$, for the angle range of [2°, 17°],
- the approximated slope of the angular dependence of the beam echo fractal dimension $D(\varphi)$, for the angle range of [4°, 19°].

The slopes were approximated using the best line fit in the minimum square error sense. The 2^D plot of the ($I(\varphi)$ slope, $D(\varphi)$ slope) pairs is presented in Fig. 3 with seabed type indicated by color and shape used to denote a single data point. Before plotting, the ($I(\varphi)$ slope, $D(\varphi)$ slope) values obtained for 10 consecutive swaths were averaged.

For comparison, the calculated values of the echo duration time T for normal incidence as well as of the echo energy E for normal incidence using the data from the same soundings, was also analysed in the similar way. The results for these quantities, corresponding to those used very often in the single beam seabed classification, are presented in a 2^D plot of the ($T(0°)$, $E(0°)$) pairs in Fig. 4.

It is visible, that in both cases (Fig. 3 and Fig 4) muddy bottom is well separable from 3 other types, which are significantly worse separable from each other. But it is generally also visible, that anthropogenic sand and mud, fine grained sand and coarse grained sand are better separable using $I(\varphi)$ slope and $D(\varphi)$ slope descriptors (Fig. 3) than using $T(0°)$ and $E(0°)$ descriptors (Fig. 4). This proves the applicability and usefullness of some echo parameters defined in a more composed way, like moment of inertia or fractal dimension, as well as the usefullness of the information aquired from the higher angles of incidence, in seafloor classification. The next stage of the investigation could be the testing and comparison of the performance of the automatic classifiers operating on both datasets, e.g. on data presented in Fig. 3 and Fig. 4.

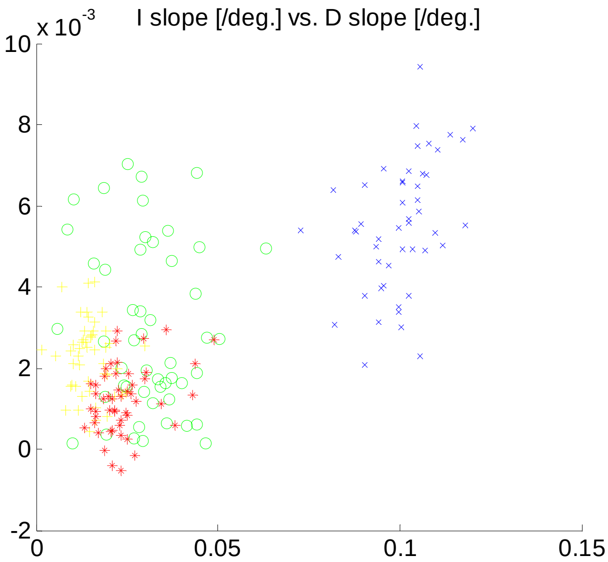

Fig.3 2^D plot of the quantitatively described features of the angular dependence of echo parameters, namely, the $I(\varphi)$ slope vs. $D(\varphi)$ slope approximation, for 4 datasets corresponding to 4 investigated seabed types: mud (blue, x letters), anthropogenic sand and mud (green, circles), fine grained sand (yellow, crosses) and coarse grained sand with stones (red, stars)

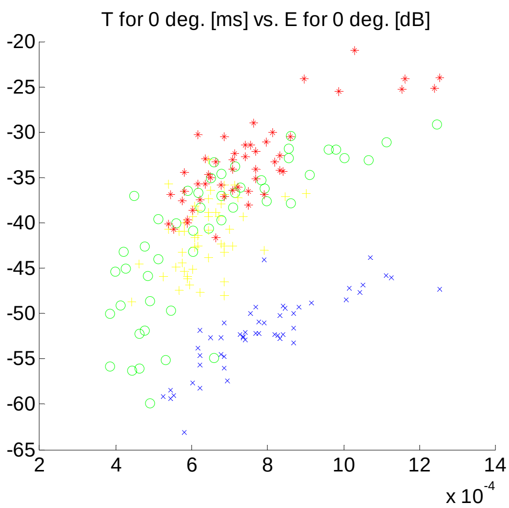

Fig.4 2^D plot of the obtained echo duration time for 0° incidence angle vs. echo energy for 0° incidence angle, for 4 datasets corresponding to 4 investigated seabed types: mud (blue, x letters), anthropogenic sand and mud (green, circles), fine grained sand (yellow, crosses) and coarse grained sand with stones (red, stars)

3. CONCLUSION

It has been primarily justified by the obtained results that the information extracted from multibeam seafloor sensing data in a form of an angular dependence of several echo parameter value, may be useful in seafloor characterisation. The usefulness of the proposed parameters of a beam echo waveform and its angular dependence in seabed classification has been preliminarily tested. In particular, it has been shown that some of echo parameters defined in more composed way, like the moment of inertia for instance, has more regular (what could mean – less sensitive to local experiment conditions) dependence on the incident angle than in a case of other parameters, i.e. echo energy or duration time. Also, it was proved that application of the former should result in better classification performance.

However, it must be pointed out that to obtain the more reliable results, the verification of the proposed approach using the larger amount of experimental data as well as with application of a more reliable ground truthing mehod is needed.

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REFERENCES

1. Z. Łubniewski, Application of fractal analysis and inverse filtering in the remote seabed classification and monitoring, PhD thesis, Gdańsk University of Technology, 2001.
2. J. Tęgowski, Z. Łubniewski, Application of some echo parameters to the seabed classification - methodological analysis, Hydroacoustics, 4, 237-240, 2001.
3. Z. Łubniewski, K. Bikonis, A. Chybicki, A. Stepnowski, Application of angular dependence of sonar echo features in seafloor characterisation and imaging, Revista de Acustica, 38, 3-4, 2007, Special Issue: Official Publication of the 19th International Congress on Acoustics ICA 2007, Madrid.
4. Z. Łubniewski, A. Chybicki, Seabed classification using multibeam echosounder, Proceedings of the 1st International Conference on Information Technology, Gdańsk 2008.
5. J. E. Hughes Clarke, B. W, Danforth, P. Valentine, Aereal seabed classification using backscatter angular response at 95 kHz, Saclantcen Conference Proceedings Series CP-45, High Frequency Acoustics in Shallow Water, 243-250, La Spezia 1997.