SEAFLOOR ECHO WAVEFORM MODELLING USING ACOUSTIC PRESSURE IMPULSE RESPONSE OF FRACTAL SURFACE

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Summary

The paper presents the simulations of narrow band signals backscattering on artificially generated fractal seabed surfaces. The pressure waveforms for simulated echoes were derived from pressure impulse response of surface. The impulse responses for bottom surfaces of different fractal dimension were calculated under assumption that the Kirchhoff approximation constrains were satisfied. The influence of bottom surface complexity on irregularity and other features of backscattered signals and their envelopes was investigated, with respect also to echosounder parameters, e.g. frequency, pulse duration, beamwidth etc.

The obtained results allow for evaluation, to some extent, of the conditions for transferring the seabed surface fractal structure onto the backscattered echo, and subsequently, the possibility of application of fractal dimension method in seabed characterisation and classification.

Introduction

Acoustic methods of seabed characterisation, which are non-invasive, more cost effective and more versatile than direct methods, are still the subject of extensive research. The promising method with use of the backscattered single beam echo envelope fractal dimension was developed by the author recently [1, 2]. Along with empirical verification of this method, the theoretical modelling was performed to evaluate the relationship between fractal dimension of seabed surface which measures its shape complexity, and fractal dimension of scattered signal envelope. In one method of an echo modelling presented previously [3], the statistical approach was used and the echo was simulated in the intensity domain assuming the domination of incoherent scattering. In the alternative method which is presented in this paper, the deterministic approach is used. It allows for exact calculation of an echo signal in pressure domain $p(t)$ from a given bottom surface $z = f(x, y)$, assuming the depth H, transmitted pulse $p_s(t)$ and other parameters of experiment, without any assumptions concerning the statistical properties of the surface.

The modelling procedure

For the modelling purpose, the artificial seabed surface of different fractal dimension D were generated using the method of the 2-dimensional inverse Fourier transformation of the spatial variability spectrum, which was assumed to be in the power law form [3].

The modelling of acoustic wave scattering was performed in time domain and was based on the BORIS model proposed by E. Pouliquen *et al*. [4]. It was assumed that in the interaction with seafloor, the signal is scattered only on surface of bottom and does not penetrate the volume of sediment. It may be good approximation of the reality for signal frequencies of hundreds kHz and higher. In the BORIS model, Kirchhoff approximation is used, what makes the following assumptions be satisfied: 1) the radius of curvature of the insonified surface is significantly large in comparison with the wavelength and 2) the incident angle is low (not greater than 20 - 25°).

Applying the BORIS model [4], assuming that the source transmits a signal $p_{tr}(t) = p_0 s(t)$, the pressure-time dependence of echo $p(t)$ from scattering surface is:

$$p(t) = A \iint_S \frac{\cos[\gamma(\mathbf{R})]b^2(\mathbf{R})}{R^2} s'\left(t - \frac{2R}{c_0}\right) ds\,, \qquad (1)$$

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, $\mathbf{R}$ - vector from 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 $s(t)$.

In the development of numerical simulation procedure, some transformations of the eq. (1) was made. In particular, its alternative form of the convolution of transmitted signal $s(t)$ with the "system" impulse response $k(t)$ was proposed [1]:

$$p(t) = k(t) * s(t) = $$
$$= k(t) * \left[A \cdot \frac{d^2}{dt^2} \left(\iint_{S_t} \frac{\cos[\gamma(\mathbf{R})]b^2(\mathbf{R})}{R^2} ds \right) \right], \qquad (2)$$

where S_t at a given time t is such a subset of the whole surface S, for which $R \le \frac{c_0 t}{2}$.

Results

The numerical simulations of echo $p(t)$ were made for three bottom surfaces of different fractal dimension D = 2.1, 2.3 and 2.5 and for variable values of pulse duration T, operating frequency f_0 and 3 dB beamwidth Θ_{3dB}. The transmitted pulse envelope was assumed to be initially rectangular, deformed due to bandpass filtering in the transducer.

