

APPLICATIONS OF THE HUANG – HILBERT TRANSFORMATION IN NON-INVASIVE RESEARCH OF THE SEABED IN THE SOUTHERN BALTIC SEA

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This article aims at describing methods for extracting the Quaternary facies and detection of a buried pipeline at the bottom with the Huang – Hilbert transformation (HHT) based on acoustic data recorded by the sub-bottom profiler (SBP). The aforementioned transformation allows a study of nonlinear and/or non-stationary phenomena. A good example of this type of problem is the propagation and reflection of acoustic waves in water and the geological formations occurring beneath the surface of the seabed, as well as their scattering on objects at the bottom. The area in which research has been executed was the southern Baltic Sea, specifically the Outer Puck Bay for Quaternary facies and the stretch north from Władysławowo, for the pipeline. On the basis of the processed data with the HHT, Quaternary facies and the pipeline were determined and identified.

INTRODUCTION

Measured data is essential information, obtained by examining the world, and the phenomena therein. Often, data must be processed in an appropriate way to have a logical and physical sense. In the case of stationary data, a more or less complicated analysis and transformation are carried out, in order to extract the relevant content. The situation becomes more complicated when the studied phenomenon is non-linear and/or non-stationary. A problem is that a very large part of operating mechanisms and processes generated by human activity are non-linear and non-stationary. Traditional methods of data analysis fail in such cases. Tools and methods aimed at the analysis of non-linear and/or non-stationary processes

reveal themselves as helpful. One of them is the Huang - Hilbert transformation (HHT). This transformation consists of two steps: empirical mode decomposition (EMD) and Hilbert spectral analysis (HSA) [4]. With these transformations, it was possible to extract a detailed description of non-linear distorted waves occurring naturally in non-stationary processes.

The main objective of the Huang - Hilbert transformation is that any function, even a complicated one, can be decomposed into an intrinsic mode function (IMF), and then, using Hilbert spectral analysis, the instantaneous frequency and instantaneous amplitude of the input function can be found. This approach allows us to achieve, in a relatively simple way, a description of non-stationary data and to obtain reliable physical values. The Huang - Hilbert transformation has also found a wide application in biomedical engineering, chemistry, economy, mechanics, and the creation of mechanisms of speech recognition, as well as the processing of images.

The purpose of this article is to present the results of the HHT method for the detection of geological facies at the bottom of the Baltic Sea and the objects buried in the seabed with the example of the pipeline.

1. THE HUANG – HILBERT TRANSFORMATION METHOD

The first stage of empirical mode decomposition (EMD) is the decomposition of the input signal $x(t)$ for intrinsic mode functions (IMF), which are finite. The IMFs are obtained by using a screening algorithm, which must fulfil two conditions: 1) in the entire set of analysed data, the number of extremes and roots must be equal to itself or differ by 1; 2) at each point the values of the average of the envelope defined by the local maxima and local minima are equal to zero [4]. Screening begins by finding the local extremes of the input function $x(t)$ (Fig. 1).

