Open Journal of Acoustics, 2025, 13(3), 53-64
https://www.scirp.org/journal/oja
ISSN Online: 2162-5794
ISSN Print: 2162-5786

Amelioration of the Analysis of the Ultrasonic Measurement Using the Wavelet Method

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How to cite this paper: Kemiha, F. and Bouhadjera, A. (2025) Amelioration of the Analysis of the Ultrasonic Measurement Using the Wavelet Method. *Open Journal of Acoustics*, **13**, 53-64.
https://doi.org/10.4236/oja.2025.133004

Received: February 23, 2025
Accepted: August 1, 2025
Published: August 4, 2025

Abstract

The experimental ultrasound data is always trained by measurement errors, internal and external noise. For this reason, it is always necessary to apply some signal processing operations, such as filtering, the Fourier transform, the Laplace transform, the wavelet transform, and the statistical and intelligent methods to extract relevant information desired in case of instabilities of measurements. The wavelet method is a method that has proven its importance in scientific research, especially in noise filtering, signal analysis, superimposed signal separation and data compression. It also allows you to view the variation of signals as a function of time and frequency at the same time. In this article, we will apply the wavelet transform on experimental ultrasound data to minimize noise, separate the different superimposed signals and extract the desired information, and better analyse the experimental data from an ultrasonic wave measurement. Applying the ultrasonic prism method on fresh concrete samples results in reflected ultrasound signals, which are rich in information about the properties and different characteristics of the sample under test. These measurements are sometimes unstable, noisy, and contains several interesting information about the testing sample overlapping each other. These signals are processed and analysed by the wavelet method in order to improve the exploitation of the ultrasonic measurements. The results obtained are discussed and compared with those published in literature.

Keywords

Wavelet, Ultrasonic Measurement, Fresh and Hardened Concrete, Ultrasonic Prism Technique

1. Introduction

There are much background and mixture noise in the course of ultrasonic wave transmission under materiel tested such as air bubbles and mechanical noise. Because of these factors, the useful signal and the high noise signals are combined together, which affect the precision of the reflected and refracted ultrasonic wave. Ultrasonic echo signal is decomposed into three larger wavelets, and a threshold is set to process the wavelet coefficients, then the signal is reconstructed accordingly, the influence of noise on the measurement precision is effectively restrained. The wavelet transform is applied to analysis of ultrasonic waves for improved signal detection and analysis of the signals. In instances where the mother wavelet is well defined, the wavelet transform has relative insensitivity to noise and does not need windowing [1]-[3].

2. Wavelet Theories

2.1. Introduction

Signal processing offers a large variety of tools, the most popular technique, Fourier analysis, breaks down a signal to sinusoidal constituents of several frequencies, transforming a signal in the time domain into its counterpart in the frequency domain. For signals with well-defined frequencies and where this information meets the requirements, Fourier analysis is more than satisfactory. However, there are some disadvantages, especially when it is used with signals that undergo sudden changes, fluctuations, discontinuities or localized phenomena, among others. The wavelet theory has been used in recent years to cover some of the limitation in Fourier analysis. it is based on windowing the signal into variable sized regions, using long time intervals for information on low frequencies and shorter intervals for high frequencies, thus allowing analysis of localised areas without losing the time information, furthermore, in opposition to the smooth and continuous shape of harmonic function, the wavelets my present peaks and discontinuities and improve the sensibility for abrupt phenomena, the mother wavelet db3, used in this work, is orthogonal and asymmetrical and present irregular shape as shown in **Figure 1**.

