NON LINEAR FILTERING OF ULTRASONIC SIGNAL USING TIME SCALE DEBAUCHEE DECOMPOSITION

F. Bettayeb[1], S. Haciane[2], S. Aoudia[2].
[1]Scientific research center on welding and control, Algiers, Algeria,[2] University of science and technology, Algiers, Algeria.

Abstract: Nowadays, ultrasonic flaw detection is an important research topic in material NDE. However, to enhance the flaw characterization, methods based on threshold have given good results only when the signal to noise ratio is high. Since bandwidth of the reflected signals as well as its principal frequency is subject to wide variation, it is impossible to create an appropriate band pass filter for de-noising. So linear filtering does not provide good results, because both the structure noise and flaw signal concentrate energy in the same frequency band. Non linear filtering can be used to reduce or suppress the noise from ultrasonic signals. One way out is to use the time scale filtration. The method is based on the Wavelet packet decomposition. The "Debauchee 8" procedure has been chosen after successive tests on the analyzing wavelet function for ultrasonic data. So each measured ultrasonic signal is analyzed by a filter bank through only 3 levels wavelet packet decomposition. This work demonstrates that the multi-resolution analysis is very efficient with respect to signal recovery from noisy data. The experimental results have shown that the proposed method has excellent performances on SNR enhancements.

Keywords: flaw detection, de-noising, wavelet packet

Introduction: A signal is a physical support of the information. It can have different sources. Generally, It's described as a temporal evolution of a measurement obtained by a captor. When we want to generate a signal simultaneously in time and frequency, the first interesting natural position is the one that gives a sense to an instantaneous spectral countenance. The Fourier duality makes the temporal and frequency signal description, needful and insufficient. Needful, because the information are displayed in a complementary way. Insufficient, because the display is far from the exploitable physical reality [1]. 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 and time-scale representations which can approach the physical reality of the measured signal. In the goal to assure the reliability of ultrasonic non destructive testing and the suitability of the enhancement of the flaw detection, a non linear filtering method based on the multi resolution analysis has been experimented.

Due to its computational efficiency, one powerful tool to filter out noise from ultrasonic signal is the wavelet theory. 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 [2]. Wavelet noise filters are constructed by calculating the wavelet transform of a signal, and then applying an algorithm which computes the wavelet coefficients, and chooses the coefficient vectors that should be modified (set to zero). 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) [3]. In contrast to the wavelet transform, all information about time in the Fourier transform are wasted and only frequency remains.

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 [4]. The wavelet packet transform is 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 without threshold, 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 discrete 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.

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 [4]. The signal is then decomposed in approximations and details coefficients which represent the low frequency and the high frequency 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 fig(1). 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.

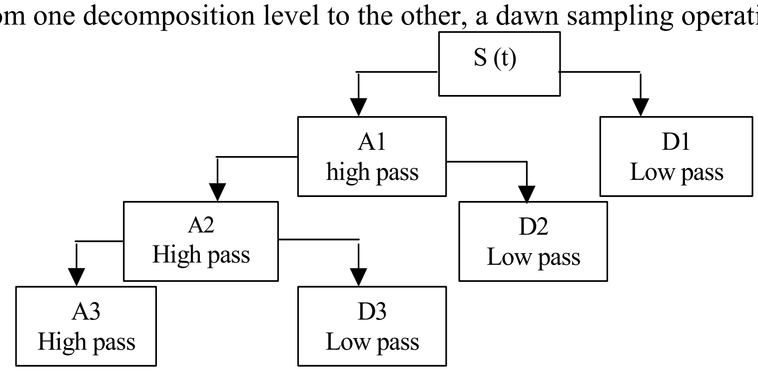


Fig 1: "Discrete multi-resolution scheme"

This decomposition in effect halves the time resolution, and doubles the frequency resolution. The high pass filtered signals constitute the DWT coefficients. 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.

The reconstruction at each level is performed only on the approximations, and some information brought by the details are lost fig (2).

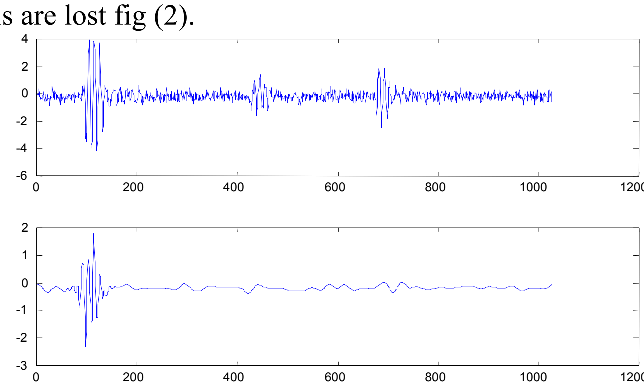


Fig 2: "DWT filtering of a 5mm circle signal"

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 fig (3). This produces an amount number of wavelet coefficients.

