WAVELET BASED DENOISIONG OF ACOUSTIC SIGNAL

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Abstract

This paper introduces the method of noise reduction in acoustic emission signal based on wavelet transform. Acquiring real time signal & analyzing it, is a very difficult task. In data acquisition (DAQ) system, the data can be acquired, measured and analyzed from electrical, mechanical and physical phenomena.

In this paper, acoustic signal is generated from pencil lead break at different locations on metal sheet. Acoustic emission (AE) sensor is used to acquire the data of physical phenomenon. It converts the physical parameters into the electrical signal, which is very small (in mV). This has been amplified by using a preamplifier of suitable gain. Amplified signal is transformed into digital signal by using USB data acquisition module. But this signal contains noise. So for processing, digitized signal is connected to computer using USB and processing is done in Matlab software. This amplified signal is filtered using conventional filtering or wavelet filtering. In conventional filtering, Butterworth filter is used but it gives more attenuation. Hence wavelet filtering is better. In wavelet filtering, there are four methods of wavelet threshold denoising that are heursure, minimaxi, rigrsure and sqtwolog. These methods are compared based on the energy, standard deviation and percentage attenuation in filtered signal. The best choice for threshold noise reduction in case of AE signal obtained by pencil lead break is rigrsure. The filtered signal is good for analysis so that different parameters can be easily measured.

KeyWords: *DAQ system, AE sensor, Threshold noise reduction, Wavelet Transform and GUI.*

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1.INTRODUCTION

1.1 Fourier transform and its drawbacks

Time-amplitude representation of the signal is not always the efficient way of representing the signal for most of signal processing related applications. The frequency content of the signal contains the most significant information in many cases. The frequency spectrum of a signal basically contains the frequency components (spectral components) of that signal. This implies that frequency spectrum of a signal shows which frequencies exist in the signal.

Fourier transform (FT) gives frequency spectrum of the signal. The frequency spectrum of real valued signal is symmetric. Fourier transform gives the information about frequencies existing in the signal, but it does not show at what time those frequency components exist in the signal. When the signal is stationary, information about location of frequencies is not needed. Stationary signal means a signal whose frequency content does not change with time. This implies that for stationary signal, all frequency components exist at all times.

A non-stationary signal is a signal whose frequency continuously changes with time. FT gives only spectral content of the signal, but it does not give information regarding at what time those spectral components appear. FT is not good for non-stationary signal when time-frequency information of signal is required. When time localization of spectral components is needed, a transform giving time-frequency representation of the signal is required. STFT (Short Time Fourier Transform) overcomes FT, as it gives the frequency information of signal over period of time. In STFT, signal is divided into small segments and each segment is assumed to be stationary. For this purpose, window function is chosen in such a manner that length of each segment of signal must be equal to width of window. STFT is nothing but FT multiplied by window function. For getting more stationary part, window should be narrow. Narrow window gives good time resolution & poor frequency resolution while wide window violates the condition of stationarity. STFT gives fixed resolution. So STFT is having resolution related problems. The ultimate solution to this problem is wavelet transform.

1.2 Wavelet transform

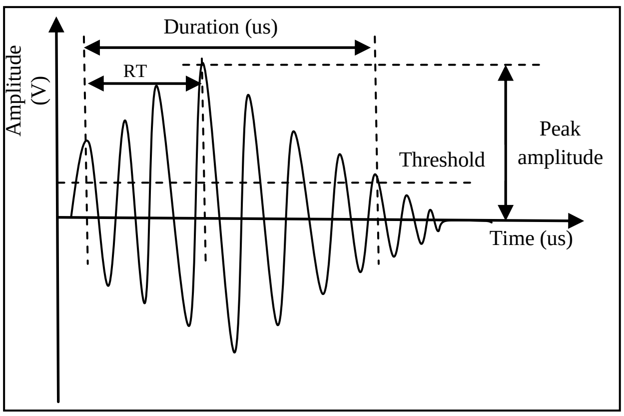


Fig -1: Typical acoustic emission signal

Any signal can be analysed at different frequencies with different resolutions using multi-resolution analysis (MRA). MRA is designed to give good time resolution and poor frequency resolution at high frequencies and good frequency resolution and poor time resolution. MRA is useful if signal has high frequency components for short duration and low frequency components for long duration. The AE signal obtained is of same type. Typical AE signal is shown in Fig-1.

