HYDROACOUSTICS
4, 153-156 (2001)

MODELLING THE SEAFLOOR 3^D RELIEF AND ITS RECONSTRUCTION FROM MULTIBEAM SONAR DATA

Z. Łubniewski and M. Moszyński

Department of Remote Sensing and Monitoring Systems,
Technical University of Gdańsk, Narutowicza 11/12, 80-952 Gdańsk, Poland.
,email: lubniew@eti.pg.gda.pl, marmo@pg.gda.pl

The simple, real-time procedure for seafloor relief reconstruction and simultaneous seabed type identification using echo data from hypothetical multibeam sonar system was proposed. The algorithm was tested using artificially generated relief and seabed type data. In the first stage, 3^D surface of seafloor was generated, using the inverse Fourier transformation of the 2^D spatial frequency spectrum of power law form. In the second stage, the generation of the set of multibeam sonar data, which simulated echoes collected from seabed, was performed with account for the the distances from transducer to particular surface elements, scattering coefficient and the angles of insonification. Finally, the spatial form of seabed was reconstructed using the simulated data, while bottom type was identified simultaneously using estimated angular dependence of backscattering coefficient. The obtained results showed the good performance of the proposed reconstruction procedure for artificial data and suggested verification of the algorithm using real data.

INTRODUCTION

There are known advantages of application of multibeam sonars over single-beam echosounders in remote seafloor characterisation. For each transmission performed by multibeam sonar, a set of echoes scattered with different insonification angles and on different seabed parts is acquired. There are also known applications of multibeam sonars in enhanced bathymetry measurements and seafloor relief mapping [4]. Less work is done up to date in the subject of multibeam seabed classification methods, which would utilise the angular dependence of bottom backscattering strength, for instance [1]. The authors propose the algorithm of real-time multibeam data processing, which aim is both to recover the bottom relief and to classify the seabed type simultaneously.

2. THE CONCEPT

When the multibeam sonar system with N_b beams transmits sounding signal towards seabed, a set of N_b echoes $e_1(t)$, $e_2(t)$, ..., $e_{N_b}(t)$ corresponding to N_b angles of incidence θ_1, θ_2, ..., θ_{N_b} is obtained for each scan (Fig. 1a). In the simple processing algorithm, each echo $e_i(t)$

may be characterised by two parameters: the time delay of bottom echo return t_i , $i = 1, 2, ..., N_b$ and the echo amplitude A_i which contains the information about seafloor backscattering strength. The set of delay times t_i may be used to reconstruct the geometric relief of bottom $z(x)$ along the vertical crossection corresponding to the single scan, by interpolating (x_i, z_i) points, where:

$$x_i = \frac{ct_i}{2}\sin\theta_i , \quad z_i = H - \frac{ct_i}{2}\cos\theta_i \tag{1}$$

where c - sound speed in water, H - bottom depth.

Assuming that the ship moves along the y axis (Fig. 1a) and consecutive multibeam scans correspond to successive values y_i with constant interval y, the relief $z = f(x, y)$ of the whole investigated seabed surface may be reconstructed by interpolation.

The amplitudes A_i depend on many factors, which include the angle of insonification (which depends on the transmission angle and the bottom slope), the backscattering coefficient, the insonified area etc. The authors assume, that the bottom slope and successively, the angles of incidence $_{inci}$ may be approximated from the reconstructed surface shape $z = f(x, y)$. Then, the dependence of backscattering coefficient s_s on the incidence angle $_{inc}$ may be estimated from the amplitudes A_i, after compensation of the influence of acoustic system on the particular echoes level, due to the variability of insonified area with $_{inc}$ angle for instance. The estimated $s_s(_{inc})$ function may be then used to classify the bottom type, by comparison with theoretical predictions or using the ground-truthed measurements performed previously.

In the presented approach, a number of usually important effects is neglected, e.g. the influence of beamwidth, pulse length or refraction in water column upon the geometry and the delay time t_i, the effect of shading etc. These factors will be taken into consideration to improve the algorithm in future.

