On Algorithm Details in Multibeam Seafloor Classification

Zbigniew ŁUBNIEWSKI, Dariusz SĘK

Gdańsk University of Technology
Faculty of Electronics, Telecommunications and Informatics
Department of Geoinformatics
Gdańsk, Narutowicza 11/12, Poland
Zbigniew.Lubniewski@eti.pg.gda.pl

Remote sensing of the seafloor constitutes an important topic in exploration, management, protection and other investigations of the marine environment. In the paper, a combined approach to seafloor characterisation is presented. It relies on calculation of several descriptors related to seabed type using three different types of multibeam sonar data obtained during seafloor sensing, viz.: 1) the grey-level sonar images (echograms) of the seabed, 2) the 3D model of the seabed surface which consists of bathymetric data, 3) the set of time domain bottom echo envelopes received in the consecutive sonar beams. The proposed methodology has been tested using field data records acquired from several bottom types in the Southern Baltic Sea. Using the examples of particular parameters, the influence on the specific manner and details regarding their calculation, i.e. the size of the applied current local window to a sonar image, on the obtained classification performance, is discussed.

Keywords: seafloor classification, multibeam sonar, sonar data processing

1. Introduction

Multibeam sonars are widely used in applications like high resolution bathymetry measurements, or underwater object detection and imaging. For multibeam seafloor characterisation and classification, several approaches have been investigated and utilised. Many of published works, e.g. [1], are based in principle on investigation of the characteristic, local features of a sonar image which is composed of pixels, the grey level of which corresponds to backscattering strength for particular beam echoes and transmissions.

Another approach utilises the dependence of echo properties on the incident angle in multibeam sounding, mainly the derived backscattering strength. The detailed discussion on the appropriate pre-processing of multibeam echoes, including the need of calibration and artefact removal, as well as on the statistical properties of the seafloor echo backscattering strength, is given in [2]. In [3][4] the statistical Bayesian approach to seabed classification using backscattering strength calculated for multibeam echoes is presented.

The newer work of Stephens and Diesing [5] contains a detailed study on supervised seabed sediment classification performance based on multibeam data and ground- truth sampling data, with respect to several bathymetric and acoustic features, various classification methods, and generalisation capabilities of a given classification scheme (e.g. its sensitivity to noise features).

Finally, besides the approaches mentioned above based mainly on utilisation of measured data features in the phenomenological manner, the multibeam seafloor characterisation methods relying on the inversion of seabed physical parameters have been also investigated. For instance, in [6] the authors presented the model-based geo-acoustic seabed properties inversion scheme to be applied on the dependence of multibeam seafloor reverberation on the beam incident angle. The model used in this study was the extension of the BORIS model mentioned in the previous section, the so-called BORIS Small Slope Approximation (BORIS-SSA) model.

The comprehensive overview of acoustic seabed seafloor classification methods, including the use of single beam echosounders, sidescan sonars, multibeam sonars, seismic sources and other equipment, is given in [7].

Many authors, e.g. [3][5][7] admit that the methodology of seafloor classification by means of underwater acoustics still has several shortcomings, e.g. the variable and often unpredictable usefulness of particular utilised features in classification, sensitivity of a method performance to variability of a water region, as well as the used equipment characteristics, difficulties in obtaining the ground-truth data etc. In this context, the author's contribution to the subject seems to be valuable. In the paper, the concept of a combined method of multibeam sonar data processing for seabed classification is presented. It relies on extracting features characterising seabed from three types of information which is obtained from multibeam seafloor sensing: grey-level sonar echograms, bathymetric 3D point cloud model of seabed surface and the set of echo signal envelopes corresponding to a set of beams. In the presented paper, the main focus is paid to the influence of the algorithm specific settings, e.g. the size in pixels of the source data subset used in a single run of the feature extraction procedure, onto the final classification results.

2. The concept

The proposed approach to seafloor classification relies on the combined use of three different techniques. In each of them, a set of descriptors foreseen to be applied in the seabed classification procedure, is calculated using a given type of data obtained from the multibeam sonar system. The schematic concept of the applied approach is shown in Fig. 1.