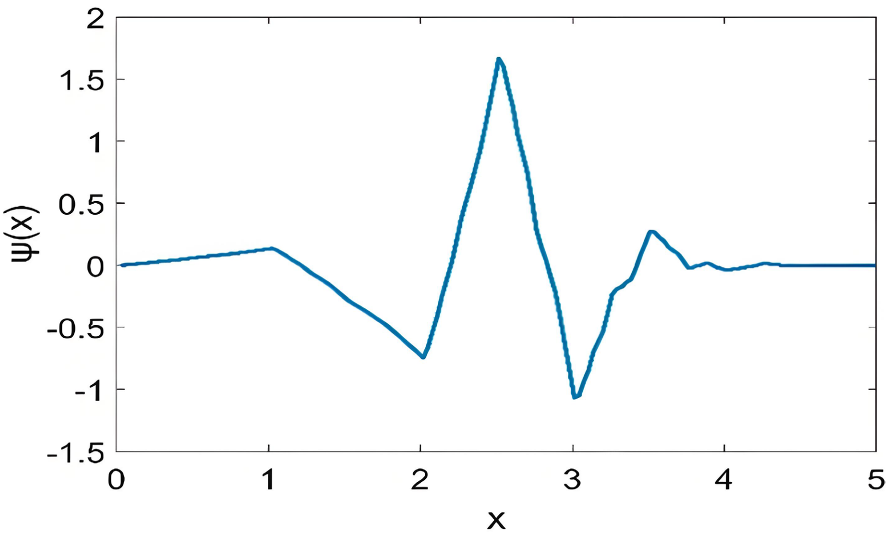


Figure 1. db3 wavelet transform.

The wavelet transform breaks down a signal into components (wavelets) which very "in scale" (stretched or compressed) and in location (shifted). Maintaining the Integrity of the Specifications [3].

2.2. Definition

Wavelet analysis is becoming a common tool for analysing localised variations of power within a time series. By decomposing a time series into a frequency space, one is able to determine both the dominant modes of variability and how those modes vary in time. A wavelet is wave like oscillation with an amplitude that begins at zero, increases or decreases, and then returns to zero one or more times wavelets are termed a "brief oscillation", a taxonomy of wavelets has been established, based on the number and direction of its pulses [4] [5].

2.3. Different Types of Wavelets

2.3.1. Continuous Wavelet Analysis (CWT)

To meet the needs for adaptive time-frequency analysis in applied mathematics, physiques and engineering, the wavelet theory was developed in the late 1980 by Morlet and Daubechies (see Mallat, 1990). In wavelet transform (WT), a signal of interest is decomposed by examining the coefficients of the wavelet transform is a convenient tool for processing non-stationary signals. It has been widely used to analyse machining signals for tool condition monitoring. Let $\psi_{a,b}(t), a, b \int R, a \neq 0$, be a family of functions defined as translations and rescales of single function $\psi_{a,b}(t) \epsilon L^2(R)$ (Mallat, 1989):

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) \tag{1}$$

With the following basic properties

$$\int_R \psi_{a,b}(t) \mathrm{d}t = 0 \quad \text{and} \quad \int_R \psi_{a,b}^2(t) \mathrm{d}t = 1 \tag{2}$$

These properties indicate that the wavelet is small wave oscillating around zero and diminishing quickly (finite energy). The fundamental idea of wavelet transform is that the transformation should allow only changes in time extension, but not shape, imposing a restriction on choosing suitable basis functions. Changes in the time extension are expected to conform to the corresponding analysis frequency of the bases function. Based on the uncertainty principle of signal processing $\Delta t^* \Delta w \geq (1/2)$, where t represents time and w angular frequency. The higher the required resolution in time, the lower the resolution in frequency has to be. The larger the extension of the analysis windows is chosen, the larger is the value of Δt [5] [6]. When Δt is large:

1) Bad time resolution

2) good frequency resolution

3) Low frequency, large scaling factor

when Δt is small

1) Good time resolution

2) Bad frequency resolution
3) High frequency, small scaling factor.

2.3.2. Discrete Wavelet Transform

In numerical analysis and functional analysis, a discrete wavelet transform (DWT) is a wavelet transform for which the wavelets are discretely sampled. As with other wavelet transforms, a key advantage it has over Fourier transforms is temporal resolution, it capture both frequency and location information (location in time). The DWT of a signal *x* is calculated by passing it through a series of filters. First the samples are passed through a low-pass filter with impulse response g resulting in a convolution of two [5] [6]:

$$y=[n]=(x*g)[n]\sum_{k=-\infty}^{+\infty}x[k]g[n-k] \tag{3}$$

The signal is also decomposed simultaneously using a high-pass filter *h*. The outputs give the detailed coefficients (from the high-pass filter) and approximation coefficients (from the low-pass). It is important that the two filters are related to each other and they are known as a quadrature mirror. However, since half the frequencies of the signal have now been removed, half the sample can be discated according to Nyquist's rule [4] [5] (**Figure 2**).