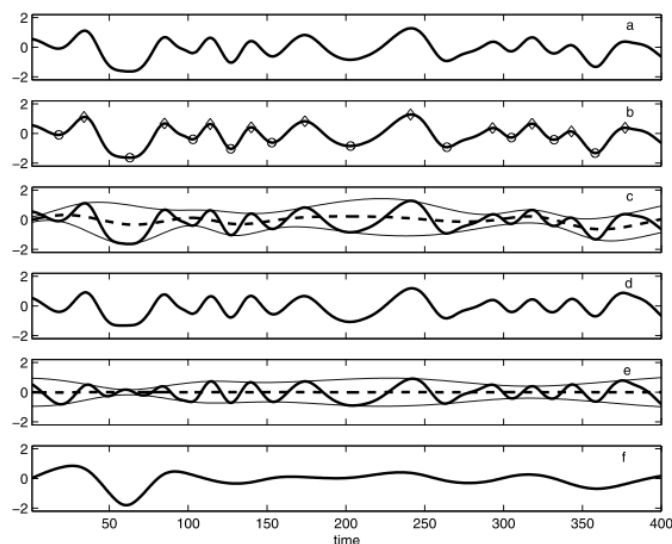


Fig. 1. Empirical mode decomposition (EMD) - process of screening: (a) the input signal $x(t)$, (b) the identification of the maxima (diamonds) and minima (circles) function of the input signal; (c) the upper and lower envelope (thin line) and their average (dashed line); (d) the first component of the IMF (the difference between the input signal $x(t)$ - thick line, and average envelope - the dotted line in Fig. 1c); (e) the creation of another IMF component analogous to Fig. 1c; (f) the third component of the IMF subtracted from the input signal $x(t)$ [4].

Furthermore, extremes are bonded together in order to form the upper and lower envelope (Fig. 1c), and their mean is determined, which is a local average of the input signal m_1 . In the next step, the average m_1 is subtracted from the input signal $x(t)$ (Fig. 1d). In this way, we create the first component of the function of the IMF (1).

$$h_1 = x(t) - m_1 \quad (1)$$

The whole algorithm is repeated several times, except for the function h_1 , which is treated as a "new" input signal.

$$h_1 - m_{11} = h_{11} \quad (2)$$

After k - fold repetition of the procedure:

$$h_{1k} = h_{1(k-1)} - m_{1k} \quad (3)$$

The entire process is stopped when the envelope becomes symmetrical. This situation is called the screening stop conditions which satisfies the assumptions (1) and (2). After completing these steps the IMF function is obtained (4).

$$c_1 = h_{1k} \quad (4)$$

After completing these steps, the function c_1 should contain the scale and components of the periods of the input signal $x(t)$. In addition, we define residues by subtracting the IMF c_1 function from $x(t)$ (Fig. 2b):

$$r_1 = x(t) - c_1. \quad (5)$$

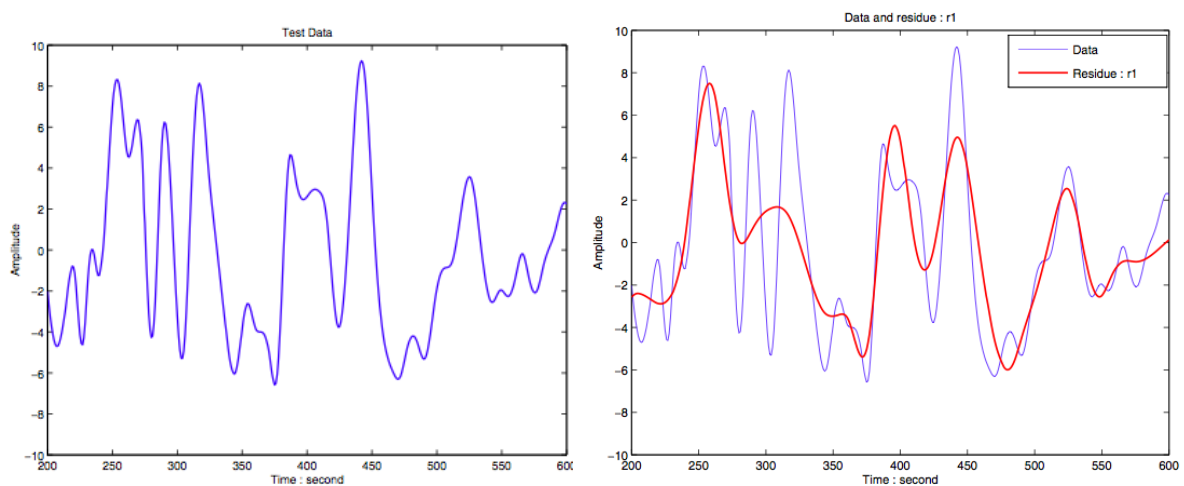


Fig. 2. (a) the sample signal, (b) the original signal (blue line) and the residuum r_1 (red line) [3].

