17th SYMPOSIUM
ON
HYDROACOUSTICS
Jurata May 23-26, 2000

NUMERICAL SIMULATIONS OF ACOUSTIC BACKSCATTERING ON FRACTALLY CORRUGATED SEA BED SURFACE

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

The numerical simulations of echosounder signals scattering by fractally corrugated sea bed surface are presented. In particular, the relations between fractal dimension, describing the large scale roughness of sea bottom, and received echo envelope shape, were investigated. The fractal large scale relief of seabed surface was generated assuming the power law form of the spatial frequency power spectrum, with exponent related to fractal dimension, and subsequently applying the two dimensional inverse FFT algorithm. In the second stage, the bottom echo waveform was numerically modelled as an incoherent sum of contributing echoes from all surface elements. For each element, the echo amplitude was calculated assuming the form of angular dependence of bottom backscattering coefficient for small scale roughness. The obtained results of simulations have revealed some conditions for the transferring of the seabed surface fractal structure onto the shape of echo waveform.

1. INTRODUCTION

It is known that the surface of sea bottom may be one of the examples of fractally structured objects in nature [1]. The acoustical method of seabed classification with use of fractal dimension was developed and tested on the real data with promising results [2]. This method was based on the hypothesis, that fractal structure of bottom surface is transferred onto the shape of seabed impulse response or echo envelope. As numerical simulations of acoustic wave scattering on fractally corrugated surface should check this hypothesis, in this paper the authors presents the procedure for this purpose and some preliminary results.

2. THE MODELLING PROCEDURE DESCRIPTION

The first task to perform in the simulation procedure was to generate the fractal surface. The large scale 2^D relief of seabed surface, which consisted of a number of harmonic two-dimensional sine waves, was generated assuming the power law form of its spatial frequency amplitude 2^D spectrum [1]:

$$A\left(f_x, f_y\right) = C \cdot \left(f_x^{\,2} + f_y^{\,2}\right)^{-\frac{1}{4} - H_D}, \qquad (1)$$

where C is a constant and exponent H_D is related to fractal dimension D of the surface by

$$H_D = 3 - D. \tag{2}$$

The phase of all components was randomly generated using the uniform distribution within the $[0, 2\pi]$ interval. Subsequently, the two dimensional inverse FFT algorithm was applied to obtain the surface in the space domain.

In the second stage of the simulation procedure, the bottom echo envelope from fractal surface was calculated numerically. The surface scattering model described in [3] was used for this purpose. In this model, the domination of incoherent component in backscattered echo was assumed. It means that the echo intensity, which is proportional to the squared echo envelope, is the sum of echo intensities from all elementary scattering elements. In such a case, if the echosounder sounding rectangular pulse is transmitted downwards, the backscattering on a seabed surface results in the squared echo envelope $y(t)$:

$$y(t) = \int_S b^2[\varphi(\mathrm{s})] R^{-4}(\mathrm{s}) s_s[\varphi_i(\mathrm{s})] ds\,, \tag{3}$$

where S is a bottom surface insonified at time t, s denotes a point on S corresponding to elemental surface element ds, φ and φ_i are the transmission and incidence angles at s respectively, b is the circularly symmetrical transducer transmitting/receiving beampattern, R denotes the distance from s to transducer, and s_s is the bottom surface reverberation coefficient, dependent on φ_i and the bottom physical properties. The $s_s(\varphi_i)$ angular dependence was modelled using Kirchhoff approximation as [3]

$$s_s(\varphi_i) = \frac{\Re_r^2(\varphi_i) e^{-\tan\left(\frac{\varphi_i^2}{2\delta^2}\right)}}{8\pi\delta^2 \cos^4 \varphi_i}\,, \tag{4}$$

where $\Re_r$ denotes the plane wave reflection coefficient for water-bottom interface and δ is the bottom surface rms slope describing its small scale roughness.