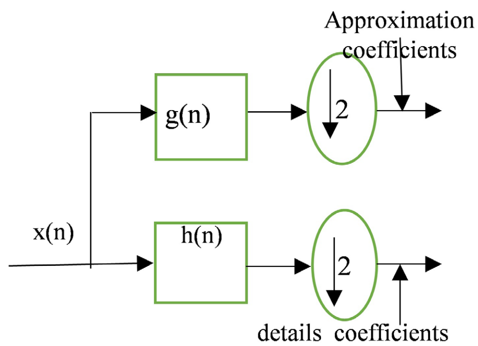


Figure 2. block diagram of filter analysis.

3. Ultrasonic Measurement

Ultrasound has consistently proven its usefulness and importance in almost every field (medicine, industry, communication, imaging, etc.) since its invention. It allows for the processing and analysis of various environments and materials, whether human or not. For this reason, improving the analysis of ultrasonic responses from the various analyzed environments is necessary through new theories, such as artificial intelligence, wavelet transforms, new statistical methods, etc. In this section, we will use the ultrasonic prism technique to analyze several samples in its different states (hard and fresh). The schematic of the experiment used is shown in **Figure 3**, it consists of a transmitter/receiver sensor, an interface containing the fresh sample, and data acquisition devices (oscilloscope and PC). An example of the signal obtained from this experiment is shown in **Figure 3**. These signals are usually affected by measurement errors or noise, so many of the echoes are overlapped, for this reason we will apply different types of wavelet transforms to the obtained ultrasonic measurements shown in **Figure 4** [6]-[8].

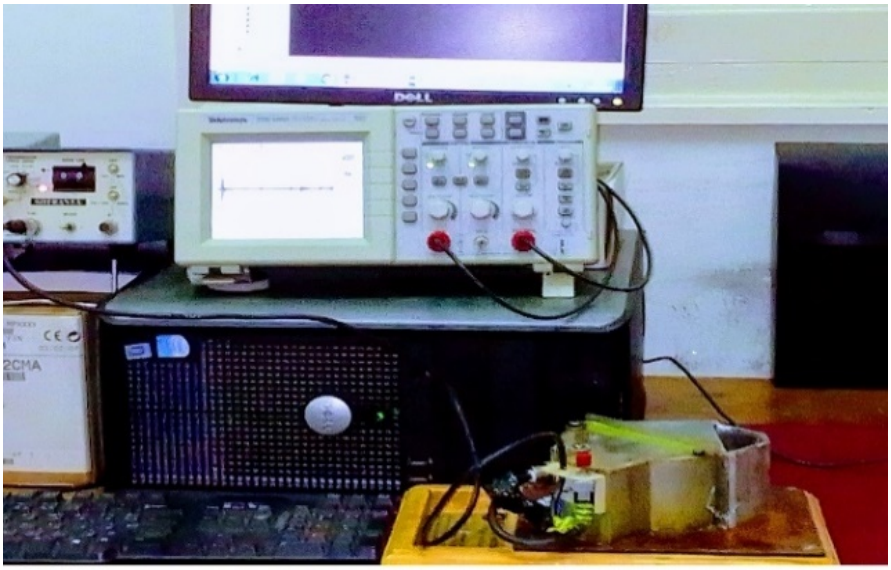


Figure 3. image of ultrasonic prism technique.

