A NOVEL APPROACH TO BOTTOM SCATTERING USING A NARROW ACOUSTIC BEAM

ADAM ZIELINSKI[1], JAROSLAW TEGOWSKI[2],
ZBIGNIEW LUBNIEWSKI[3], JERZY DEMKOWICZ[3]

[1]University of Victoria, Department of Electrical and Computer Engineering,
P.O. Box 3055, Victoria, BC V8W 3P6 Canada
adam@uvic.ca

[2]Institute of Oceanology, Polish Academy of Sciences,
Powstancow Warszawy 55, 81-712 Sopot, Poland
tegowski@iopan.gda.pl

[3]Gdansk University of Technology, Department of Geoinformatics,
Narutowicza 11/12, 80-952 Gdansk, Poland
lubniew@eti.pg.gda.pl

The acoustic response of the ocean bottom to a probing pulse is a complex and complicated process. This process is influenced by with the form of an acoustic transmitting/receiving beam and by the physical processes involved in sound scattering from the surface and the volume of the ocean bottom. The complexities of these phenomena often obscure an intuitive understanding of the underlying principles of echo formation and its reception. In this paper, we propose a simplistic model for this complex process using filter theory. The bottom is represented as a surface reflector with an acoustic wave front sweeping over it with time-varying velocity. The impulse response of a smooth flat bottom is characteristic of a low pass-filter that will greatly attenuate the impinging high frequency pulse. On the other hand, bottom undulations will modulate the reflected signal such that it can be represented by the impulse response of a band-pass filter. The received echo can be represented as the response of such filter to a high frequency pulse. The characteristics and amplitude of the echo are dependent on frequency spectrum overlap between the transmitted pulse spectrum and the filter frequency response. In the paper, we discuss several cases of interest with the intent to provide a solid intuitive understanding of the echo formation from the system point of view.

INTRODUCTION

Understanding of acoustic echo formation from a random reflecting boundary such as a seabed is essential in many applications. These applications include seafloor characterization using features of the generated echo [2]. The echo formation involves several complex physical processes responsible for sound scattering and may be simulated by involved and computationally intensive numerical modelling procedures [3]. On the other hand, an alternative approach using simplistic models for prediction of some echo parameters such as signal level, energy, duration time and spectral characteristic has been recently proposed [1]. This approach predicts echo properties by looking at a transmitted pulse and a scattering seabed as a linear system and utilizes filter theory.

In this paper a specific scenario is considered where a singular scatterers representing stones are regularly distributed along the straight line on the bottom surface. These scatterers are isonifised using a narrow, fan-like acoustic beam.

1. MODELLING DESCRIPTION

In the model used in this investigation, the scene is described in two dimensions: along the horizontal axis x and the vertical z. We assume that the bottom is covered by point reflectors -stones. The distance T_x between reflectors is constant. The acoustic source generates a fan-like beam, narrow in one axis and wide in another, orthogonal axis. The beam covers an angular sector (φ_1,φ_2) such as in side-looking sonar and is not pointed vertically toward the bottom. The footprint of such a beam on a flat bottom can be represented by a narrow strip extending from distance $x_1 = D\tan\varphi_1$ to $x_2 = D\tan\varphi_2$ as shown in Fig. 1.