In the first technique used, i.e. *Method 1* in the figure, the grey-level sonar echograms of seabed surface are utilised [8]. In the course of data processing, a set of parameters describing the local region of sonar image is calculated for each bottom type. The parameter set includes, but is not limited to: 1) basic statistical parameters describing the grey level distribution, i.e. local mean (*MEAN*) and standard deviation (*STD*), 2) the slope of the autocorrelation function of a grey level (in along track direction) approximated for a local region of the image (*SL_AUTC*). The pixel grey level corresponds to the calibrated backscattering strength of the seabed, with removed influence of the device settings or signal amplification. It should be noticed that the influence of the beam angle on the backscattering strength is not being removed from the data.

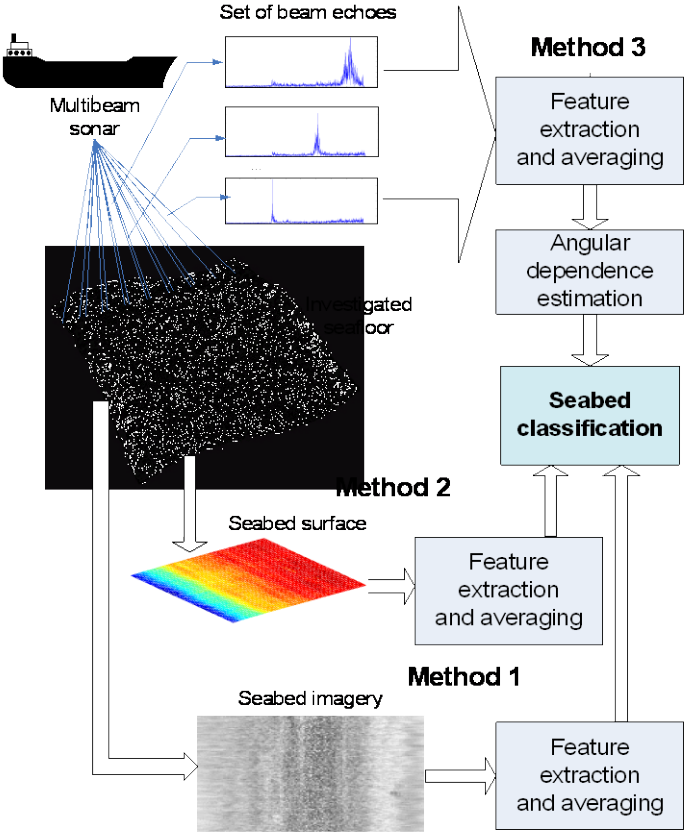

Fig. 1. The scheme of the integration of three different techniques in one combined method of seafloor classification using multibeam sonar

In the second technique of multibeam sonar data processing (*Method 2* in Figure 1), the 3D “bathymetric” model of seabed surface is utilised [9]. It is constructed as a set of (x, y, z) points obtained from the detected bottom range for each beam, within the multibeam sonar seafloor imaging procedure. Next, for the local region of the constructed seabed surface, the set of descriptors is calculated, namely: rms height (*SURF_RMS*), skewness of height (*SURF_SKEW*), seabed surface local curtosis (*SURF_CURT*) and seabed surface local autocorrelation slope (*SURF_AUTC*).

In the third technique of multibeam sonar data processing (*Method 3* in Figure 1), the set of echo signal envelopes received in the particular beams is analysed [10]. The data processing procedure in this method is more complex than in the two previous ones. Firstly, after detection of a bottom echo in the received signal, the set of echo parameters is calculated for an appropriate part of each beam echo. The parameters include: 1) the normalised moment of inertia I of the echo envelope, with respect to the axis containing its gravity centre [8], 2) fractal dimension D of an echo envelope, interpreted as a measure of its shape irregularity [8]. In the next stage, for each seabed type, the dependence of I and D parameter values of the particular beam incident angle is estimated. Using the estimated I and D angular dependence, the following parameters are calculated for each sounding (swath) for the application in the seafloor classification procedure: 1) the approximated slope of the angular dependence of the beam echo moment of inertia $I(\varphi)$, for the angle range of [2°, 17°] (*I_SLOPE*), and 2) the same approximated slope for the beam echo fractal dimension $D(\varphi)$, for the angle range of [4°, 19°] (*D_SLOPE*).