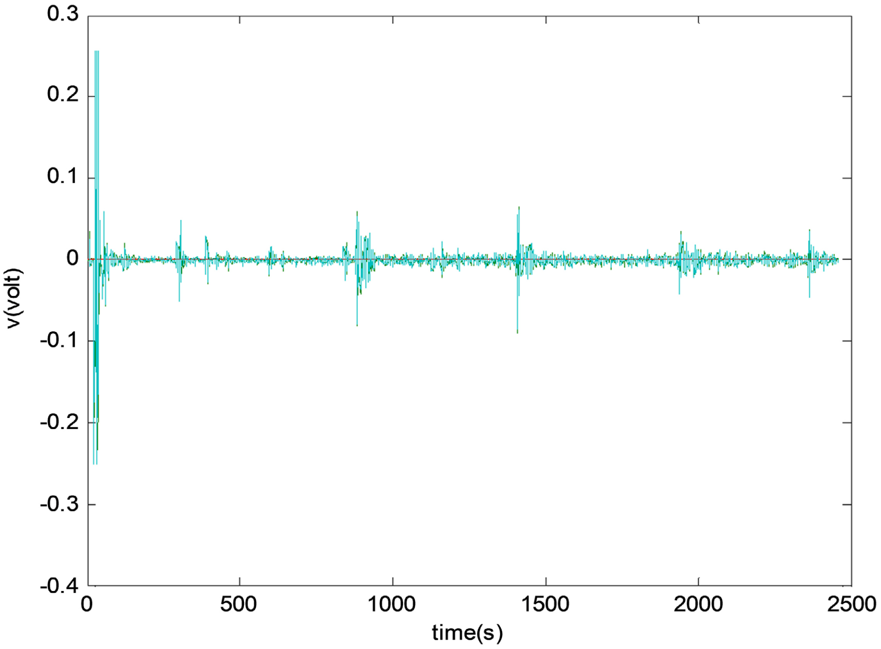


Figure 4. Original ultrasonic measurement signal.

4. Application the Wavelet upon Ultrasonic Measurement

The coefficients act as filters, which are arranged in the form of a transformation matrix that uses two patterns, one acting as a smoothing filter and the other providing information about details. Additional details can be obtained in graps and polikar. The discrete wavelet packet analysis, which is a more compete and versatile tool. IT allows the decomposition of both approximation and details into new approximation and details.

4.1. Ultrasonic Signal Decomposition by Wavelet

The ultrasonic signals obtained during a measurement are always enriched with information on the characterized environment, sometimes this information is overlapped between them, or invisible, drowned in the high frequencies for this reason it is necessary to decompose the signals obtained in order to obtain the maximum information on the tested environment. Figures 5-12 below show the decomposition of the measured ultrasonic signal obtained by the prism technique.

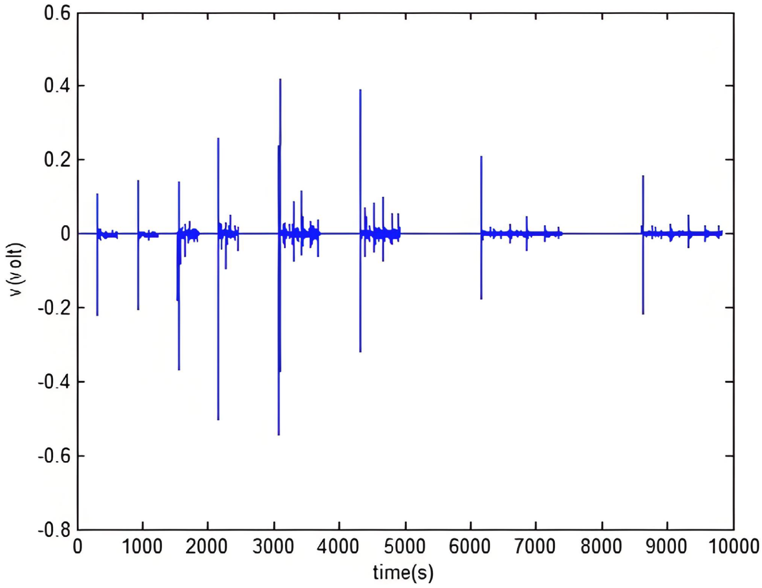


Figure 5. Separation with wavelet db1.