Residua contain important information for researchers, therefore we submit them for a screening process several times, similar to the method used for signal $x(t)$:

$$\begin{aligned} r_2 &= r_1 - c_1 \\ &\cdot \\ &\cdot \\ &\cdot \\ r_n &= r_{n-1} - c_n \end{aligned} \quad (6)$$

The whole procedure of empirical mode decomposition (EMD) ends when components c_n or the residues r_n become monotonic functions, from which the following components of IMF can no longer be extracted, or these functions cease to satisfy assumptions 1) and 2).

The general formula for expressing the above-described recursive algorithm can be represented as:

$$x(t) = \sum_{j=1}^n c_j + r_n \quad (7)$$

where $x(t)$ is the input signal, n - the number of repetition screenings, c_j - other components of IMF and r_n - other residua.

2. DESCRIPTION OF THE TEST APPARATUS AND MEASURING RESERVOIRS

The data that was transformed was recorded using the sub-bottom profiler of a Pipeliner 3010 type, produced by Orectech. For the detection of facies and the pipeline, the same frequency of the transmitted signal, equal to 3.5 kHz, was used. The sampling frequency was 45,454 Hz in both cases. The speed of the research vessel during the seabed investigation was about 3 knots.

The areas from which acoustic data has been derived:

a) For the pipeline - the area north of Władysławowo and Jastrzębia Góra. The precise location is shown in figure 3. In this area, where the pipeline is buried, the dominant grounds are fine-grained sands. The bottom surface is flat at this point so that the aforementioned object remains under a layer of sediment.

b) For Quaternary facies: the area of data collection is located in the north - western part of the Bay of Gdansk, near the Hel peninsula. An acoustic transect is shown in figure 4. This is the outer part of the Bay of Puck. The average depth of this area is from 1 to 2 meters. The transformed data is derived from the final section of the transect (marked by a red arrow), northeast of Gdynia.

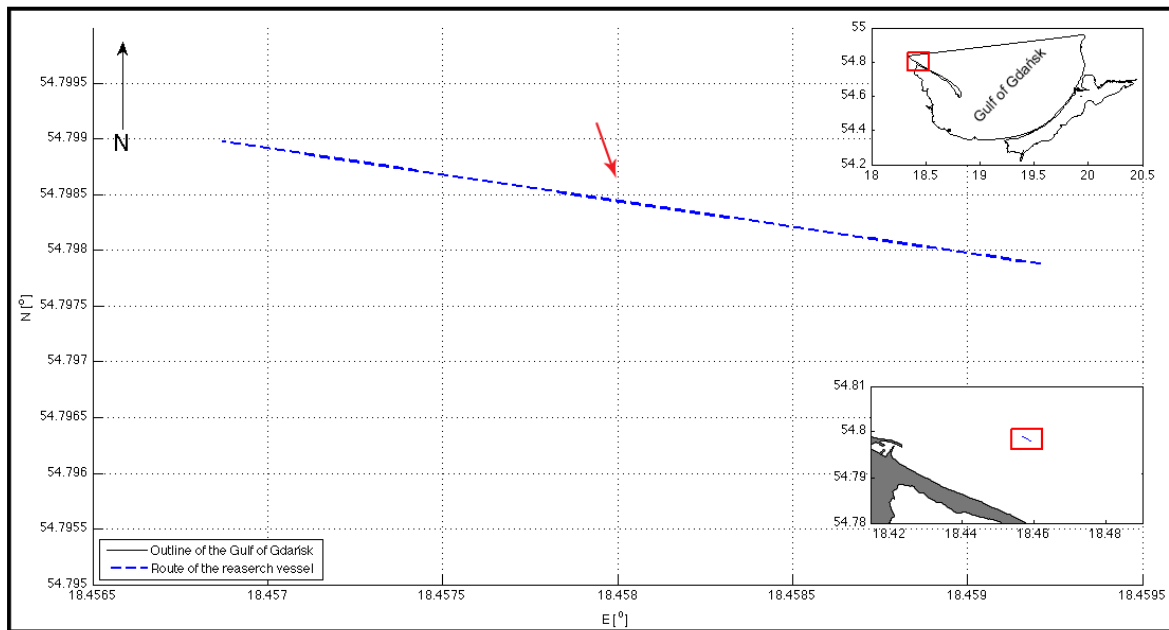


Fig. 3. Map of the Southern Baltic Sea with a marked place where the profiling was carried out in order to detect the pipeline. The red arrow indicates the place where the pipeline runs.