Finally, using the results obtained by the techniques described above, the 2D or 3D plots of calculated values for selected pairs of echo parameters were constructed. Also, using the calculated parameters, the supervised classification tests have been performed, with the use 20% of the dataset as a training set with respect to each case of seabed type. Sample results are presented.

3. The experiment

The field data acquisition for verification of the proposed approach is summarized as follows. The measurements were conducted using Kongsberg EM 3002 sonar in the Gulf of Gdansk region of the Southern Baltic from 2007 to 2009. Several sites of different seafloor types were investigated, but the results of the current investigation refer to 4 selected sites, characterised by the following true 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. Fig. 2 presents the simplified geological chart of the investigated water region, taken from [11], along with locations of multibeam data acquisition sites. The sonar operating settings were as follows: frequency: 300 kHz, beamwidth: 1.5° x 1.5°, transmitted pulse length: 0.15 ms, echo envelope sampling rate: 14.3 kHz. The bottom depth was in the 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°.

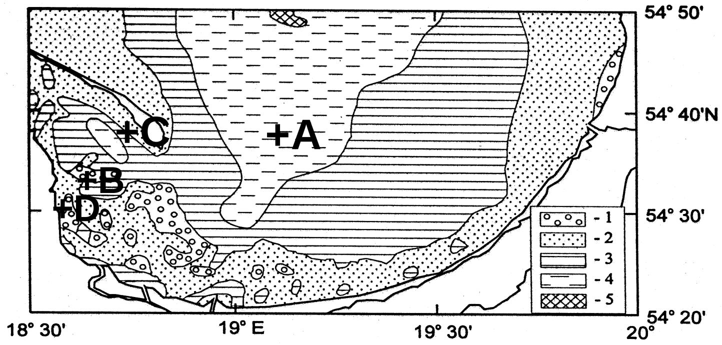

Fig. 2. The geological map of the Gdańsk Bay, taken from [11]: 1 – gravels, stones, 2 – sands, 3 – marine silty clay, 4 – mud, silt, 5 – glacial marine clay, with added locations of measurements indicated by letters A, B, C and D corresponding to seabed types listed in the Fig. 3 caption

4. Sample results

Sample results, with respect to the selected triplet of parameters: *I_SLOPE, STD, SL_AUTC* as seabed type descriptors, are presented in the form of the 3D plot in Fig. 3, and in a form of classification procedure confusion matrix in Tab. 1. The simple minimum distance classifier with Euclidean metrics was used.

It is visible that the choice of this set of 3 descriptors allows for quite good separation of the particular seabed classes as well as for very good classification performance – expressed in a total of 97.19% correct classifications. Only the fine grained sand overlaps to some extent with the coarse grained sand (but it should be taken into account that these two bottom types do not differ too much from each other).

However, it should be strongly pointed out that although the achieved seabed classification accuracy (near 100% in several cases) is very high in comparison with the results of 70-80% reported by other authors, it may not be the proof of the advantage of the proposed methodology over the other approaches. The amount of data used for the verification was small, and the acquired data corresponding to 4 separate sites of the particular 4 seabed types differ significantly, which is well visible in 2D or 3D plots of parameter values (see Fig. 3, or some plots in Fig 4 and Fig. 5). It is predictable that this will not occur in the case of a larger investigated water region, or more complicated classification task (e.g. concerning sensing the seafloor continuously in space, with mixed seabed types and gradually changing sediment properties). So, the proposed methodology should be more widely verified; in specific, by using a larger amount of field data, and with respect to several water regions.

