SEAFLOOR CHARACTERISATION USING MULTIBEAM SONAR ECHO SIGNAL PROCESSING AND IMAGE ANALYSIS

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The authors propose the approach to multibeam seafloor characterisation which relies on the combined, concurrent use of two different techniques of multibeam sonar data processing. The first one is based on constructing the grey-level sonar images of seabed using the echoes received in the consecutive beams. Then, the parameters describing the local region of sonar image, namely, the local standard deviation of a grey level, and the slope of a local autocorrelation function of a grey level, are calculated. The second technique assumes the use of a set of parameters of the multibeam echo envelope, similarly as in single beam classification. For selected parameters, namely, for echo envelope moment of inertia and for echo envelope fractal dimension, the slope of their angular dependence is calculated. Finally, the quantities obtained by these 2 techniques have been combined together and the multidimensional distributions of sets of them have been analysed in the context of seabed classification procedure. The approach has been tested using multibeam data records acquired from several bottom types in the Gulf of Gdańsk region. The preliminary results show that application of the proposed combined approach should improve the classification performance in comparison with that of using only the one scheme of seafloor multibeam data processing.

INTRODUCTION

The multibeam sonars, besides their well verified and widely used applications like high resolution bathymetry and underwater object detection and imaging, are also the promising tool in seafloor characterization and classification, having several advantages over conventional single beam echosounders. However, the efficient and reliable methods of multibeam data processing for seabed classification have not been stated and verified enough yet and they are still the subject of the extensive research.

The proposed approach relies on the combined use of two different techniques of multibeam sonar echoes processing. The first one is based on constructing the grey-level sonar images of seabed extracted from the echoes received in the consecutive beams. Then, the set of parameters describing the local region of sonar image is calculated. The second technique has been already applied and preliminarily tested by the authors (see [1] for instance). It assumes the use of a set of parameters of the multibeam echo envelope and estimation of the dependence of their values on the beam incident angle.

1. MATERIALS AND METHODS

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

As it was mentioned in the introductory section, the combination of two techniques of multibeam sonar data processing was utilised. Using the first technique, the set of echo envelopes corresponding to particular beams was obtained as a multibeam sonar output in the sonar „water column" mode. After detection of a bottom echo in the received signal, the set of echo parameters was calculated for an appropriate part of each beam echo [1]. In this work, two echo parameters were used in further processing:

