An Energetic Smoothing Analysis for the Ultrasonic Signal De-noising and Defect Detection

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Abstract. The requirements for reliable Ndt methods are increasing significantly. In Ultrasonic testing a good understanding of the interaction of the elastic waves with boundaries and defects is essential. Due to multiple scattering, the visibility of flaw echoes is corrupted by noise and the interpretation of detected signals become difficult. In this work we have been able to extract the noise features by an improved energetic smoothing procedure and we have been able to develop the noise analysing wavelet function which has been found different from the signal analysing one. In this stage we have been able to deduce that the random nature of the noise in the spatial domain has been surpassed. The energetic characterisation of the noise and the defect has allowed an easiest filtering of the ultrasonic signal, and a good flaw detection process. The minima-maxima smoothing method, developed in this study has given an accurate signal reconstruction without any distortion.

1. Introduction

Acoustical characterization is an important item in non destructive testing of materials. An often used technique is the echo-graphic one which consists of analyzing the waves reflected by the material heterogeneities. Since, the reflected signal is always corrupted by noise; the process of signal filtering may be the most fundamental task in the framework of material characterization. Numerically, the ultrasonic signal is represented by time dependant functions and filtering is represented as a convolution of the signal and the filter impulse response. The ultrasonic signal is non stationary in nature and the difficulty of its analysis is in the extraction of the useful information.

The wavelet analysis is a multi-resolution time scale method which enables to perform a time localized analysis of signals. The result of the wavelet function is the difference between value calculated and the data. The ability of a wavelet filter to exactly reconstruct a signal component depends on how closely the wavelet function approximates the signal. Since, no signal can be simultaneously and arbitrary localized in time and frequency, so the gauss signal which is the more concentrated one must be interpreted as an elementary carrier signal of minimum information.

The wavelet transform consists in correlating the analyzed signal with a family of wavelets obtained by dilating and oscillating functions of finite duration [1]. In this respect, the wavelet transform is able to give a quantitative measure of the local appearance of the signal at different scales.

Many studies have been conducted on the use of the wavelet theory for ultrasonic signal de-noising, but no one has been done on the structural noise features and its possible analyzing wavelet function. In the framework of the automation of the ultrasonic signal analysis project, we haven't make the exception, and we have followed the exploration of the wavelet theory, from the continuous transforms to the discrete ones without disregarding the wavelet packet.

The filter bank of the continuous wavelet transform gives good results for the highest frequencies, but requires a fine study of the noise threshold in the low frequencies, which needs many experiments on each defect signature [2].

The filter bank of the discrete wavelet transforms needs extensive tree decomposition for each signal, and an amount of time computing for the choice of the best averaging. Even, the reconstruction of the signal components is not complete due to the waste of some useful information from the filter bank tree. The wavelet packet allows a biggest decomposition and a lot of time computing with a refined signal reconstruction [3]. So, the improvement of the automatic threshold control is based on the investigation of the noise features. The proposed algorithm runs on a one cycle for each signal analysis and provides a reconstructed signal without distortion.

2. Description of the process and results

A time scale analysis allows a larger view of the signal energetic configuration which permits the ultrasonic noise features extraction [4]. The acoustic noise is supposed to be a gauss random variable with a zero averaging and a limited band power spectrum function [5]. As the ultrasonic energies are concentrated in the frequency band, the different frequencies beside the band are represented in the transform domain by very weak amplitudes and can be scattered without loss of information.

The proposed algorithm that we called "energetic smoothing algorithm" is subdivided into the following tasks (figure 1):

- Evaluation of the signal frequency band by a power spectrum analysis,
- Evaluation of the signal energetic distribution and estimation of the different coefficients by a time scale analysis. Here the chosen analyzing function is the 8^{th} derivative gauss function [2],
- Noise extraction process based on wavelet coefficients regulation by an energetic smoothing of the maximums,
- Result: time scale mapping of the energetic distribution of the noise,
- Inverse wavelet transform, and statistical noise features calculation: variance, averaging, standard deviation…
- Filtering process with the minima–maxima calculation method, based on the energetic coefficients reduction between the signal and the noise time scale representations.
- Optimization of the filter with a selection of the best analyzing wavelet function for the noise representation.