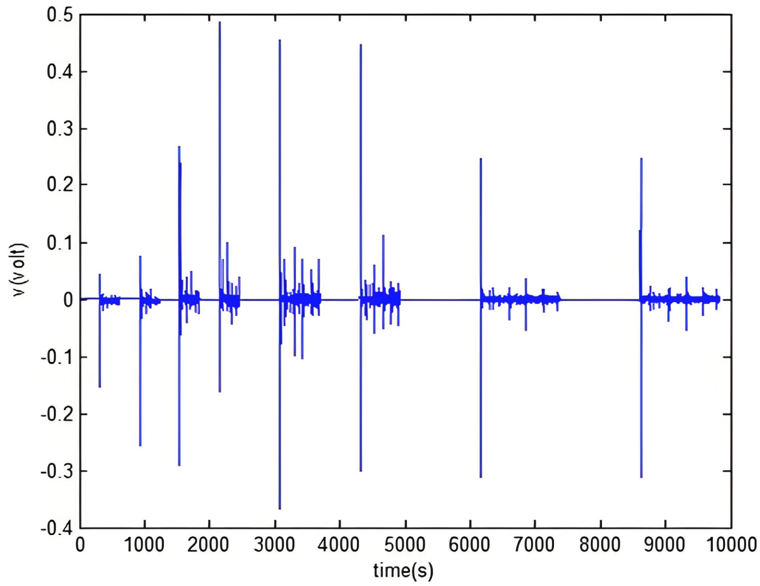


Figure 6. Separation with wavelet db2.

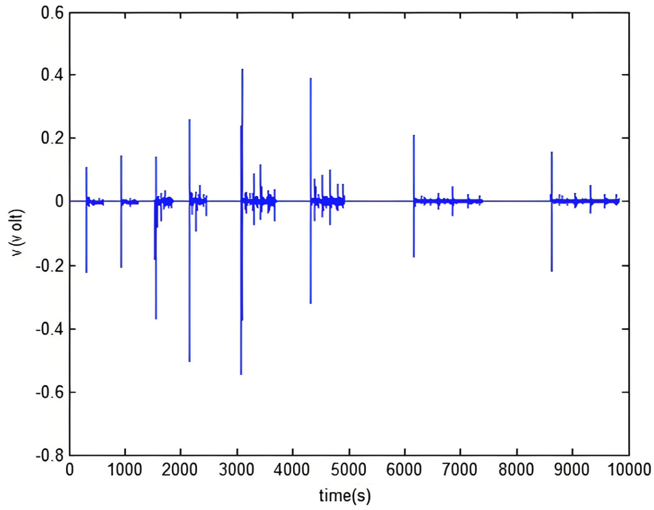


Figure 7. Separation with wavelet db3.

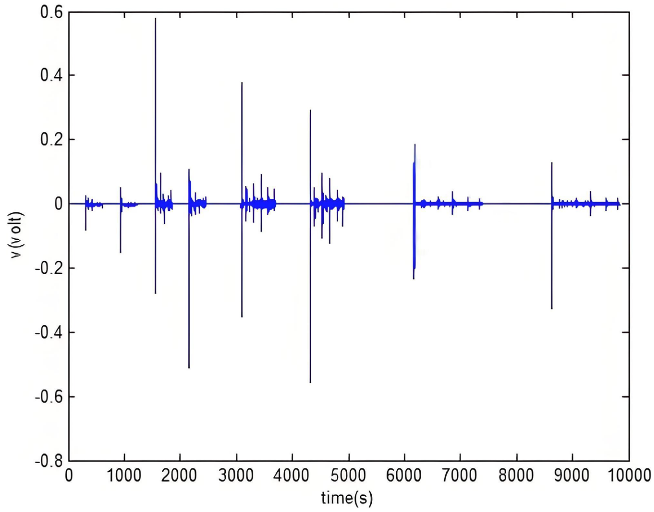


Figure 8. Separation with wavelet db4.

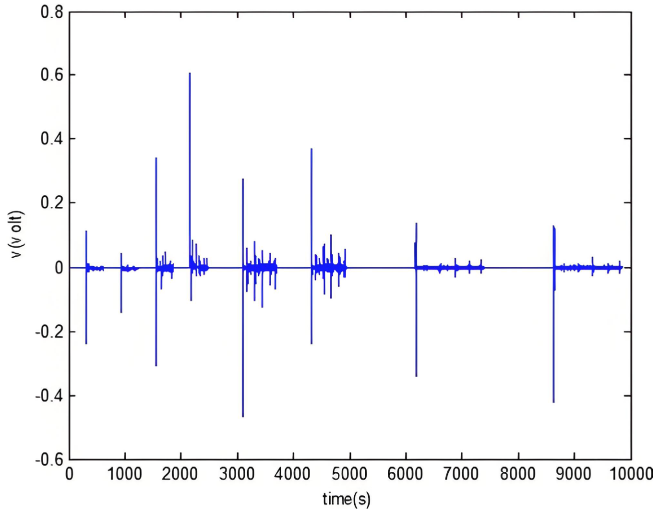


Figure 9. Separation with wavelet db5.

