IMPROVING THE MATERIAL ULTRASONIC CHARACTERIZATION AND THE SIGNAL NOISE RATIO BY THE WAVELET PACKET

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Abstract: In ultrasonic testing of welds, detection of small flaws is often difficult by the introduced distortion due to the material grain structure. The scattering of ultrasonic waves from grain boundaries can interfere and introduce disturbance in the received signal that can sometimes mask indications due to a small but potentially dangerous defect. However, to enhance the flaw characterization, methods based on “thresholding” have given good results only when the signal to noise ratio is high. Since, both the structure noise and flaw signal concentrate energy in the same frequency band, linear filtering does not provide good results while non linear filtering can improve the signal resolution. One way out is to use the time frequency transforms, the method is based on the wavelet packet decomposition. The Debauchee of order 8 function has been chosen as the analyzing function, and each measured ultrasonic signal is analyzed by a filter bank through only 3 levels of decomposition. This work demonstrates that the following analysis is very efficient with respect to signal recovery from noisy data. The experiments have shown that the proposed method has excellent performances on SNR enhancements.

1. Introduction

In pulse echo technique, a pulse is emitted and if a flaw exists, a delayed echo is expected. But in any case, the material response introduces grain noise, which hinders echo detection, especially in the case of welds where the grain structure is particularly inhomogeneous. In general, the pulse changes as it travels into the specimen due to the different propagation characteristics of each frequency components. The received signal may be considered as the convolution of the excitation pulse with the reflectivity of the material. Generally when we want to generate a signal simultaneously in time and frequency, the first interesting information is the one that gives a sense to the instantaneous spectral countenance. The Fourier duality makes the temporal and frequency signal description, needful and insufficient. So, if we want to renounce to the linearity of the representations, we have to build bilinear solutions with the covariance principle [1]. At this time, we can generate infinity of time-frequency representations which can approach the physical reality of the measured signal. Due to its computational efficiency, one powerful tool to enhance the signal noise ratio of ultrasonic signal is the multi resolution analysis [2]. Indeed, a wavelet has the characteristics of a pass band filter and the wavelet transform has the properties of a continuous filter bank with a constant voltage [3]. Wavelet noise filters are built by calculating the signal wavelet transform, and then applying an algorithm which computes the wavelet coefficients, and chooses the coefficient vectors that should be modified (set to zero) [4]. Wavelet coefficients are the result of the high pass filter applied to the signal. These coefficients are associated with frequency components and are modified in the time domain (each coefficient corresponds to a time range) [4]. In contrast to the wavelet transform, all information about time in the Fourier transform are wasted and only frequency remains [5].The wavelet packet transform is a signal analysis tool that has the frequency resolution power of the Fourier transform and the time resolution power of the wavelet transform. It can be applied to time varying signals, where the Fourier transform does not produce useful results, and the wavelet transform does not produce sufficient results [6]. The wavelet packet transform can be considered as an extension to the discrete wavelet transform, which performs better reconstruction process than the discrete one.

In this work we have followed two filtering stages, the first is a continuous wavelet filter bank where the wavelet coefficients outside the signal frequency band are set to zero, the signal reconstruction is performed in the frequency interval. The second is a wavelet packet filter bank which performs the de-noising in the frequency band interval. The choice of this strategy is related to a computational efficiency of reduced tree decomposition and a better regulation of the noise threshold. The critical role that the mother wavelets play in the following analysis is examined with particular attention.

2. Description of the process and results

The multi resolution called the DWT analysis defines linear operators for a signal analysis at different scales, which needs signal tree decomposition [2]. The signal is then decomposed in approximations and details coefficients which represent the low frequencies and the high frequencies respectively. The original signal S(t) is passed through a high pass wavelet filter and a low pass wavelet filter (it's the first level of the decomposition), to reach the second level, only the output of the low pass filter is once again passed through a pair of high pass and low pass filters. And this is repeated a finite number of times. So a signal that has 2^n points can be decomposed into n levels, which will produce 2^{n+1} sets of coefficients, where the level n has 2^n coefficients. And to move from one decomposition level to the other, a dawn sampling operation is needed. The high pass filtered signal represents the DWT coefficients. This decomposition in effect halves the time resolution, and doubles the frequency resolution. This procedure resolves the high frequencies better in time and the low frequencies better in frequency, but requires an increased computing time and memory space. Even, the reconstruction at each level is performed only on the approximations, and some information brought by the details can be discarded fig (1).