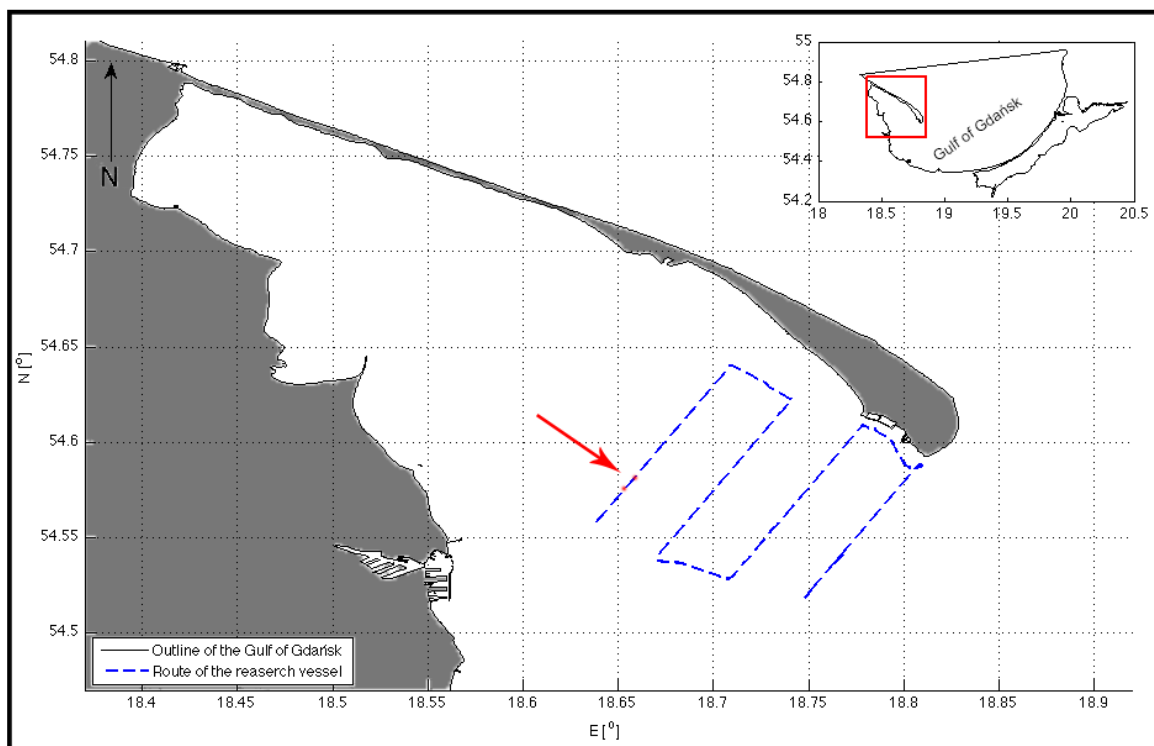