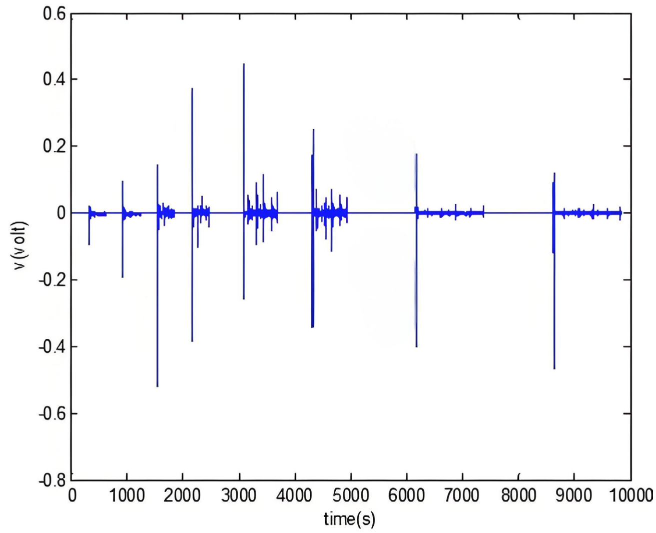


Figure 10. Separation with wavelet db6.

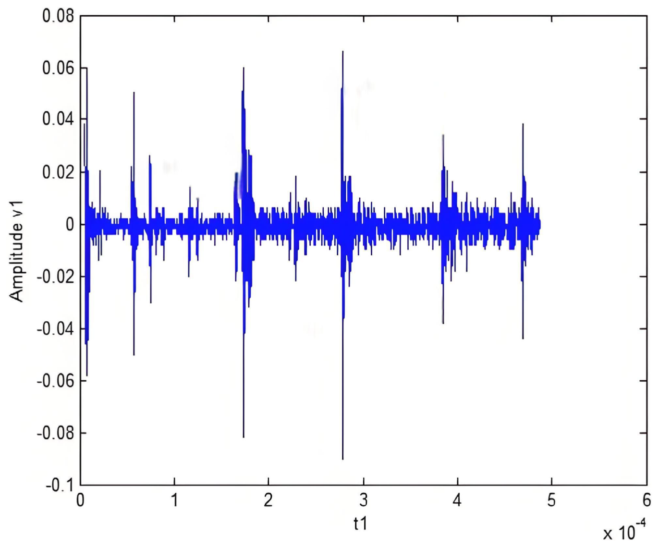
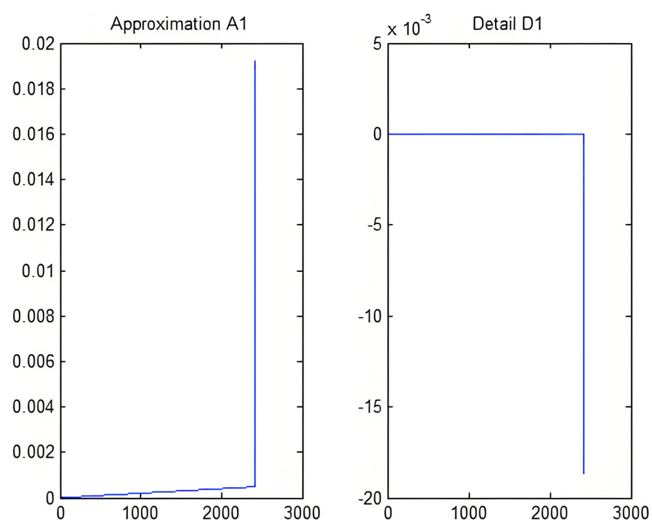


Figure 11. Original signal.



