SENSITIVITY OF ECHO ENVELOPE FRACTAL DIMENSION TO BOTTOM TYPE AND BOTTOM DEPTH - NUMERICAL RESULTS

ZBIGNIEW ŁUBNIEWSKI

Gdańsk University of Technology, Department of Remote Sensing Systems,
Narutowicza 11/12, 80-952 Gdańsk, Poland
lubniew@eti.pg.gda.pl

The presented results are a part of those obtained within the author's latest work on application of normal incidence methods in acoustic seafloor characterisation. The work included both theoretical and experimental studies on selection of appropriate methods of seafloor echo processing and feature extraction for characterisation of the bottom type, especially, the study of the usefulness of several echo parameters like fractal dimension or statistical moments of the echo envelope. In this paper, the simulation results of the echo envelope fractal dimension dependence on bottom type and bottom depth are presented. They show that to some extent, fractal dimension of an echo may be useful for bottom identification even in a case of varying depth, however, more detailed, theoretical as well as experimental studies are needed.

INTRODUCTION

The underwater acoustic methods of seafloor characterisation, which are non-invasive and also more simple, fast, versatile and cost effective in comparison with alternative methods like the use of geological cores or video cameras, have achieved special attention during last decades and are still a subject of extensive research. Obviously, the methods based on multi beam measurements are more reliable and providing more information than those using single beam echosounders, however, taking into account the competitive price of conventional echosounders and also the introduction of multi-sensor approaches in the mentioned area, the single beam, normal incidence methods are still in development and use, as complementary to more advanced techniques.

One of the most known approaches to the normal incidence seafloor characterisation is calculating several parameters of an echo and use their values as descriptive indexes allowing for recognition of bottom type. Besides some widely used, typical echo parameters, like echo energy (i.e. in ROXANN method [1]) or duration time, also other parameters were proposed by different authors. In the presented work, the author has carried out the research with regards to application of echo envelope fractal dimension for this purpose. The use of this parameter in seabed classification was motivated in the author's previous papers [2], [3].

In the area of seafloor characterisation, the depth influence on an echo waveform and on its descriptive parameters is one of more important aspects and at the same time, the one which is not examined sufficiently well. In the presented simulations, the influence of depth dependence on an echo envelope fractal dimension is also investigated.

1. MODELLING PROCEDURE

The bottom echo simulations were based on theory of the acoustic wave scattering on seabed. Only surface scattering was considered. The surface roughness was modelled using the power law form of the surface power spectrum, assuming isotropy of the surface [4]:

$$W(\mathbf{K}) = \beta K^{-\gamma}, \tag{1}$$

where $\mathbf{K}$ is 2-dimensional spatial wave number, β is the coefficient related to surface rms height and γ is the exponent related to surface fractal dimension, describing the surface roughness.

The modelling of acoustic wave scattering was based on the BORIS model [5]. In this model, assuming that the source transmits a signal $p_{tr}(t) = p_0 s(t)$ downwards to the seabed, the pressure-time dependence of the echo $p(t)$ from scattering surface is calculated as:

$$p(t) = A\iint_S \frac{\cos[\gamma(\mathbf{R})]b^2(\mathbf{R})}{R^2} s'\left(t - \frac{2R}{c_0}\right) ds\,, \tag{2}$$

where $A = p_0 \Re_r / (2\pi c_0)$, p_0 - transmitted wave amplitude, $\Re_r$ - plane wave reflection coefficient for water-bottom interface, c_0 - sound speed in water, R - vector from the transducer to surface element ds, γ - incident angle, b - beampattern value for element ds, assumed to be the same for transmitting and receiving, $s'(t)$ - first time derivative of transmitted signal $s(t)$.

The echo simulations were performed for several realisations of the surface satisfying (1), for 3 different bottom types of properties summarised in Table 1, different echosounder frequencies, and for gradually varied depth, and then the echo fractal dimension was calculated.