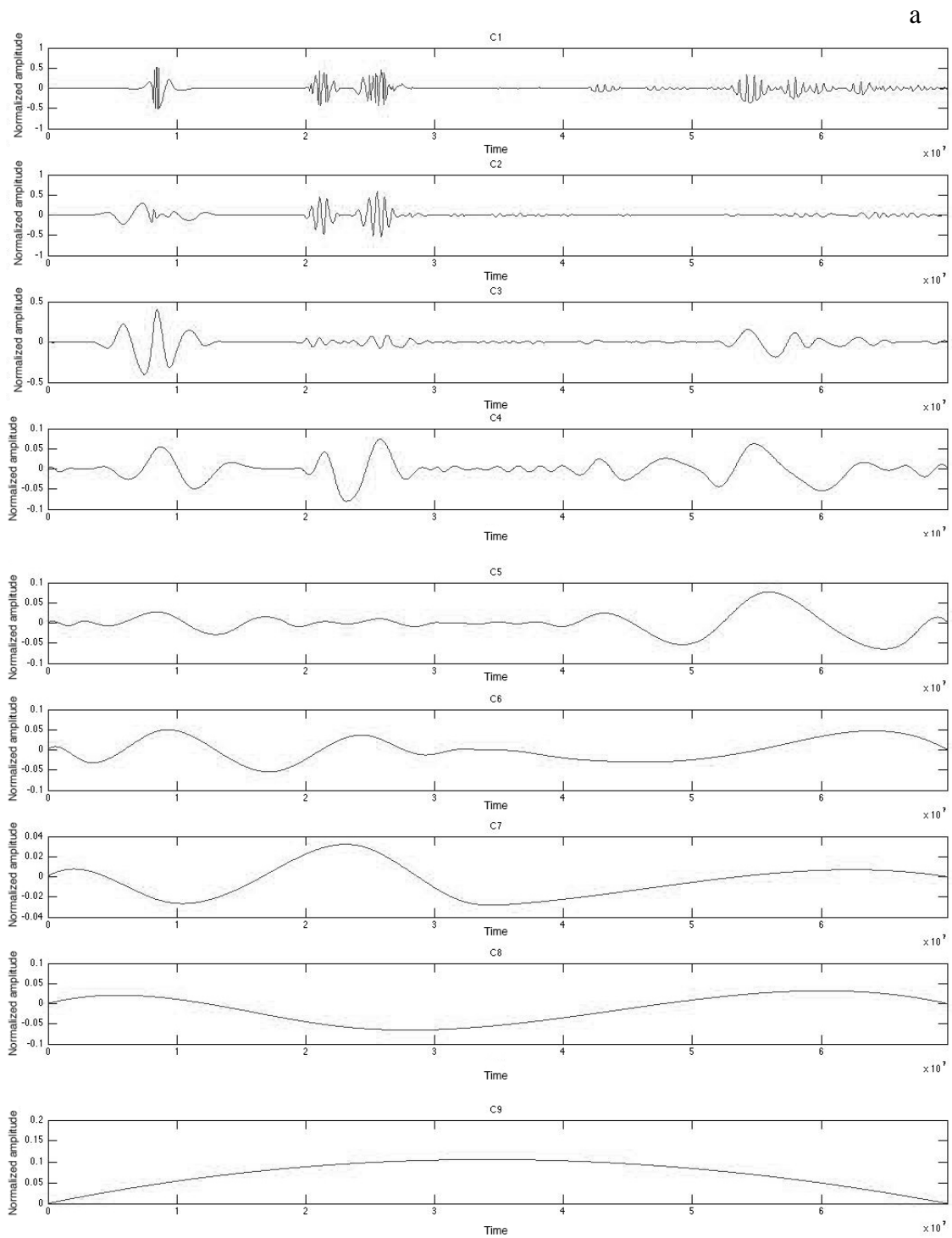