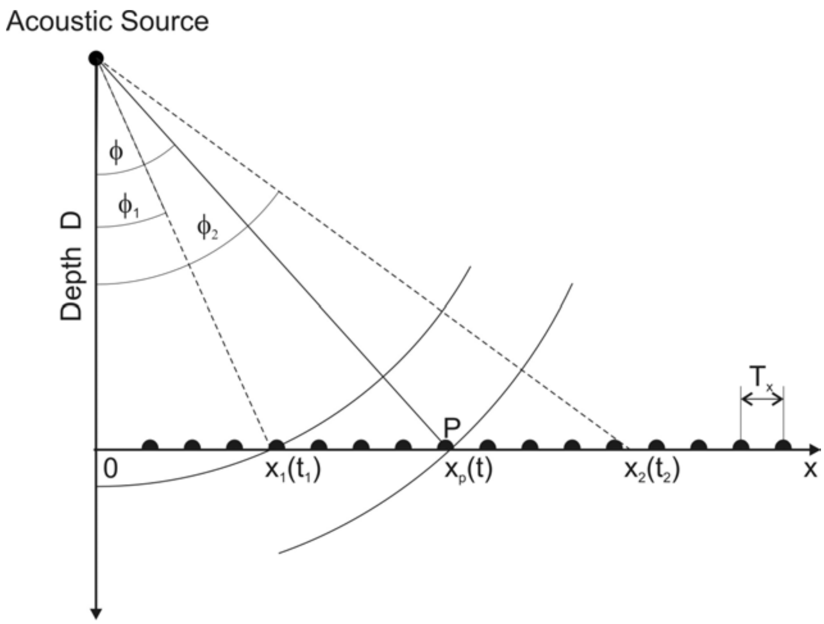

Fig. 1. Geometry of the acoustic beam

The spherical wave front originating from the source travels with sound velocity c = 1500 m/s and intercepts the bottom at point P which position $x_P(t)$ moves along the x-axis as a function of time given by [1]:

$$x_P(t) = \sqrt{(D+ct)^2 - D^2}\,. \tag{1}$$

We choose the time origin t = 0 as the time when the spherical wave front intercepts the bottom first at point $x(0) = 0$.

The distance from the origin of the coordinate system to the first reflector is assumed $x_1 = D\tan\varphi_1$ and the distance to the i-th scatterer is $x_i = x_1 + (i-1)\cdot T_x$. The time of obtaining the echo from the i-th scatterer is $\tau_i = 2R_i/c$, where $R_i = \sqrt{D^2 + x_i^2}$. As the stones are assumed to be point reflectors, the seabed impulse response will be expressed as a sum of Dirac pulses $\delta(t)$ properly shifted and attenuated:

$$k(t) = \sum_{i=1}^{N} k_i \delta(t - \tau_i), \tag{2}$$

where N is the number of singular scatterers,

$$k_i = R_i^{-2}, \tag{3}$$

$$\tau_i = \frac{2\sqrt{D^2 + (x_1 + (i-1)T_x)^2}}{c}, \tag{4}$$

as we assumed the amplitude reducing due to geometrical spherical spreading is proportional to $1/R^2$.

2. RESULTS

Simulations were performed for different values of space interval T_x and bottom depth D. Sample results are presented in Fig. 2, 3, 4 and 5. The bottom impulse response is plotted in the form of a set of vertical lines symbolising the Dirac pulses (left pictures). The dependence of $1/\delta\tau_i$ on time, where $\delta\tau_i$ is the interval between $\tau_i + 1$ and τ_i, is also plotted (right pictures in Fig. 2, 3, 4, and 5). The following parameters were assumed: D = 50 m, 25 m, T_x = 0.125 m, 0.25 m, ϕ_1 = 5°, ϕ_2 = 25°, and c = 1500 m/s.

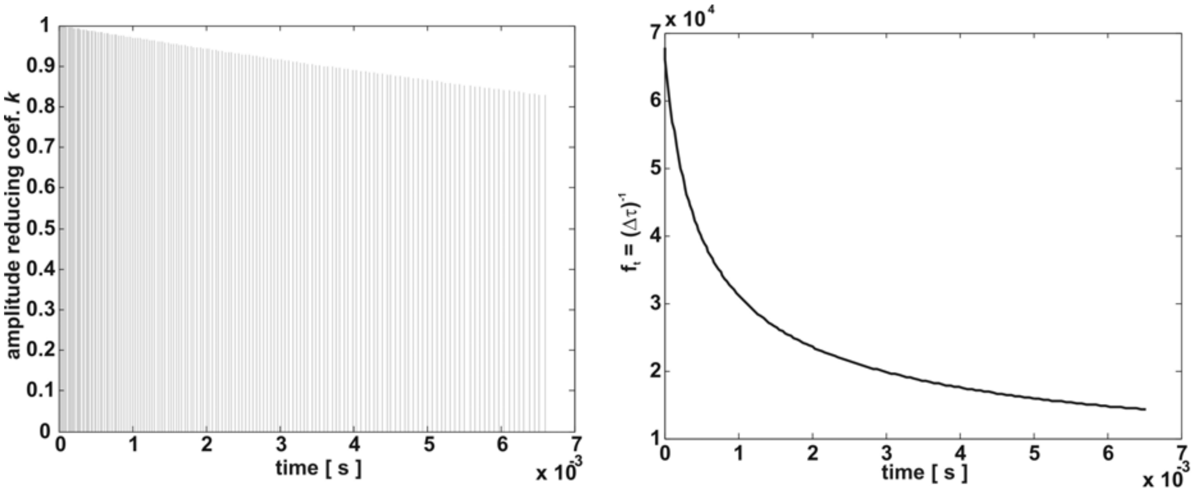

Fig. 2. The bottom impulse response plotted in the form of a set of vertical lines symbolizing the Dirac pulses (left pictures). The dependence of $1/\delta\tau_i$ on time, where $\delta\tau_i$ is the interval between $\tau_i + 1$ and τ_i, is also plotted (right). φ_1 = 5°, φ_2 = 25°, c = 1500 m/s, *D* = 50 m, T_x = 0.125 m.