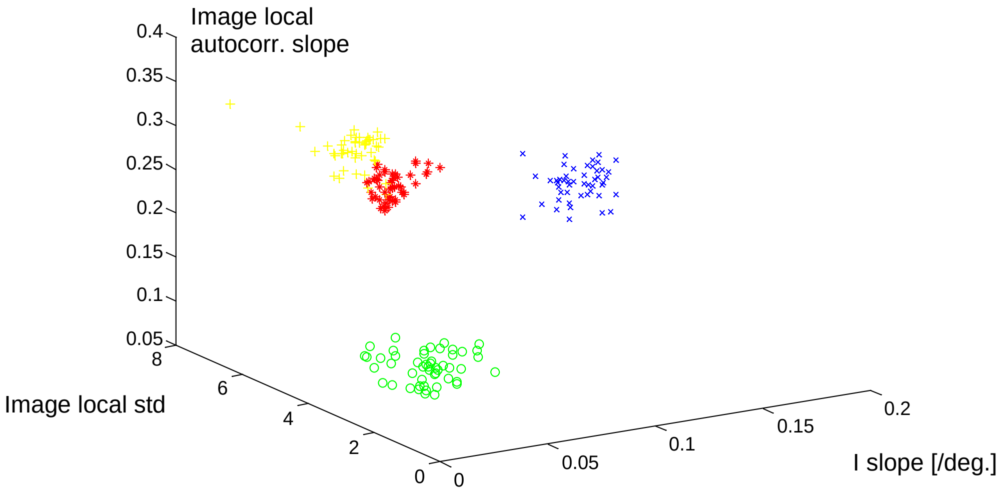

Fig. 3. Plot of triplets of calculated parameter values: (*I_SLOPE*, *STD*, *SL_AUTC*) for 4 seabed types: mud (blue, x letters), anthropogenic sand and mud (green, circles), fine grained sand (yellow, crosses) and coarse grained sand (red, stars)

Tab. 1. Confusion matrix for minimum distance classification of 4 seabed types using (*I_SLOPE*, *STD*, *SL_AUTC*) triplets as the descriptors

Assigned class / **True class**	**Mud**	**Anthr. sand and mud**	**Fine grained sand**	**Coarse grained sand**
Mud	**100%**	0%	0%	0%
Anthr. sand and mud	0%	**100%**	0%	0%
Fine grained sand	1.25%	0%	**90%**	8.75%
Coarse grained sand	0%	0%	1.25%	**98.75%**
Correct classifications - total: 97.19%				

5. Algorithm details influence on the results

In the course of the presented investigation, a study regarding the details on the manner used in particular parameters calculation, have been performed. In particular, the algorithms for *STD* and *SL_AUTC* calculation have been more deeply tested, namely, the influence of the particular (somehow arbitrary) choice of the algorithm settings like:

- the used sector of beams (i.e. the range of beam angles) in defining the sonar image subset for processing (*BEAMS*);
- the used sonar image subset size in along-track direction (number of lines/soundings) (*SOUNDINGS*); *BEAMS* and *SOUNDINGS* values define the size (*BEAMS* defines also the across-track location) of the image subset used for single parameter value calculation;
- the used maximum offset in the autocorrelation function slope estimation (*MAX_LAG*)

on the results have been investigated.

Sample results are presented in Fig. 4 and Fig. 5 in the form of 2D plots of the calculated (*STD*, *SL_AUTC*) parameter values for 4 seabed types, for 2 cases of the algorithm particular settings.

As can be partially derived from Fig. 4 and Fig. 5 contents, the obtained results might be summarised as follows:

- The obtained class separation as well the classification results are quite sensitive to the choice of BEAMS. In particular, results significantly better than in other cases have been obtained for the beams range from beam no. 86 to beam no. 95 (with total number of 160 beams) which corresponds to beam angles near normal incidence, but not including the 0° beam. As, according to the results reported by other researches, more representative are other angle ranges, this finding needs further verification.