The fractal dimension of echo envelope was calculated following the definition of box dimension [6], which is as follows. Let $N(\Delta s)$ denote the number of boxes in a grid of the linear scale Δs which meet the set X on a plane. Then X has a box dimension

$$D_{box} = \lim_{\Delta s \to 0} \frac{-\log N(\Delta s)}{\log \Delta s}\,. \tag{3}$$

The exact definition of box dimension with limit given by formula (3) never can be used for digitised echo pulses which consist of finite sets of samples and are not real fractals. So, it was assumed that the investigated graph of a function had fractal properties within some range of $\Delta s \in [\Delta s_1, \Delta s_2]$. Then, the box dimension D_{box} was evaluated as a slope of the line which fits the points of a log-log plot of $N(\Delta s)$ versus $1/\Delta s$ for a range $[\Delta s_1, \Delta s_2]$. The $N(\Delta s)$ value is evaluated using the grid of square boxes of side Δs superimposed on the graph of an echo envelope and calculating the number of boxes that meet the fragments of the graph [2], [6].

Table 1. Physical properties of 3 bottom types assumed for use in simulations. Other properties of bottom and also the acquisition setting were assumed the same in all 3 cases: γ exponent: 3.25; water sound speed: 1490 m/s; water density: 1000 kg/m^3; beamwidth: 15°; echosounder frequency: 50, 120 or 240 kHz; pulse duration: 0.3 ms.

Bottom type	rms height [m]	Sound speed [m/s]	Density [kg/m^3]
Sandy mud	0.005	1471	1149
Medium sand	0.0147	1765	1845
Very coarse sand	0.0226	1947	2041

2. NUMERICAL RESULTS

Fig. 1 shows the fractal dimension calculation results (see figure caption for details). For each frequency case, the obtained D_{box} calculation results are quite similar and belong to [1.1 - 1.6] range approximately. It is clearly visible that the depth variability influences the D_{box} value significantly and follows the rule of increase of the echo envelope fractal dimension along with increase of the depth. It may be explained by increase of the insonified bottom surface area S along with depth, what causes also the change of spatial features of S. The positive correlation between bottom hardness (and its surface roughness) and the echo fractal dimension, which is important for seabed classification procedure, is also visible, better for higher frequencies, but much disturbed by the depth dependence. However, it may be seen from right pictures, that at least for sandy mud and very coarse sand, there are no overlaps between D_{box} values for small ranges of bottom depth variability.

3. CONCLUSIONS

The simulation results for investigation of the echo envelope fractal dimension dependence on bottom type and bottom depth were presented. The obtained results show that to some extent, fractal dimension of an echo envelope may be useful for bottom identification even in a case of varying depth. However, more detailed, theoretical as well as experimental studies, for different bottom properties and acquisition system settings, and also including the bottom volume scattering, are needed in this area for more general conclusions.

REFERENCES

1. R. C. Chivers, N. Emerson, D. R. Burns, New acoustic processing for underway surveying, The Hydrographic Journal, Vol. 56, 8-17, 1990.
2. Z. Łubniewski A. Stepnowski, Application of the fractal analysis in the sea bottom recognition, Archives of Acoustics, Vol. 23(4), 499-511, 1998.
3. J. Tęgowski, Z. Łubniewski, The use of fractal properties of echo signals for acoustical classification of bottom sediments, Acta Acustica, Vol. 86(2), 276-282, 2000.
4. D. R. Jackson, D. P. Winebrenner, A. Ishimaru, Application of the composite roughness model to high-frequency bottom backscattering, J. Acoust. Soc. Am., Vol. 79, 1410-1422, 1986.
5. E. Pouliquen, O. Bergem, H. G. Pace, Time-evolution modeling of seafloor scatter. I. Concept., J. Acoust. Soc. Am., Vol. 105, 3136-3141, 1999.
6. H. M. Hastings, G. Sugihara, Fractals. A user's guide for the natural sciences, Oxford University Press, 7-77, Oxford, New York, Tokyo 1994.