Fig. 4. Map of retrieving data with the transect survey vessel marked with a blue dotted line.

3. RESULTS OF ANALYSIS

Displayed below are the successive stages of the Huang – Hilbert transformation (Fig. 5a and Fig. 6a), along with the echograms showing selected IMF functions and residues (Fig. 5c, Fig. 5d and Fig. 6c, Fig. 6d). For two cases:

a) Echoes from the pipeline:



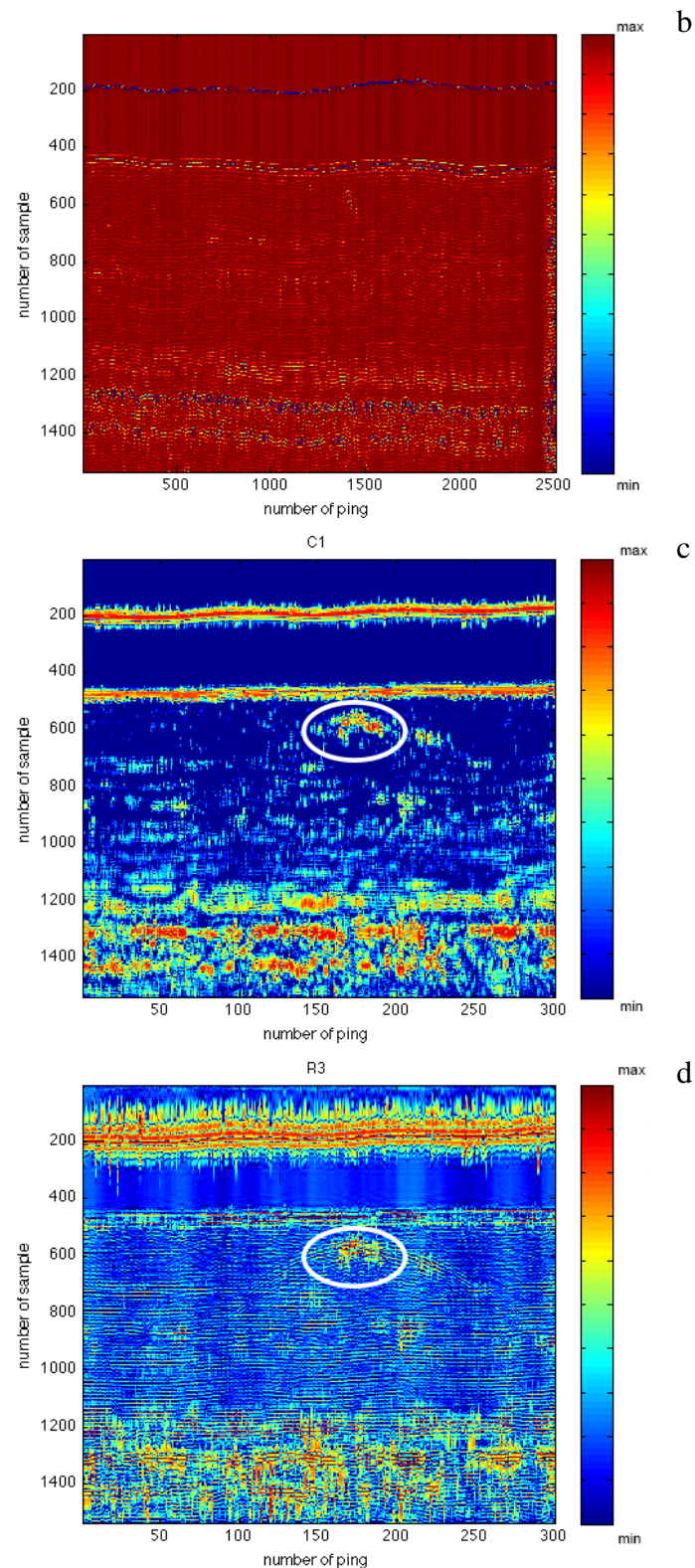
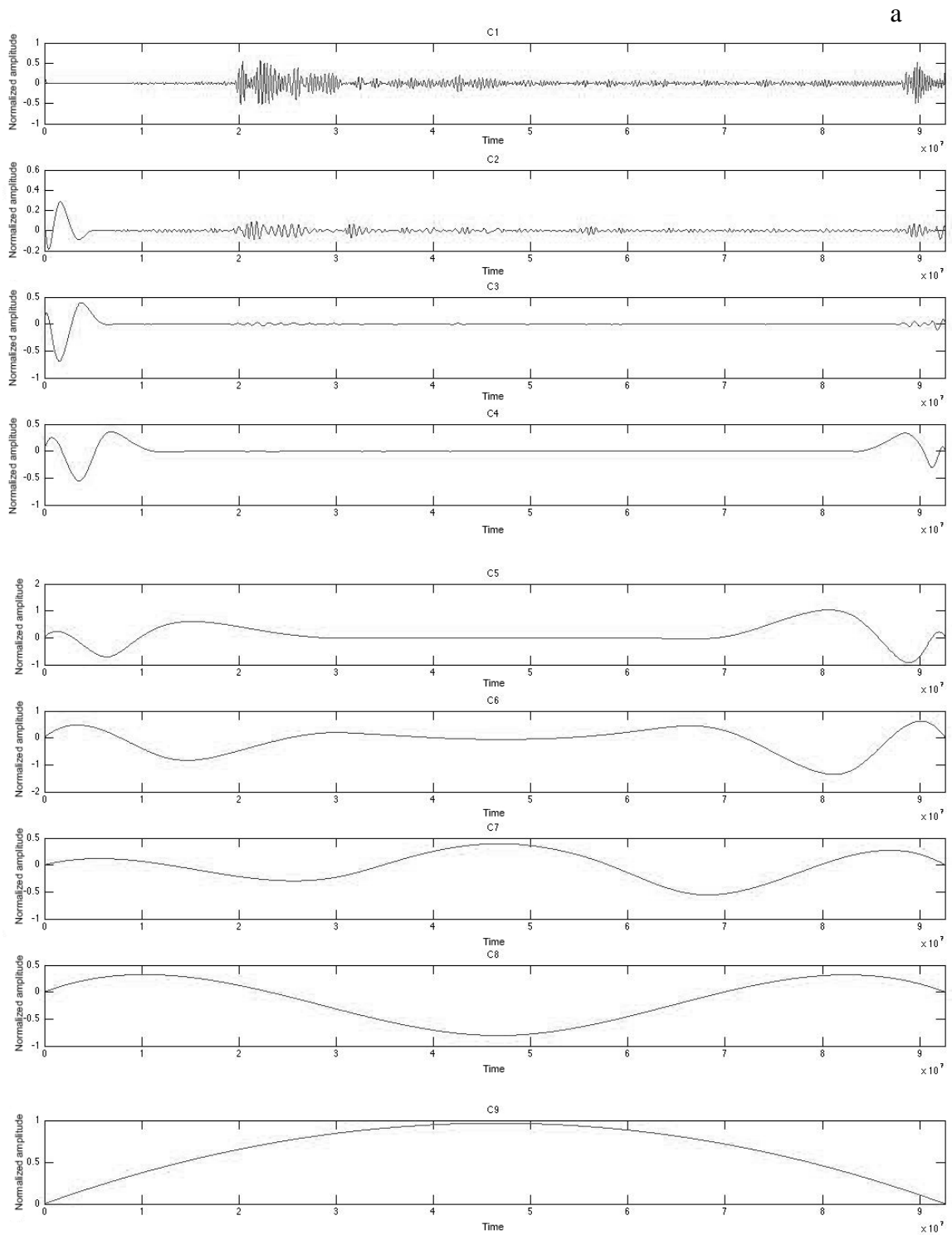