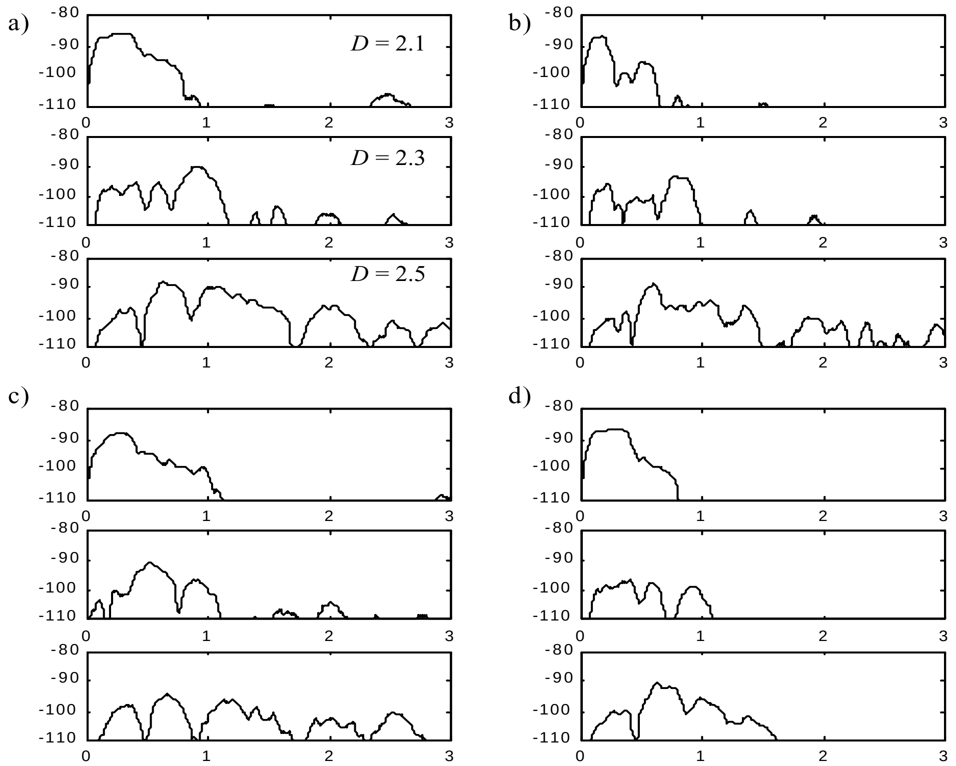

Fig. 1. The echo waveform simulation results using the pressure time-evolution modelling for different input transmitted parameters: a) $f_0 = 250$ kHz, $T = 0.36$ ms, $\Theta_{3dB} = 15^{\circ}$, b) $f_0 = 250$ kHz, $T = 0.18$ ms, $\Theta_{3dB} = 15^{\circ}$, c) $f_0 = 400$ kHz, $T = 0.36$ ms, $\Theta_{3dB} = 15^{\circ}$ and d) $f_0 = 250$ kHz, $T = 0.36$ ms, $\Theta_{3dB} = 6^{\circ}$. x axis in miliseconds, y in dB

Fig. 1. presents the selected simulation results in form of echo envelopes for three bottom surfaces: a) for $f_0 = 250$ kHz, $T = 0.36$ ms, $\Theta_{3dB} = 15^{\circ}$, b) for $f_0 = 250$ kHz, $T = 0.18$ ms, $\Theta_{3dB} = 15^{\circ}$, c) for $f_0 = 400$ kHz, $T = 0.36$ ms, $\Theta_{3dB} = 15^{\circ}$ and d) for $f_0 = 250$ kHz, $T = 0.36$ ms, $\Theta_{3dB} = 6^{\circ}$. These preliminary results show that it is rather true in all cases (more clearly in the longer pulse cases), that the more irregular, complex bottom surface (greater fractal dimension), the more corrugated, irregular echo envelope. This relation is specially visible while comparing the results for the smoothest surface ($D = 2.1$) with those of two other cases. It is visible also in the case of narrower beam (d), although, what should be expected, the differences in echo length are significantly smaller than in wider beam cases. For the higher carrier frequency (400 kHz instead of 250 kHz - (c)), there are noticeable the smaller scale features in echo waveform for surface of $D = 2.5$ (not visible in surface $D = 2.1$ and $D = 2.3$ cases), what may indicate the smaller scale features of this surface.

Conclusion

The presented results allow to conclude, that the performed time domain simulations of acoustic echo pressure due to scattering on particular bottom surfaces proves, to some extent, the hypothesis about transferring the seabed fractal structure onto the echo envelope. This fact is important in the context of verification of the newly developed seabed typing method based on the echo envelope fractal dimension [1, 2]. However, these results must be treated preliminarily and the simulations of more realistic situations and including wider variations of input parameters are needed.

References

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