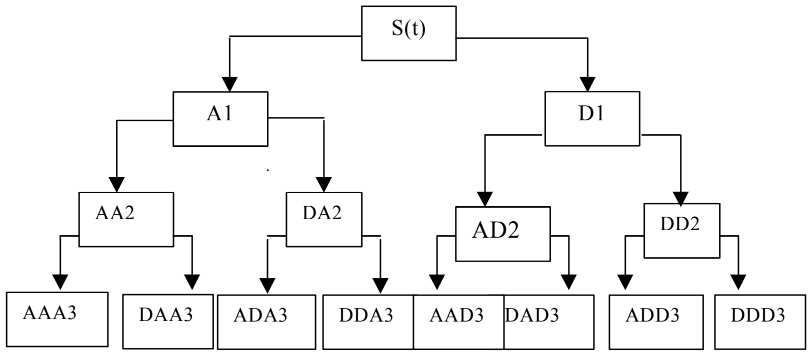


Fig 3: "Wavelet packet decomposition”

In the standard Matlab environment wavelet packet transform, the result of the low pass filter (the scaling function) is placed in the lower half of the array, and the result of the high pass filter (the wavelet function) is placed in the upper half of the array. 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 loss of information. So, achieving a wavelet packet decomposition of the whole signal, requires more and more computing time and memory space, and needs a lot of experiments for the threshold control.
To overcome this critical situation we have chosen to perform in a first stage, a continuous Gauss filter bank of the frequency spectrum, 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 (4). We can notice in fig (5) that the high frequency noise has been discarded; only speckle noise remains.

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

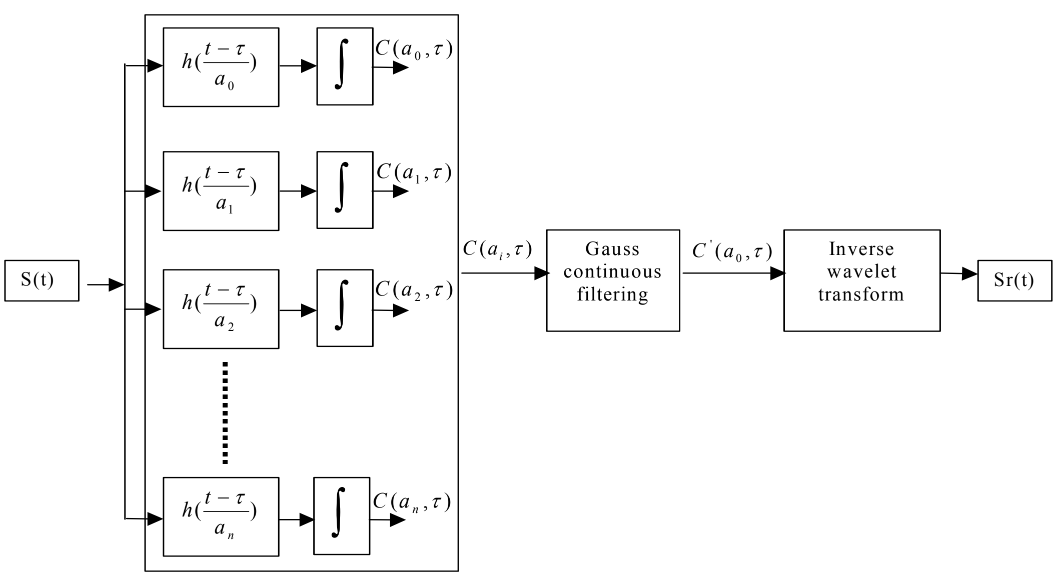
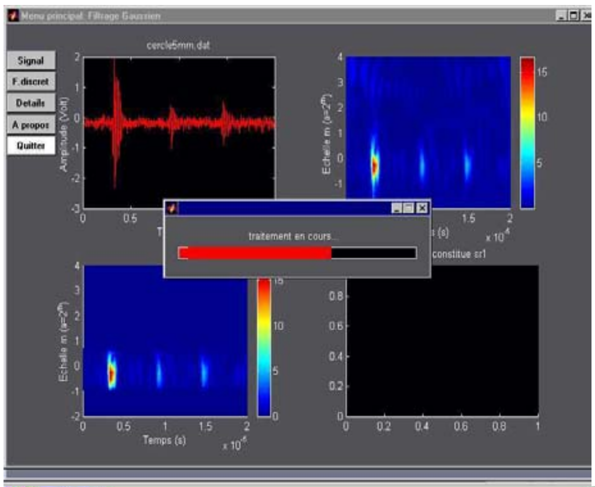


Fig 4:"Continuous filter bank of S(t)"

We go then with a second stage of filtering by a wavelet packet decomposition, which gives us a filtered signal in at least 3 levels of decomposition fig (6).