1. The normalised moment of inertia I [2] of the echo envelope, with respect to the axis containing its gravity center.

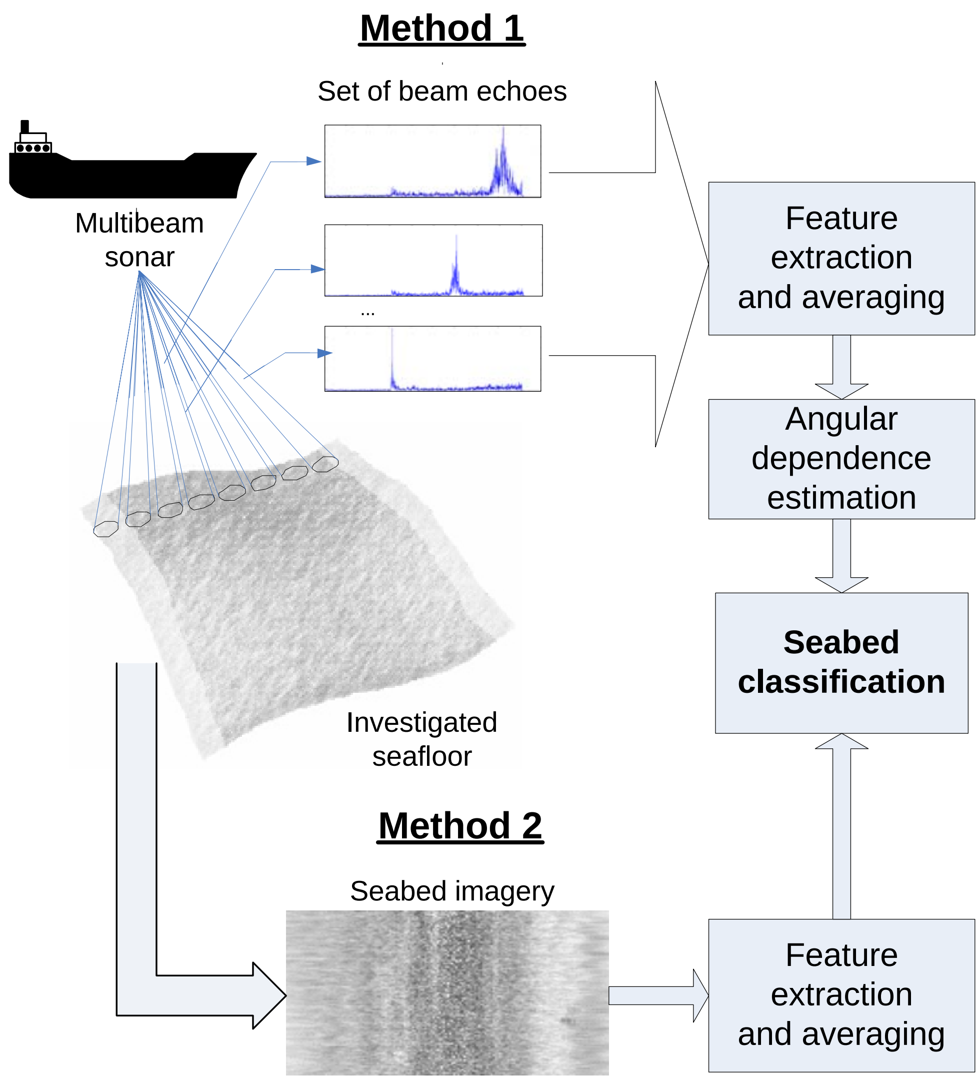

Fig.1. The used concept of multibeam sonar data processing for seafloor characterisation

2. 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].

For each seabed type, the dependence of I and D parameter values on the beam incident angle was estimated. The seafloor was assumed to be approximately flat, therefore the transmission angle was assumed to be equal to the incidence angle φ for each beam. The estimated angular dependences for a set of multibeam echo parameters may be found in [1].

In the context of the classification procedure construction and testing, the following quantities have been calculated for each sounding (swath), based on the I and D angular dependencies:

- 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.

In the second technique of multibeam sonar data processing (see Method 2 in Fig. 1), the grey-level sonar images of seabed surface were utilised, like, for instance, in [3]. Usually, such images are generated by the multibeam sonar firmware. Sample images of four seabed types are shown in Fig. 2.

Then, for each bottom type, two parameters describing the local region of sonar image were calculated:

1. Local standard deviation of a grey level (*STD*).
2. Slope of the autocorrelation function of a grey level (in along track direction) approximated for a local region of the image (*SL_AUTC*).

Finally, using the results obtained by both techniques described above, the 2^D plots of calculated values for selected pairs of echo or image parameters were constructed. They are presented in the next section.

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 of the current investigation are presented and discussed for 4 selected data measure sites corresponding to 4 seabed types: mud, anthropogenic sand and mud, fine grained sand and coarse grained sand. 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 between 10 m and 100 m. Approximately 1000 swaths from each of four seafloor types were processed. For each swath, 160 beams covered the angle sector from -65° to 65°. In the first technique, the beam echoes corresponding to angular sector from -25° to 25° were selected for further processing and parameter calculation. In the second technique, the seabed sonar image part corresponding to the beam angle sector between 15° and 30° was selected for processing. In the estimation of standard deviation of an image grey level, the size of a local image region was chosen as 11 x 11 pixels. In the estimation of the autocorrelation function slope, the used window size was 61 pixels and the maximum lag was 5 pixels.