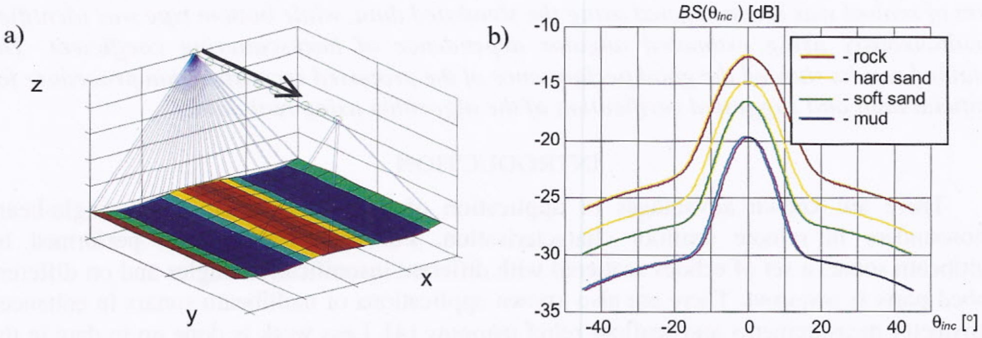

Fig. 1. a) The geometry of the problem; b) the scattering functions $BS(_{inc}) = 10\log s_s(_{inc})$ for particular bottom types used in multibeam echoes simulation procedure

3. SIMULATION AND RECONSTRUCTION PROCEDURE AND THE RESULTS

For the simulation purpose, the 3^D relief of seafloor was artificially generated using the inverse Fourier transform of the 2^D spatial variability spectrum of the form of power law, which allows to obtain the surface with fractal properties of given dimension D [3]. The regions of four bottom types: mud, soft sand, hard sand and rock were also defined (Fig. 2c). In the next step, the sets of echoes corresponding to consecutive scans of multibeam sonar system over the seafloor surface were generated. Hypothetical sonar was modelled using parameters of EM3000 multibeam sonar: operating frequency 300 kHz, size of elementary transducers 2.5 mm and 80 beams with resolution of about 1.5. The sonar was assumed to operate 10 meters above the seabed surface, while the standard deviation of surface height was approx. 0.5 m.

The delay times t_i were calculated by evaluating the distances from the transducers to elements of insonified surface along the raypaths. The amplitudes of echoes were obtained by estimating the angle of incidence for each beam and applying the following form of seafloor backscattering coefficient angular dependence $s_s(_{inc})$ [2]:

$$s_s\left(\theta_{inc}\right) = A\exp\left(-\alpha\theta_{inc}^2\right) + B\cos^{\beta}\theta_{inc}^2, \qquad (2)$$

with different A, B, and values for particular regions of bottom type evaluated using the results of research shown in [1]. The used $BS(_{inc}) = 10\log s_s(_{inc})$ scattering functions for 4 bottom types are plotted in Fig. 1b.