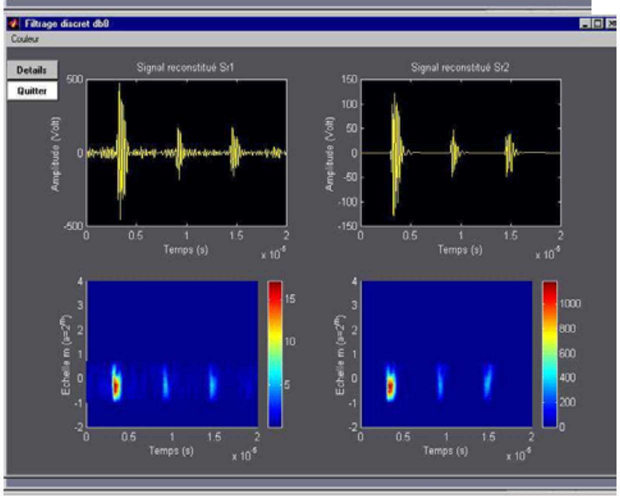
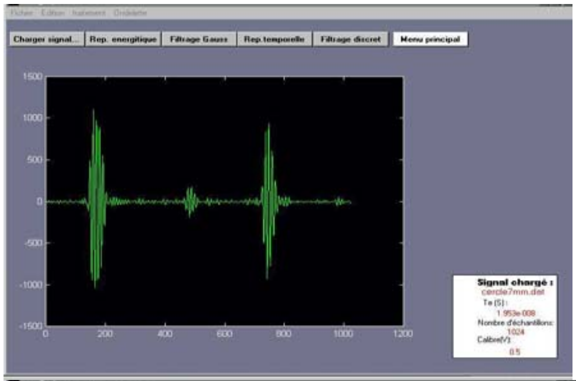


Fig 5: "Wavelet Gauss filter" Fig 6: "Wavelet packet filter"

Since the choice of the mother wavelet affects the success of the filtering, we have chosen for the continuous filtering process the 8^{th} derivative Gauss function as the analyzing mother wavelet, consequently to a correlation procedure between ultrasonic signals and the Gauss wavelet family described in [5]. And for the discrete filtering, 3 different mother wavelet were investigated in an attempt to find that the best matches the shape of the analyzed first stage filtered signal $S_r(t)$. These wavelets are the Symlet of order 1 to 5 fig (7), the Debauchees of order 1 to 8 and the Coiffet fig (8). The Debauchee of order 8 was the more suitable analyzing function and was used in the wavelet packet filtering process.



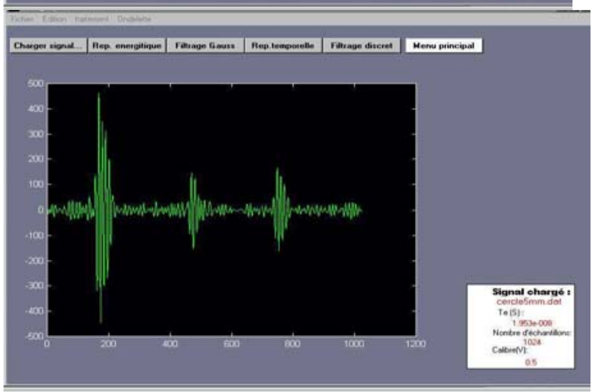


Fig 7: "Symlet 5 filtering" Fig 8: " Coiffet filtering"

The experiments have been conducted within the following environment:

- Steel piece 35 mm width, with artificial cylindrical defects of (10mm, 7mm, 5mm , 3mm, 1mm) diameter
- Steel piece 35 mm 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, 45°, 60° & 70° and 8*9 mm diameter.

Fig 9, displays a 'fault at junction of seams' flaw signal which is poorly observable, and the 2 steps of filtering, with a good detection.