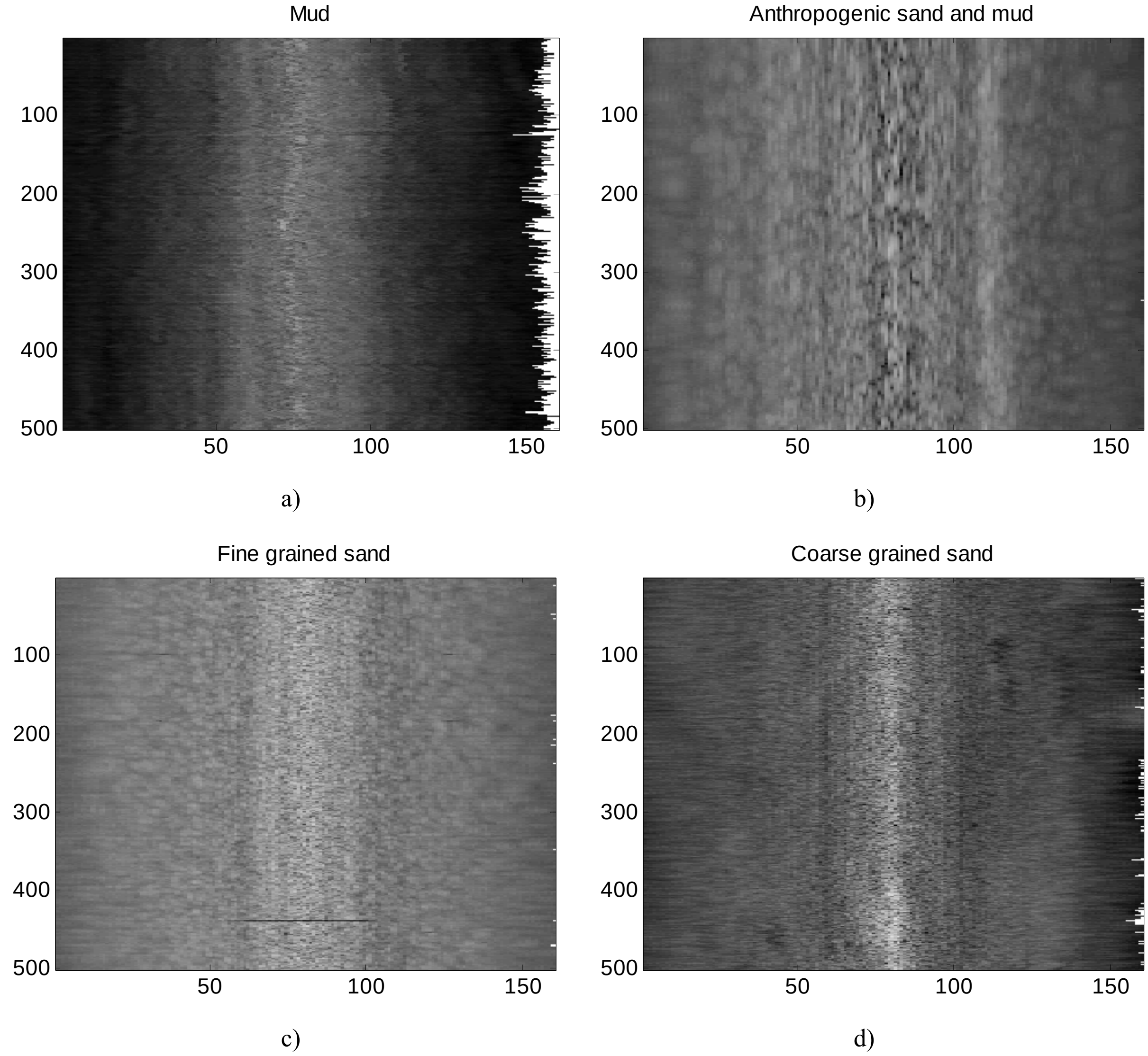

Fig.2. Sample sonar images of 4 investigated seabed types: a) mud, b) anthropogenic sand and mud, c) fine grained sand (yellow), d) coarse grained sand

2. RESULTS

The 2^D plots of pairs of parameter values are presented in Fig. 3 with seabed type indicated by color and shape used to denote a single data point.

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 as other results. 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. 3a.

The 2^D plot of the ($I(\varphi)$ slope, $D(\varphi)$ slope) pairs is presented in Fig. 3b. The 2^D plot of the (*STD*, *SL_AUTC*) pairs is presented in Fig. 3c. Finally, Fig. 4d presents of $I(\varphi)$ slope calculation results combined with *SL_AUTC* calculation results, e.g. one „echo" parameter combined with one „image" parameter.