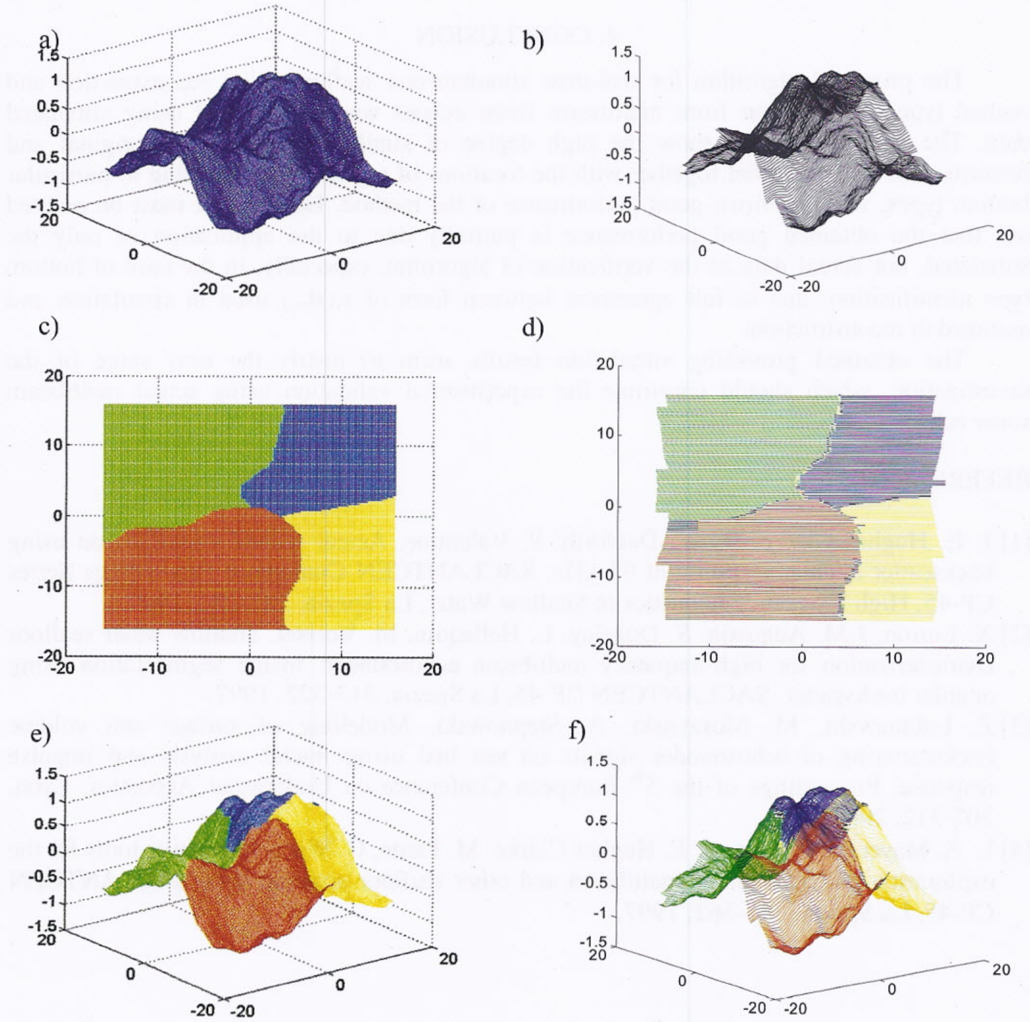

Fig. 2. The artificially generated (a) and the reconstructed (b) seafloor relief; the original (c) and reconstructed (d) locations of regions of 4 bottom types; the simulated (e) and reconstructed (f) relief with superimposed information about seabed type. Axes in meters

The consecutive step was to reconstruct the bottom relief and type from simulated data. The relief was reconstructed on the basis of formula (1). The seabed type was identified for each sequence of three consecutive beams within a given scan, using the amplitudes A_i, A_{i+1} and A_{i+2} and estimating the A, B, α and β values, which correspond to the best fit of equation (2) to A_i, A_{i+1} and A_{i+2} values. The parameters of equation (2) were then used in the bottom type identification by comparison with original quantities. In a case of larger differences between original and estimated values, no type of bottom was assigned. The analysis of the results revealed, that when using only one parameter, B gave the best performance of the algorithm.

The comparison of simulated and reconstructed relief along with type of seabed is presented in Fig. 2. It is well visible, that both in the case of relief and seabed type, the obtained results are good because of lack of significant differences between original and reconstructed seabed. The dark areas of not assigned seabed type appear only near border of particular regions.

4. CONCLUSION

The proposed algorithm for real-time simultaneous seafloor relief reconstruction and seabed type identification from multibeam sonar echoes was investigated using simulated data. The obtained results show the high degree of similarity between the original and reconstructed seafloor relief together with the locations of regions corresponding to particular bottom types, what confirms good performance of the method. However, it must be pointed out that the obtained good performance is partially due to the application of only the simulated, not actual data in the verification of algorithm, especially, in the case of bottom type identification, due to full agreement between form of $s_s(\theta_{inc})$ used in simulation and assumed in reconstruction.

The obtained promising simulation results seem to justify the next stage of the investigation, which should constitute the experimental validation using actual multibeam sonar echoes.

REFERENCES

[1] 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, La Spezia, 243-250, 1997.

[2] X. Lurton, J-M. Augustin, S. Dugelay, L. Hellequin, M. Voisset, Shallow water seafloor characterization for high-frequency multibeam echosounder: image segmentation using angular backscatter, SACLANTCEN CP-45, La Spezia, 313-322, 1997.

[3] Z. Łubniewski, M. Moszyński, A. Stepnowski, Modelling of surface and volume backscattering of echosounder signals on sea bed using fractal analysis and impulse response, Proceedings of the 5th European Conference on Underwater Acoustics, Lyon, 307-312, 2000.

[4] L. A. Mayer, S. Dijkstra, J. E. Hughes Clarke, M. Paton, C. Ware, Interactive tools for the exploration and analysis of multibeam and other seafloor acoustic data, SACLANTCEN CP-45, La Spezia, 355-362, 1997.