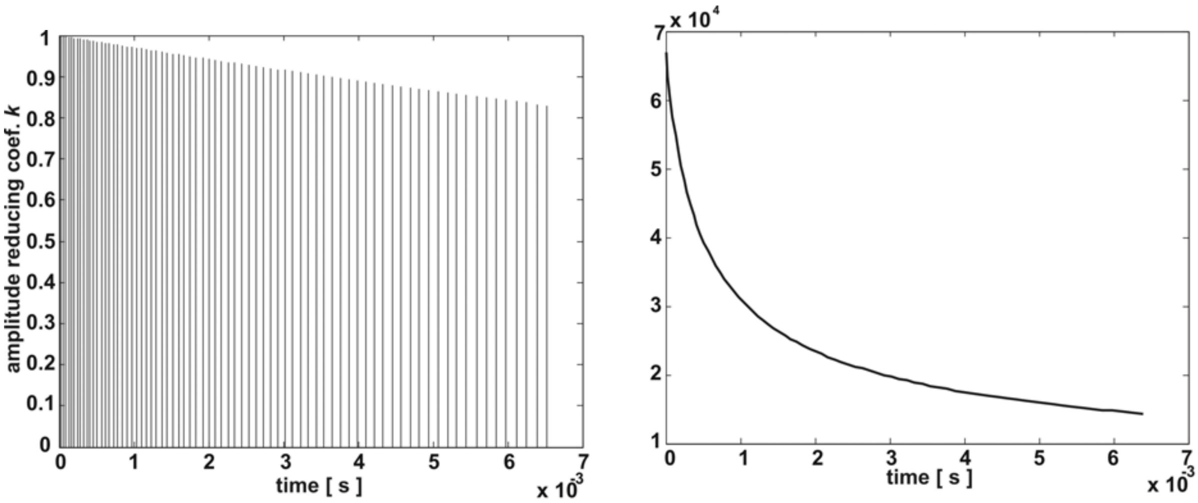

Fig. 3. The bottom impulse response plotted in the form of a set of vertical lines symbolizing the Dirac pulses (left pictures). The dependence of $1/\delta\tau_i$ on time, where $\delta\tau_i$ is the interval between $\tau_i + 1$ and τ_i, is also plotted (right). φ_1 = 5°, φ_2 = 25°, c = 1500 m/s, *D* = 50 m, T_x = 0.25 m.