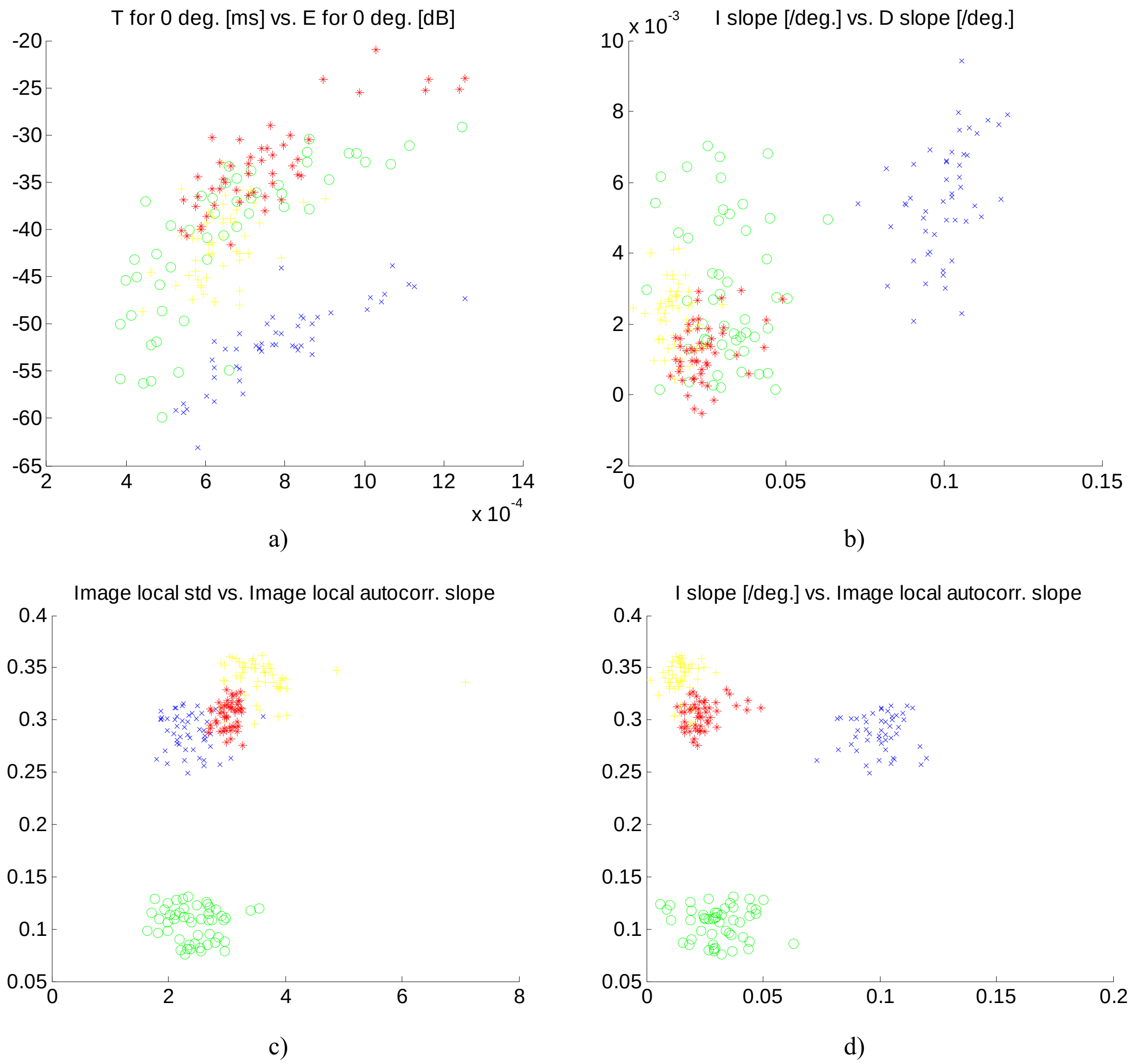

Fig.3. 2^D plots of pairs of calculated parameter values of 4 investigated seabed types: mud (blue, x letters), anthropogenic sand and mud (green, circles), fine grained sand (yellow, crosses) and coarse grained sand with stones (red, stars)

First of all, it is visible, that for all the cases b), c) and d), the results are better, e.g. the seabed classes are easier separable, than in a normal incidence parameters $T(0°)$, $E(0°)$ case – a), what preliminarily proves the advantages of the presented novel approaches.

Using the ($I(\varphi)$ slope, $D(\varphi)$ slope) pair of parameters (what has already been presented in [1]) allows for good separation of mud from 3 other seabed types – Fig.3b), while using the „image" parameter (*STD*, *SL_AUTC*) pair (Fig. 3c) makes it possible to distinct clearly between anthropogenic sand and mud and other types, especially due to differences in local autocorelation slope values. It may be pointed out that the differences between spatial autocorelation properties of this bottom type and other bottom types are also visible in sonar images presented in Fig. 2. The more coarse structure of the grey lavel variability may be noticed in Fig. 2b) in comparison with other cases.

Finally, using the $I(\varphi)$ slope combined with the *SL_AUTC* calculation results, e.g. one „echo" parameter combined with one „image" parameter, allows for very good separation of almost all seabed classes, with the only exeption of fine grained sand mixed with coarse grained sand. However, these two bottom types are very similar to each other, what is also visible in Fig. 2c and d. This result shows that the combined use of descriptors extracted from multibeam sonar echo as well as from multibeam sonar image should improve the seabed clasification performance.

3. CONCLUSION

The approach to multibeam seafloor characterisation, which relies on the combined, concurrent use of two different techniques of multibeam sonar data processing, was presented. One technique relies on the use of a set of parameters of the multibeam echo envelope and estimation of the dependence of their values on the beam incident angle, while the other is based on calculation of the the set of parameters describing the local region of sonar image. It has been primarily justified by the obtained results that both techniques may be useful in seafloor characterisation, and the combined use of the results of both of them should improve the final results.

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

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