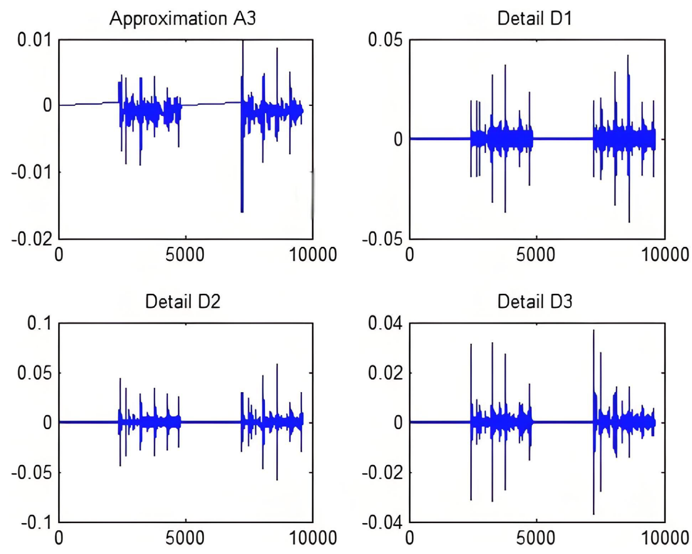


Figure 12. Decomposed the ultrasonic signal to one approximation and different details.

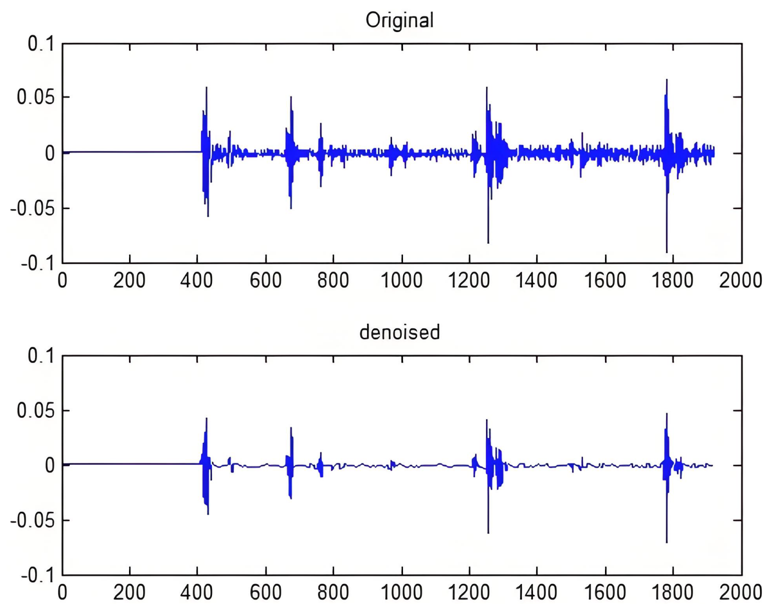


Figure 13. De-noised signal with wavelet transform.

In order to test the degree of continues wavelet we applied different degrees db1, db2, …, db6. According to the results shown in the figures, we see that db3 is the most reliable in our case, also we see also that the continuous wavelet transform allows the signal to be decomposed into eight separate signals, each signal can be information on the analyzed medium. Figure 11 and Figure 12 is another example of separation of ultrasonic measurement signal, we see the different staps of separations using continuous wavelet.