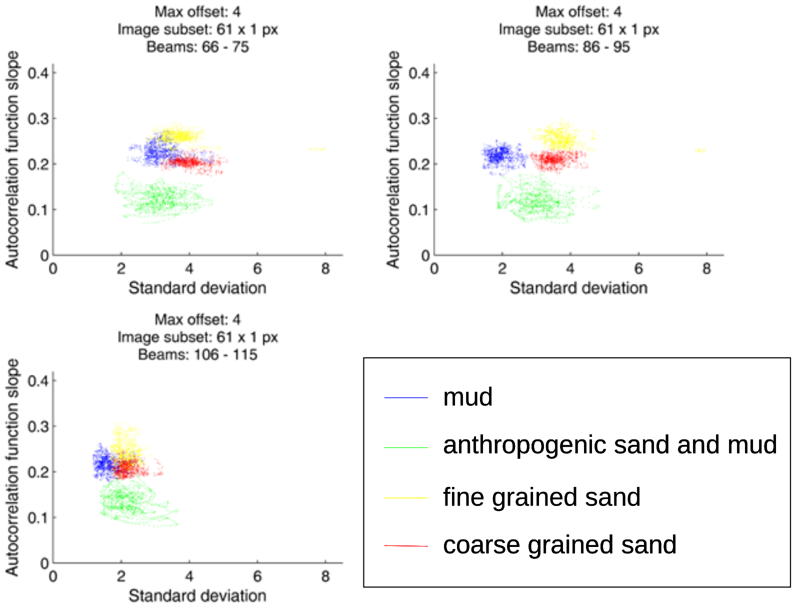

Fig. 4. Plot of pairs of calculated parameter values: (*STD*, *SL_AUTC*) for 4 seabed types, for the following details of parameter calculation algorithm: *SOUNDINGS*: 61, *MAX_LAG*: 4 and for 3 different ranges of *BEAMS*

- The obtained results are better for *SOUNDINGS* of about 40 or 60 and worse for *SOUNDINGS* above 80.
- The MAX_LAG (being equal to 3, 4, 5 or 6 pixels during calculations) does not influence significantly the results.

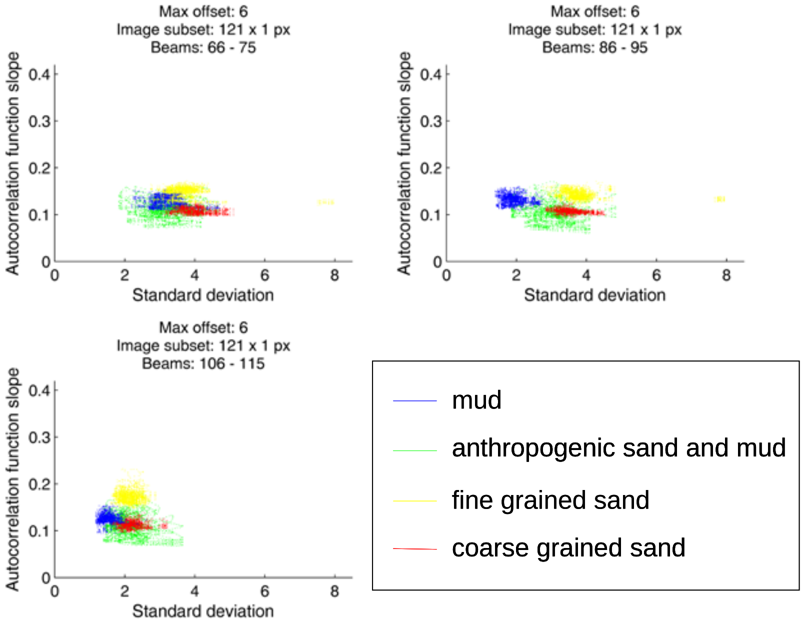

Fig. 5. Plot of pairs of calculated parameter values: (*STD*, *SL_AUTC*) for 4 seabed types, for the following algorithm details: *SOUNDINGS*: 121, *MAX_LAG*: 6, and for 3 different ranges of *BEAMS*

6. Conclusions

The approach to seafloor classification, which relies on the combined, concurrent use of three different methods of multibeam sonar data processing, was presented. It has been primarily justified that all techniques are useful in seafloor characterisation, and the fusion of them improves the classification performance. Using the examples of particular parameters, the influence on the specific manner and details regarding their calculation, i.e. the size of the applied current local window to a sonar image, on the obtained classification performance was investigated.

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