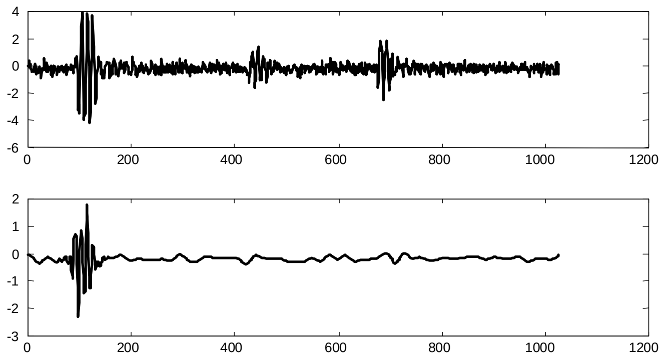

Figure 1 - *Debauchee 8 DWT filtering of a 5mm circle signal*

The wavelet packet analysis resolves this problem, but needs more detailed tree decomposition. So to reach the second level of the decomposition both the output of the low pass and the high pass filters are decomposed in a pair of filters, and this is repeated at each level which generates an amount number of wavelet coefficients.

The wavelet packet algorithm applies recursively the wavelet transforms to the high and low pass results at each level generating 2 new filter results. The signal reconstruction is realized with all the packet wavelet coefficients without information loss. So, achieving a wavelet packet decomposition of the whole signal, requires more and more computing time and memory space, than the DWT one, and needs a lot of experiments for the threshold regulation. To overcome this critical situation we have chosen to perform in a first stage, a filtering of the frequencies that are outside the frequency band by a continuous Gauss filter bank, the filter bank coefficients are generated according of the following algorithm (1). The signal is then reconstructed by an inverse wavelet transform within the frequency band interval fig (2).

$$C'(a,\tau) = \begin{cases} 0 & \text{if } a < a_1 \\ C(a,\tau) & \text{if } a \in [\, a_1 , a_2 \,] \text{ "frequency band interval"} \\ 0 & \text{if } a > a_2 \end{cases} \qquad (1)$$

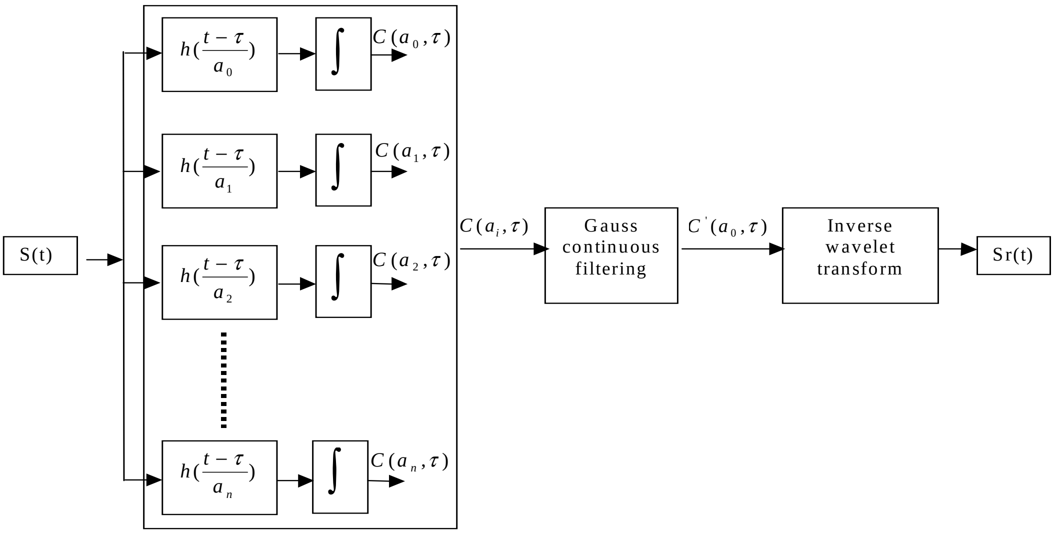

Figure 2 - *Continuous filter bank of S(t)*

We can notice in fig (3) where an artificial plan flaw signal is processed, that the high frequencies noise has been discarded; only speckle noise remains. We go then with a second stage of filtering within the frequency band interval by a wavelet packet decomposition which gives us a filtered signal in at least 3 levels of decomposition. The fig (4) shows the obtained signal Sr_2 after processing of the Gauss filtered signal Sr_1 of the above signal.
Since the choice of the mother wavelet affects the success of the filtering, we have chosen for the continuous filtering process the 8th derivative Gauss function as the analyzing mother wavelet, consequently to a correlation procedure between ultrasonic signals and the Gauss wavelet family described in [7]. And for the discrete filtering, 3 different mother wavelets were investigated in an attempt to find out that the best matches the shape of the analyzed first stage filtered signal Sr(t) obtained in fig(2).