The fractal bottom impulse responses $k_{fr}(t)$ (in the domain of the echo intensity or squared echo envelope) as well as the echo waveforms $y_{fr}(t)$ for rectangular sounding pulse were calculated. The highest spatial frequency in the generated surface was low enough (in comparison with small scale roughness and the assumed acoustical wave length) to allow for the use of the model described above.

3. RESULTS

Fig. 1 shows the 3^D view of fractal surfaces generated for different fractal dimensions: $D = 2.1$, 2.3 and 2.5. As it is visible, the surface roughness increases with fractal dimension.

Fig. 2 presents the calculation results of the impulse response as well as the echo for rectangular sounding pulse for generated seabed surfaces of particular D values: 2.1 (a, b, c, d), 2.3 (e, f, g, h) and 2.5 (i, j, k, l). The obtained impulse responses $k_{fr}(t)$ in absolute domain are shown in parts a, e and i of the figure, in logarithmic domain - in parts b, f and j. The echo envelopes $y_{fr}(t)$ in absolute domain - in c, g, k and in logarithmic domain - in d, h and l. The assumed surface small scale roughness rms slope δ was 8 °, the 3 dB beamwidth θ_{3dB} was 15° and the mean depth $H = 50$ m. The obtained large scale rms roughness of generated fractal surfaces was about 0.5 m.

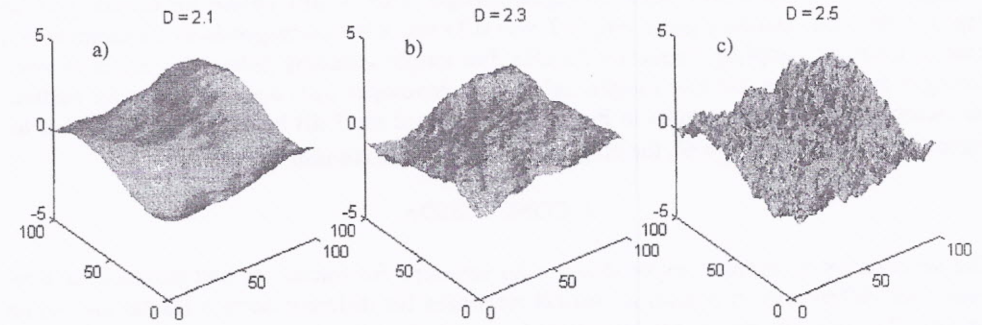

Fig. 1. The sea bottom fractal surfaces of fractal dimension $D = 2.1$ (a), 2.3 (b) and 2.5 (c), generated using the two-dimensional inverse FFT algorithm. Horizontal axes in sample numbers