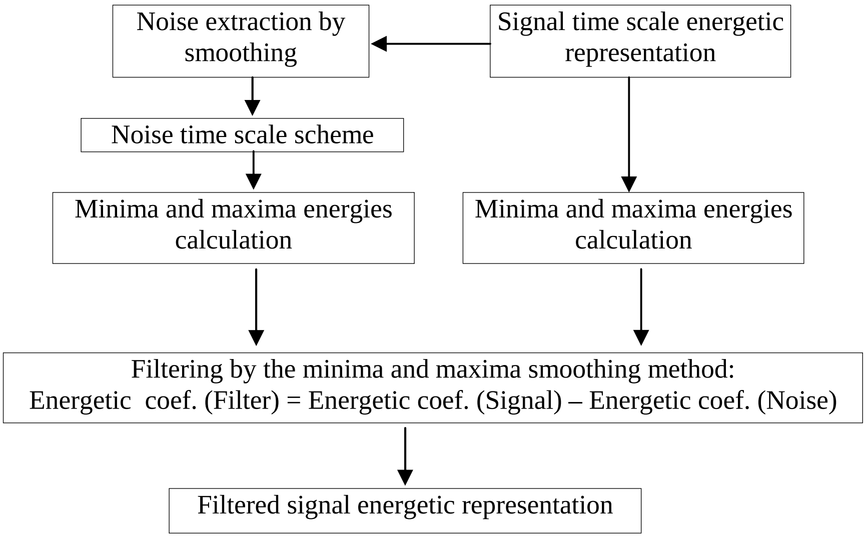
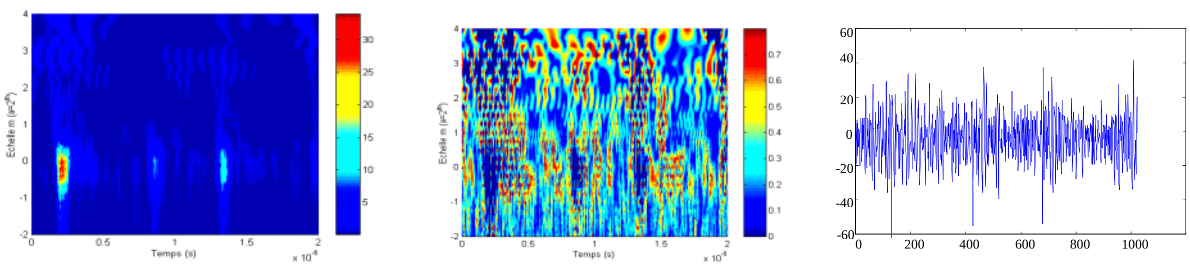


Figure 1 - Energetic Smoothing Algorithm decomposition

2.1 Noise extraction procedure

The energetic smoothing procedure for noise extraction is based on an elimination of the maximum energetic coefficients vector from the signal analyzed by the 8^{th} derivative gauss function (figure2.a), which generates the noise energetic coefficients. And from a time scale noise mapping with the Morlet function we do a computation of the noise energetic threshold (figure2.b). The statistical noise characterization is performed by an inverse procedure in the time domain (figure2.c).



(a) 8^{th}Gauss signal time scale map Signal coefficients extraction

(b) Morlet Noise time scale map Noise coefficients extraction

(c) Noise statistical features

Figure 2- Noise extraction and characterization

2.2 Filtering procedure

After calculation of the noise and signal maximum and minimum energetic coefficients vectors from the two time scale representations, the filtering is performed with the named "Minima – maxima smoothing method" based on a smoothing of the maximum noise energetic coefficients vector and the minimum signal energetic coefficients vector (figure 3). The coefficients distribution and scattering is performed without loss of information.