Fig. 5. a) successive stages of the Huang – Hilbert transformation, b) the echogram before applying the Huang - Hilbert transformation c) the echogram created from the first function of IMF - C1 with a visible pipeline between 150 and 250 ping (marked by the white circle) , d) the echogram created from the third residuum - R3 with a visible pipeline between 150 and 250 ping (marked by the white circle).

b) Quaternary facies:



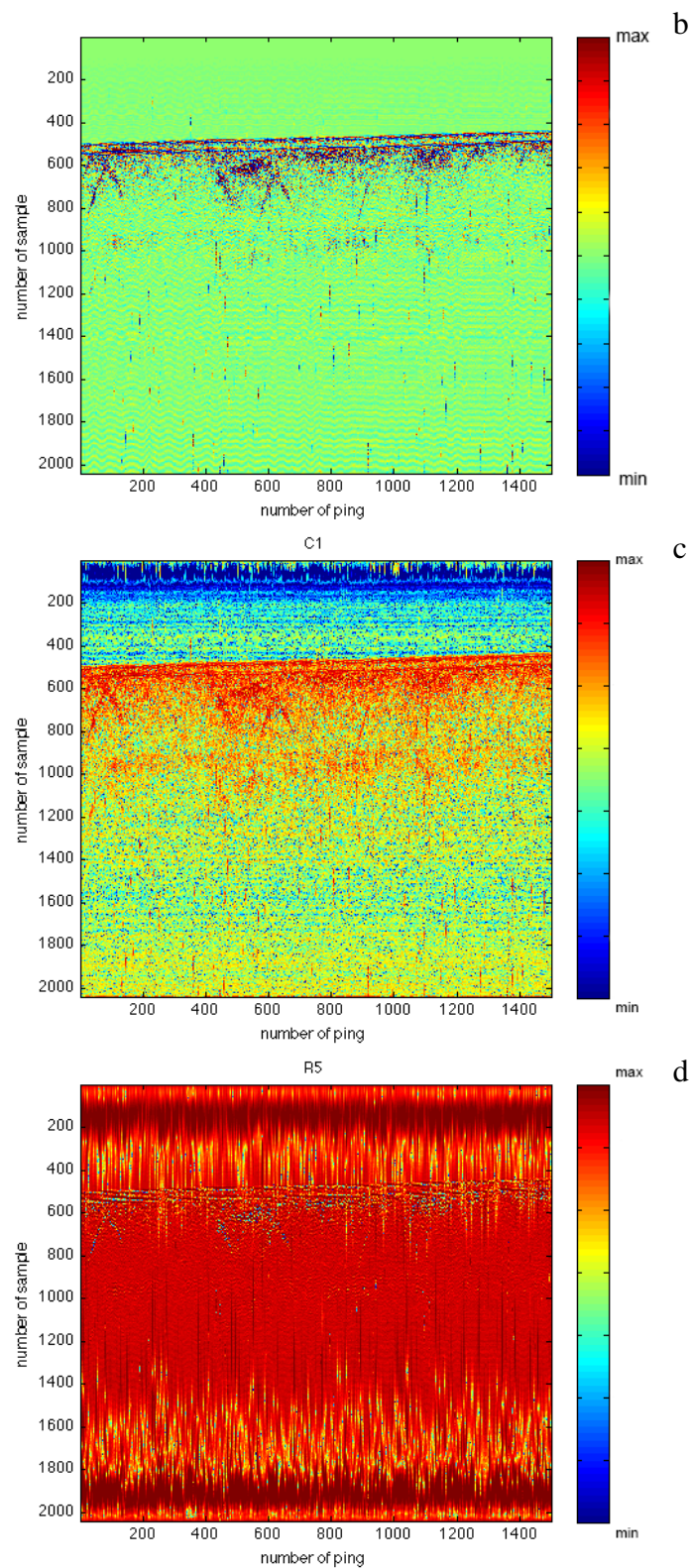


Fig. 6. a) the successive stages of the Huang – Hilbert transformation, b) the echogram before applying the Huang – Hilbert transformation, c) the echogram created from the first function IMF - C1 with exposed boulders between 1 and 900 ping and visible facies under the bottom of the surface, d) the echogram created from the fifth residuum - R5 with a visible boulder between 1 and 900 ping and visible facies under the bottom of the surface.

4. DISCUSSION OF RESULTS AND CONCLUSIONS

The phenomenon of the propagation of acoustic waves in water as well as in other media, such as geological formations or objects buried in the sediment bottom, has non-stationary characteristics, thus becoming a very complex process. A good tool for the analysis of acoustic data in the situation described above seems to be the Huang - Hilbert transformation. Apart from the application analysed above, the transformation is suitable for the description of other phenomena, such as the makeup of gas deposits [1]. Another type of analysis – for example wavelet transform - which only allows us to examine the phenomena in both a linear and non-stationary way, would also provide good results [5], although not as accurate as the solution proposed by Huang [3]. The application of the Huang - Hilbert transformation in implementing the aforementioned assumptions gave satisfactory results. Echograms after transformation are less noisy and more readable. We observe that the EMD-based method highlights geologic (facies) and pipeline features more clearly and improves the interpretation of layer variation, which proves the validity of this method in this type of analysis.

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