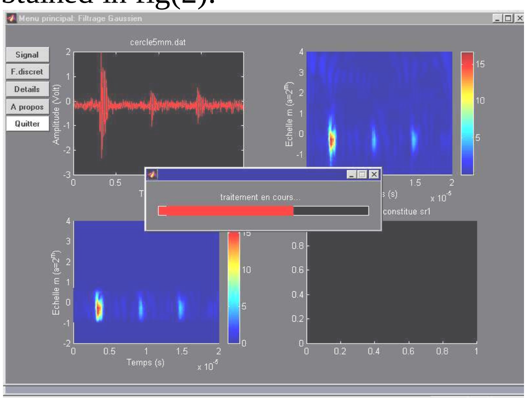

Figure 3 - Wavelet *Gauss filter*

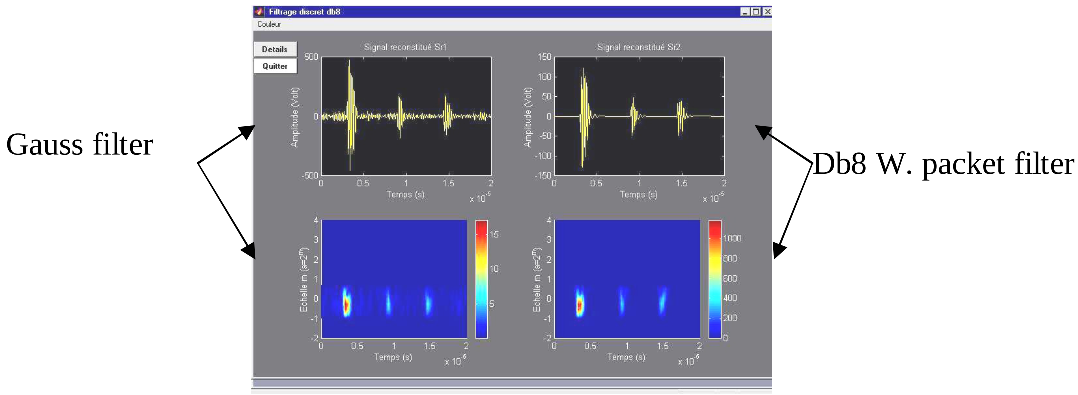

Figure 4 - Wavelet packet filter

These wavelets are the Symlet of order 1 to 5, the Coiffet and the Debauchees of order 1 to 8. The Debauchee of order 8 (Db8) was the more suitable analyzing function and has been used in the wavelet packet filtering process

The experiments have been performed within the following conditions: A Steel piece, 35 mm width, with artificial cylindrical and circular defects. An arc welded piece, 30mm width with lack of fusion and horizontal crack welding defects. And a welded piece 25mm width with group of porosity and crater pipe welding defects.

3. Discussion

Noise filtering of the original signal can be achieved if only a few wavelet coefficients representative of the signal are retained and the remaining coefficients related to the noise are discarded [3]. In this work, the called DWT method has required an extensive computing process and generally has generated a distorted reconstructed signal, du to the difficulty to produce an automatic threshold control fig (2). Since the frequency spectrum is known and the scales of the frequency range computed, the continuous wavelet transform, has given a good filtering of the high frequencies noise. The wavelet packet has needed a huge decomposition but has conducted to an enhanced filtered signal. That's why; we have worked on 2 steps. The first step of the filtering has concerned the frequencies outside the frequency range and has been performed by the continuous wavelet transform with the 8^{th} derivative gauss analyzing function. And the second step has interested the frequency band filtering, which has been achieved by the wavelet packet transform with the Debauchee of order 8 analyzing function. The tree decomposition has needed only 3 levels which have been considered as a threshold limit. The choice of the mother wavelet wasn't easy, and the investigation of the Symlet family and the Coifee wavelets hasn't produced any filtering. But the Debauchee family has given better result, particularly that of order 8.

4. Conclusions

There is an ever present need in industry to detect damage in components during assembly and in products which have to meet quality and safety regulations for use. Ultrasonic testing is extensively used in the material characterization field, and the automation of the signal analysis became a necessity. The purpose is to find out the improved automated procedure. In this paper we have proposed a combined automatic flaw detection procedure with an optimization of the analyzing wavelets, an enhancement of the signal noise ratio and an improvement of the computing time and memory space

5. References

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