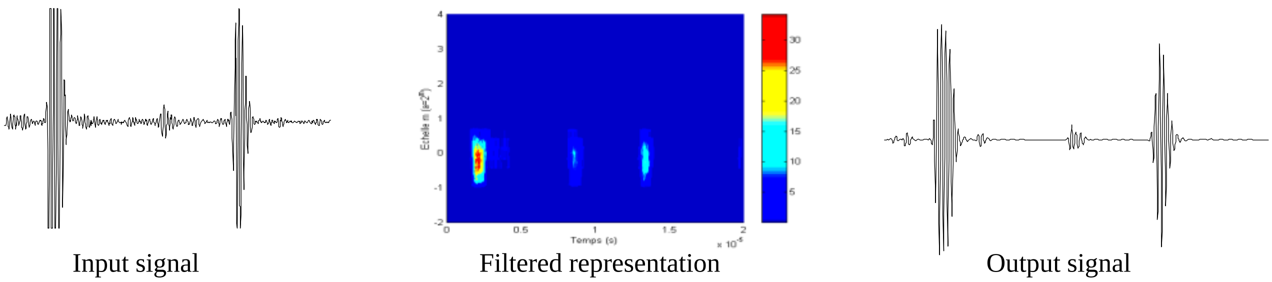


Figure 3 - Minima – maxima smoothing de-noising method

2.3 Signal and noise analyzing functions

The signal analyzing wavelet function is obtained by a correlation procedure of an ultrasonic signal data bank obtained on welded pieces and artificial flaws with the Gaussian family functions, which indicates the 8th derivative gauss function as the more appropriate analyzing function [2]. Simultaneously, a data bank of extracted noise signals is correlated with the wavelet analyzing functions; the obtained results are displayed in figure 4. The Morlet function seems to be the more suitable analyzing function of the noise, and is chosen for the filtering process.

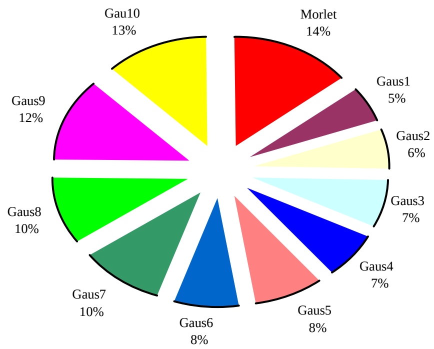


Figure 4: Correlation between wavelets and noise signals

3. Experiments

The experiments have been conducted within the following conditions:

- Steel piece 35mm width, with artificial cylindrical defects of (10mm, 7mm, 5mm , 3mm, 1mm) diameter
- Steel piece 35mm width, with artificial circular defects of (10mm,7mm,5mm ,3mm, 1mm) diameter
- Steel welded piece 30mm width with welding defects: lack of fusion, porosity, group of porosity and horizontal crack
- longitudinal transducer 4Mhz frequency and 4 mm diameter, transverse transducers of 4Mhz, 60° & 70° and 8*9mm diameter.

The figure 5 displays the ultrasonic signal of 1mm flaw completely submerged in noise and the obtained signal. Figure 6 shows a very noisy lack of fusion signal (welding flaw), and the obtained filtered signal.