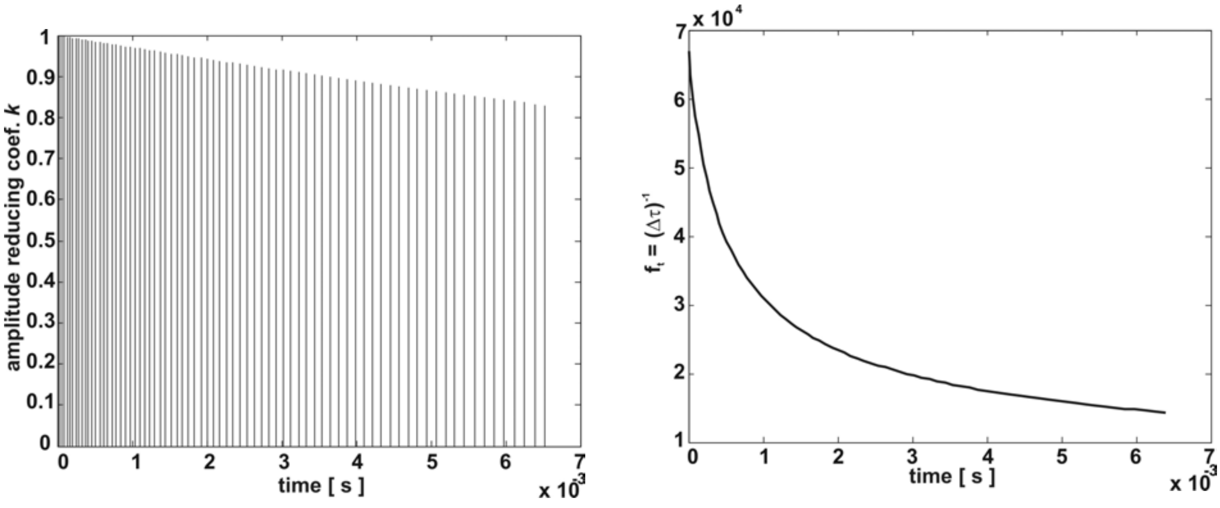

Fig. 4. The bottom impulse response plotted in the form of a set of vertical lines symbolizing the Dirac pulses (left pictures). The dependence of $1/\delta\tau_i$ on time, where $\delta\tau_i$ is the interval between $\tau_i + 1$ and τ_i, is also plotted (right). φ_1 = 5°, φ_2 = 25°, c = 1500 m/s, *D* = 25 m, T_x = 0.125 m.

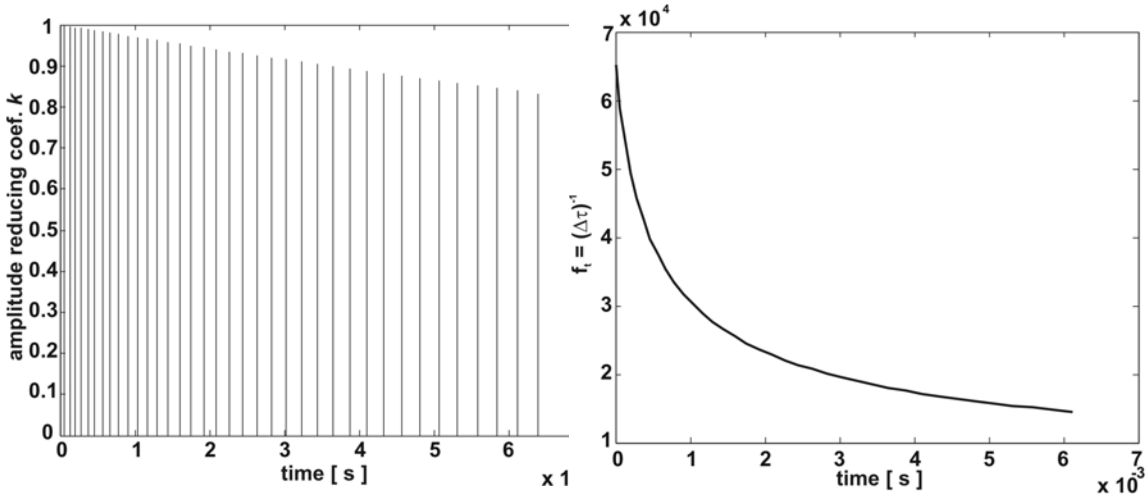

Fig. 5. The bottom impulse response plotted in the form of a set of vertical lines symbolizing the Dirac pulses (left pictures). The dependence of $1/\delta\tau_i$ on time, where $\delta\tau_i$ is the interval between $\tau_i + 1$ and τ_i, is also plotted (right). φ_1 = 5°, φ_2 = 25°, c = 1500 m/s, *D* = 25 m, T_x = 0. 25 m.

The modelled results show correspondence to the filter theory approach [1], particularly in view of the fact that intervals between consecutive components of the impulse response in the time domain decrease with decreasing values of T_x and with increase in the depth *D*. It must be pointed out that in this model, the point scatterers are an idealized approximation of the real situation, where scattering occurs not only at the singular scatterers but at the whole bottom surface. Then, the bottom impulse response would have the form of a chirp signal with an instantaneous frequency *f*(*t*) of form similar to those plotted in the right plots of figures 2, 3, 4 and 5, as predicted in [1].

Letting $t = 0$ on time axis as the moment when the acoustic wave reflected from point x_1 reaches the receiver, the instantaneous frequency $f(t)$ of the echo signal may be expressed by:

$$f(t) = \frac{c}{2T_x} \cdot \frac{D + c\left(\frac{t}{2} + t_1\right)}{\sqrt{c\left(\frac{t}{2} + t_1\right)\left[2D + c\left(\frac{t}{2} + t_1\right)\right]}}. \tag{5}$$

3. CONCLUSION

A simplistic physical model of sound scattering at a rough seabed was presented. The model assumes a set of singular scatterers regularly distributed on a flat seafloor surface. The model predictions with respect to bottom impulse response are consistent in general with the model based on filter theory introduced in [1]. In particular, the influence of the model input parameters such as the space interval T_x between stones and the bottom depth H on the seafloor impulse response was investigated.

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