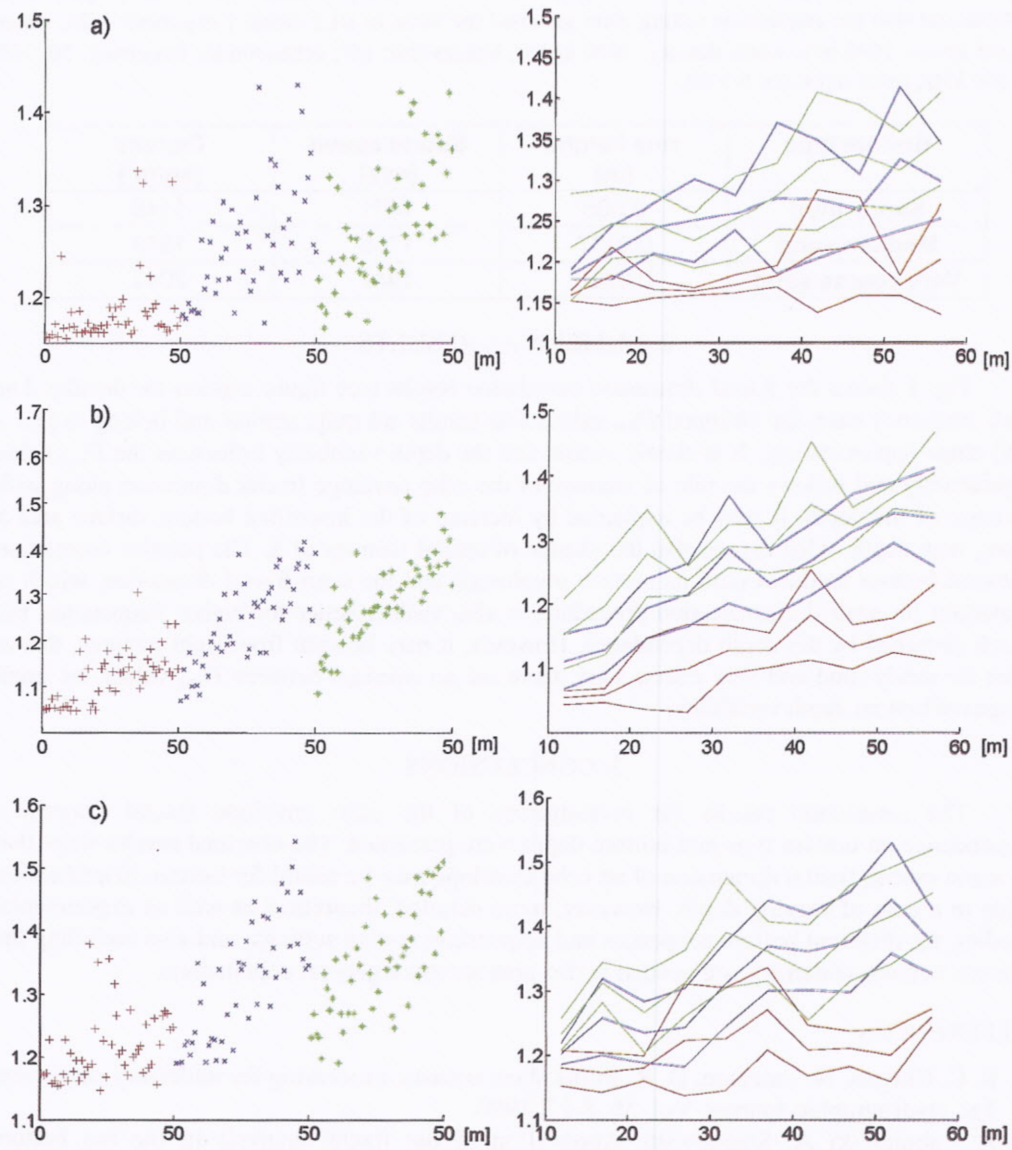

Figure 1. The fractal dimension calculation results for envelopes of simulated echoes from 3 types of seabed surface: sandy mud (red), medium sand (blue) and very coarse sand (green) for 3 assumed echosounder frequencies: a) 50 kHz, b) 120 kHz, c) 240 kHz. Physical properties of 3 bottom types are shown in Table 1. For each type, 50 realisations of seabed surface of the same statistical properties were generated with assumption of depth gradually increasing at the same time (from 10 m to 59 m). *Left picture*: Fractal dimension variability with depth increase shown for each bottom type separately; *Right picture*: Results of D_{box} averaging for groups of 5 consecutive echoes (realisations); mean, mean-std and mean+std are presented.