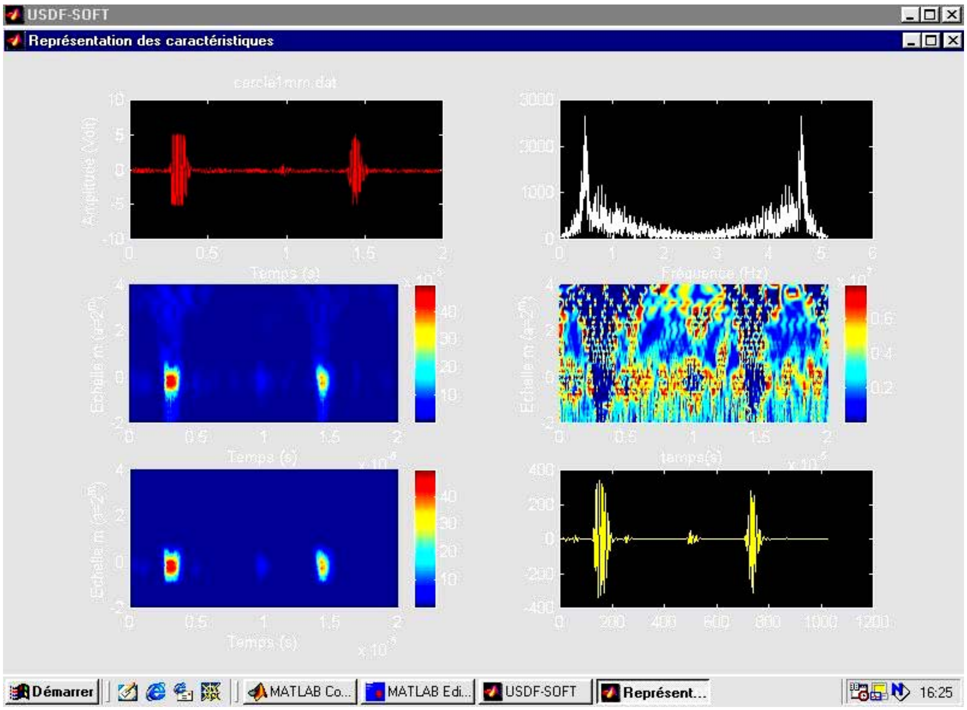


Figure 5 - discontinuity of 1mm

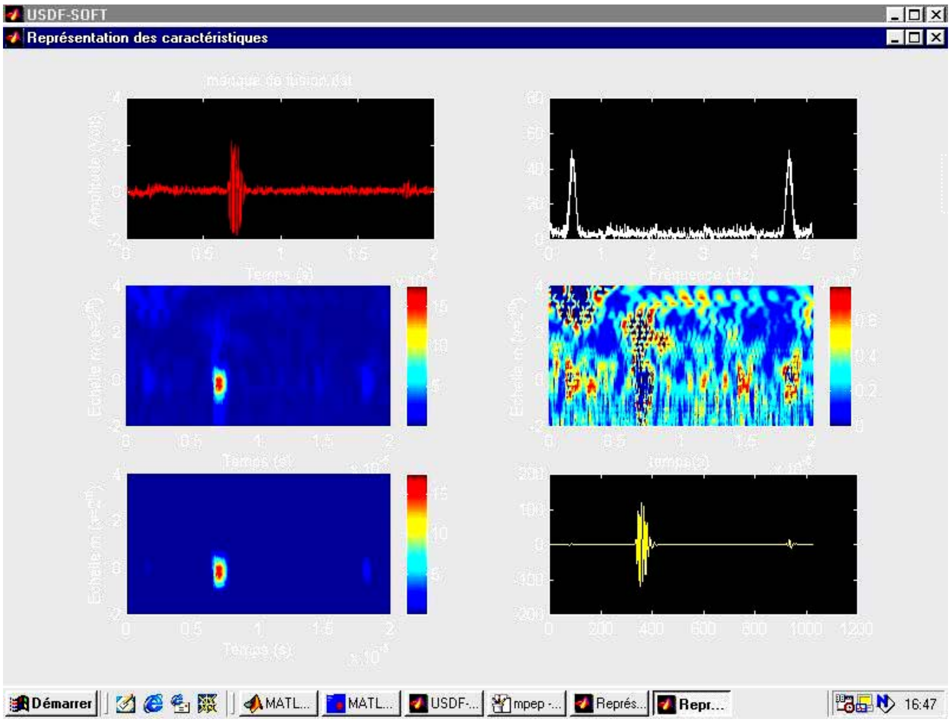


Figure 6 - lack of fusion signal flaw

4. Discussion

We can notice from the different experiments that the 8th derivative gauss function approximates the signal information, and the Morlet function approximates the noise. The above algorithm that has been developed under Matlab environment shows that the proposed de-noising process gives accurate information and improves the automatic defect detection for ultrasonic testing of steel and welded material**.**

5. Conclusion

The study shows the importance of selecting the proper analyzing wavelet function for best processing performance. The wavelet theory is a powerful tool for noise filtering, but requires an increasing test speed with greater test validation data bank. In this work we have been able to extract the noise features by an improved energetic smoothing procedure and we have been able to develop the noise analyzing wavelet function which has been found different from the signal analyzing one. In this stage we can deduce that the random nature of the noise in the spatial domain has been surpassed. The energetic characterization of the noise and the signal information has allowed an easiest filtering of the ultrasonic signal and a good flaw detection process. The minimum – maxima smoothing de-noising method developed in this study, lets an accurate signal reconstruction without any distortion, and is performed in an interesting computing time. Future work in the complete automation process concerns the welding flaw wavelet signature classification.

References

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