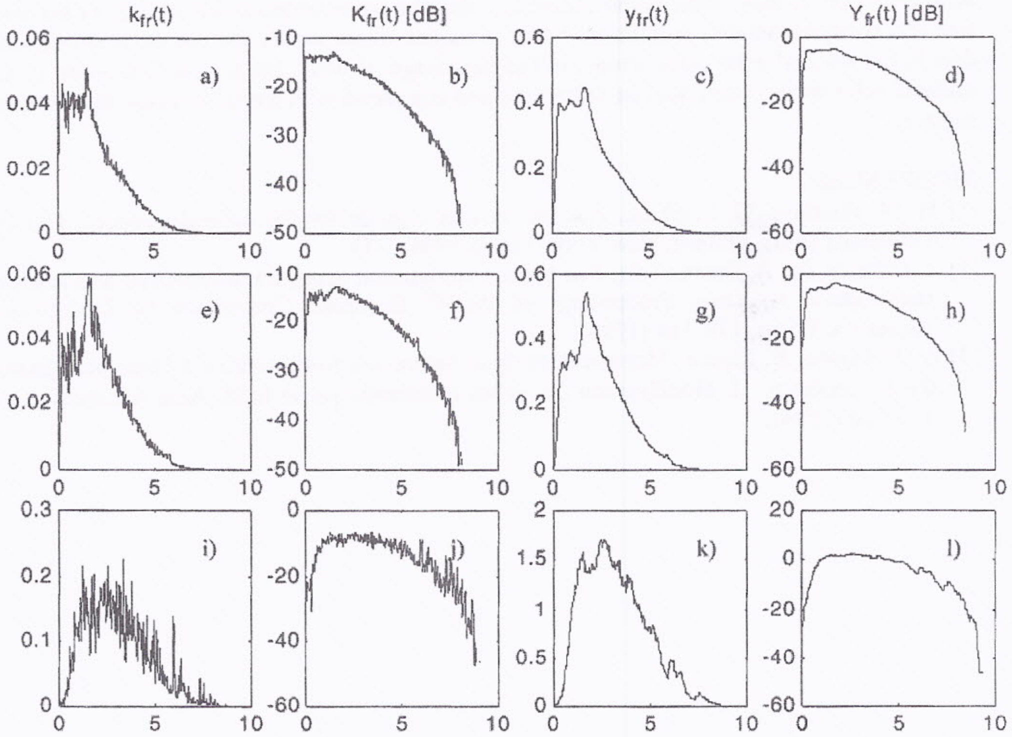

Fig. 2: The results of the impulse response and echo for rectangular sounding pulse of $T = 0.33$ ms calculations for fractal seabed surfaces of $D = 2.1$ (a, b, c, d), 2.3 (e, f, g, h) and 2.5 (i, j, k, l); a, e, i - $k_{fr}(t)$ in absolute domain, b, f, j - $k_{fr}(t)$ in logarithmic domain, c, g, k - $y_{fr}(t)$ in absolute domain, d, h, l - $y_{fr}(t)$ in logarithmic domain. $\delta = 8°$, $\theta_{3dB} = 15°$, $H = 50$ m. Sampling frequency = 30 kHz. x axis in milliseconds

The differences in results for particular surface D values are well visible, specially for impulse responses, both in absolute and logarithmic domain. The impulse response for surface of higher D, also has more rough, corrugated shape. This is also visible for echoes $y_{fr}(t)$ in Fig. 2, where the sounding pulse length T was 0.33 ms, what corresponds to 10 samples in a case of assumed sampling frequency 30 kHz. For longer sounding pulses, the effect of smoothing is more visible and the "roughness" of echo envelopes $y_{fr}(t)$ does not differ for particular surface D values. The results in Fig. 2 were obtained for 3 dB beam width of 15°, but for narrower beams, e.g. $\theta_{3dB} = 6^{\circ}$, the effects discussed above are also visible.

4. CONCLUSION

The simulations of impulse response and echo envelope for fractal sea bed surfaces have revealed the differences in bottom acoustical responses for different surface fractal dimension values. The obtained results are important for validation of newly developed algorithms of echo signals processing for bottom classification. Specifically, it was proved that the seabed surface fractal structure may be transferred onto the shape of its impulse response and the echo envelope, at least under some conditions, like the pulse length short enough, or the bottom and acoustic system's parameters being in ranges which justify the use of proposed models in the sea bed echo calculations. In the next stage of work, the fractal dimension of simulated echo waveforms could be calculated and compared with fractal dimension of seabed surface.

REFERENCES

[1] H. M. Hastings, G. Sugihara, Fractals. A user's guide for the natural sciences, Oxford University Press, Oxford, New York, Tokyo 1994, 7-77.

[2] Z. Łubniewski, A. Stepnowski, Sea bottom recognition using fractal analysis and scattering impulse response, Proceedings of the 4th European Conference on Underwater Acoustics, Rome, 179-184 (1998).

[3] E. Pouliquen, X. Lurton, Identification de la nature des fonds marins à l'aide de signaux d'écho-sondeurs - I. Modélisation des échos réverbérés par le fond, Acta Acustica, 2(1), 113-126 (1994).