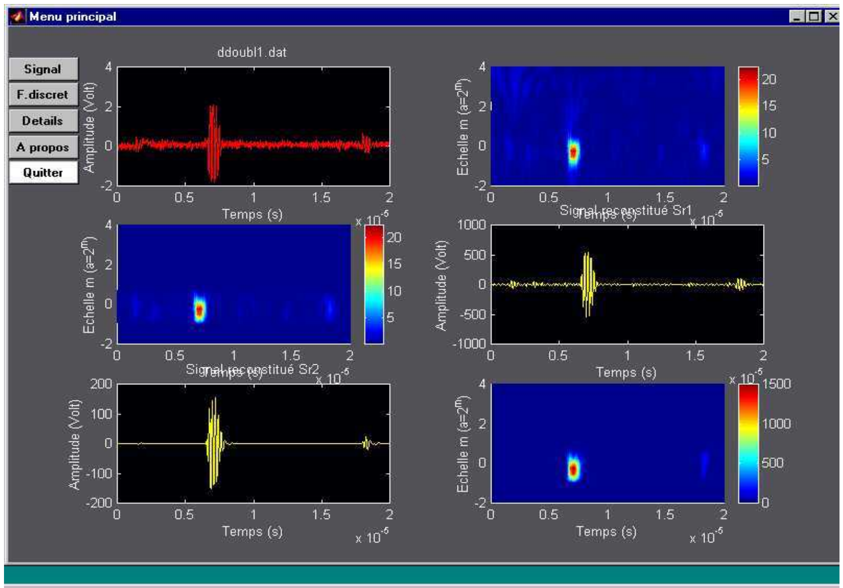


Fig 9: "fault at junction of seams flaw signal experiment"

Fig (10) displays a 'lack of fusion' defect very noisy signal, and the obtained filtered reconstructed signal, with a better signal enhancement.

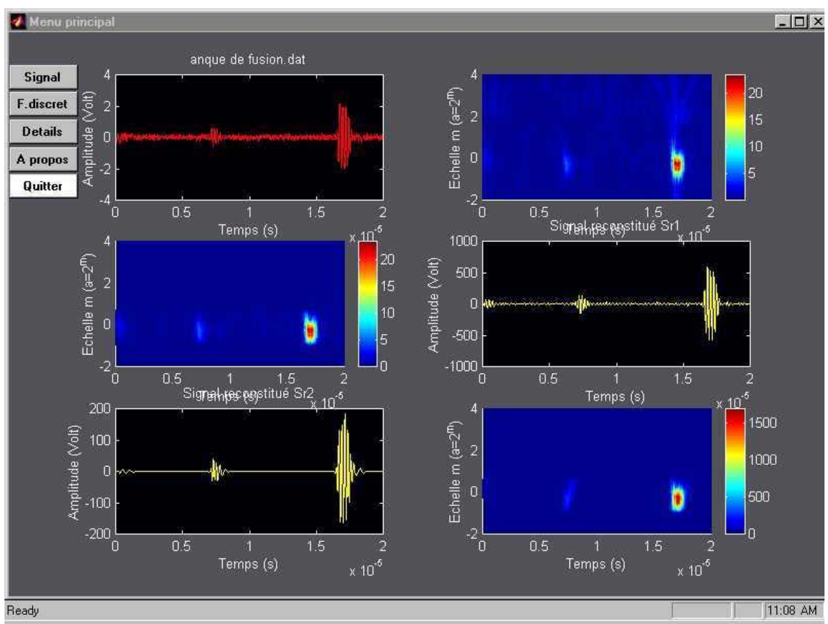


Fig 10:" Lack of fusion defect signal experiment"

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 [2]. In this work we have investigated the wavelet theory for de-noising Ndt contact ultrasonic signal. 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. The Continuous wavelet transform without any threshold control, has given a good filtering of the high frequencies noise, since the frequency spectrum is known. The Wavelet packet has needed a huge decomposition but has conducted to an enhanced filtered signal. That's why; we have worked in 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, with an improved computing time. The choice of the mother wavelet wasn't easy, and the investigation of the Symlet family and the Coiffee wavelets hasn't produced any filtering. But the Debauchee family has given better result, particularly that of order 8.

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 Ndt 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 an easy automatic flaw detection procedure with an optimization of the mother wavelets. Future work concerns the automatic classification and the characterization scheme of the welding defects.

References:

1. T.Rachin, " Application de la transformée en ondelettes et de l'analyse multi résolution en télé détection", Doctorat es science thèses, Sophia Antipolis Université, Nice, France, 1998
2. Abbate, J. Koay, J. Frankel, " Signal and noise suppression Using a wavelet transform signal processor: application to ultrasonic flaw detection", IEEE, Transaction on ultrasonic, ferroelectrics, and frequency control, Vol. 1., N° 1, Jan.97
3. P.C.Ching, H.C. So, S.Q. Wu ," on wavelet de-noising and its application to time delay estimation", IEEE Transaction on signal processing, Vol. 47, N°10, Oct 1999.
4. I.Daubauchee, "Orthogonal bases of capacity wavelets", Communications on pure and applied mathematics, Vol.41, 1998
5. F.Bettayeb, T. Rachedi, H. Benbartaoui, "An improved automated ultrasonic NDE system by wavelet and neuron networks", Ultrasonic international conference proceeding , Granada, June 03, in press, Ultrasonic journal, Elsevier editor.