4.2. De-Noising by Wavelet

The majority of measurement signals are affected by noise, Therefore, applying a

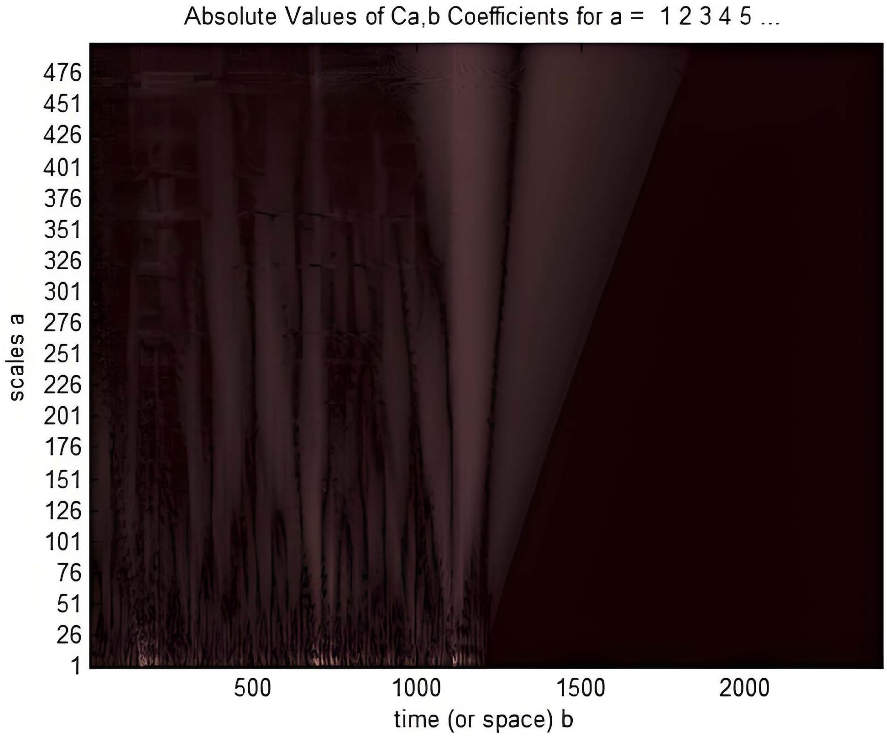


Figure 14. Two dimension presentation with wavelet transform.

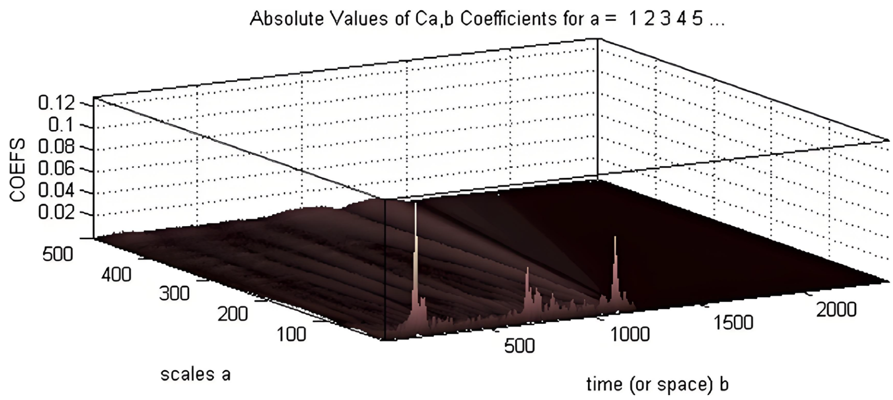


Figure 15. Three dimension presentation with wavelet transform.

filter to minimize or remove noise is crucial task throughout the measurement chain. In this section, we will apply the continuous wavelet transform to remove noise. The bending of signal is primordial problem during experimental measurements, Figure 13 is an example of the treatment of ultrasonic signals by the wavelet transformations.

4.3. Two and Three Dimensional Presentation Using Continuous Wavelet Transforms

Figure 14 and Figure 15 show the image of ultrasonic measurement in two dimension presentation and three presentation respectively using wavelet transform.

5. Interpretation and Discussion

The results obtained in this article are satisfactory using the wavelet transform on experimental ultrasound measurements allows us to effectively separate overlapped signals, filter out the noise produced in the measured signals, view the time-frequency representation simultaneously, and also create a two- or three-dimensional image of the measured signal. To improve this study in future, we can apply other types of continuous wavelet, for example sym wavelate, or apply the discrete wavelet transform.

Fourier transforms approximation a function by decomposing it into sums of sinusoidal functions, while wavelet analysis makes use of mother wavelet, both methods are capable of detecting dominant frequencies in the signal, however, wavelets are more efficient in dealing with time-frequency analysis. Also, wavelet is used for the visualization, analysis, compression, and de-noising of complex data, there are dozens of different wavelet shapes, what bay itself is a big difference from Fourier analysis Research results indicate that wavelet transform method is very useful for noise reduction in signals. its precision is higher than that of adaptive filtering method [8]-[10].

6. Conclusion

Wavelet analysis is an exciting new method for solving difficult problems in mathematics, physics, and engineering, with modern applications as diverse as wave propagation, data compression, signal processing, image processing, pattern recognition, computer graphics, the detection of aircraft and submarines and other. In this paper wavelet transform is used to decomposing, de-noising the ultrasound measurement signal. The result is satisfactory and can be ameliorate in future by using other type of wavelet transform. In conclusion, the wavelet analysis can be named mathematic microscopic for analysis non-stationary signal.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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