Wavelet transform gives variable resolution. In wavelet transform, the width of window is varied as transform is computed for every single spectral component [1]. Continuous wavelet transform is given by equation 1,

$$\Psi_x^{\psi}(\tau, s) = \frac{1}{\sqrt{|s|}} \int x(t).\varphi^*\left(\frac{t-\tau}{s}\right) dt \qquad (1)$$

Transformed signal is function of two variables, scale (s) and translation (τ). Scale is the inverse of frequency and translation represents the location of window which corresponds to time information in transformation domain. High scales mean low frequencies implies non detailed information and vice versa. $\psi(t)$istransforming function, which is called as motherwavelet. Mother wavelet is prototype for generating different window functions.

The discrete wavelet transform analyses the signal at different frequency bands with different resolution by decomposing the signal into a coarse approximation and detail information [1]. In DWT scale and translation parameters are discretised so that redundancy is reduced and implementation becomes easier. DWT uses two sets of functions, called scaling functions and wavelet functions, which are associated with low pass and high pass filters, respectively. The decomposition of the signal into different frequency bands is done by successive high pass and low pass filtering of the time domain signal. The original signal x[n] is first passed through a half band high pass filter g[n] and a low pass filter h[n]. By DWT, time resolution reduces by 2 at each level and frequency resolution increases by 2.The decomposition of a signal can be mathematically expressed by equation 2,

$$y[n] = \sum_{k=-\infty}^{\infty} h[k].x[2n-k] \qquad (2)$$

DWT is given by equation 3,

$$\Psi(j,k) = 2^{j/2} \int x(t).\varphi^*(2^j t - k) dt \qquad (3)$$

DWT of original signal is obtained by concatenating the coefficients starting from last level of decomposition (2 coefficients) with the coefficients obtained by high pass filtering at preceding levels. The DWT will have same number of coefficients as that of original signal.

1.3 Noise reduction based on Wavelet analysis

The acoustic signal is obtained using pencil lead break on metal sheet [5]. This signal is not the typical signal shown in fig. 1. It contains noise, due to which exact parameters of signal cannot be found. So it is necessary to reduce the noise in the signal. Conventional filtering is used to reduce the noise in the practical AE signal. Filtering is done using Butterworth filter of certain order. But attenuation in this case is more.

So the noise reduction using wavelet transform is preferred. In this case, selection of appropriate wavelet &threshold noise reduction method is important.

Generally in the wavelet transform, the relatively large amplitude wavelet coefficients represent mainly the signal, while the relatively small amplitude wavelet coefficients represent the noise. Noise reduction with threshold is to decompose noisy signal, retain the wavelet coefficients greater than the threshold and adjust the wavelet coefficients less than the threshold to zero. Finally, reconstruct the signal with the treated wavelet coefficients. This is nonlinear wavelet transform method of noise reduction.

2. THRESHOLD DENOISING METHODS USING WAVELET

Generally, wavelet threshold denoising method consists of following three steps [1]-

1. Decomposition: It involves choosing the wavelet and determining the level N of decomposition. For this the signal is passed through high pass and low pass filters and these coefficients are then down sampled by 2. High frequency coefficients are decomposed at each level. Fig- 2 shows decomposition of signal.

2. Threshold high frequency coefficients: High frequency coefficients give the detail information and low frequency coefficients give the approximate information. For each level from 1 to N, set the proper threshold by applying soft thresholding.

3. Reconstruction: The signal can be reconstructed by concatenating high frequency coefficients of levels 1 to N with low frequency coefficients of the N^{th} level. Thresholding may be soft or hard. Generally soft thresholding is preferred.

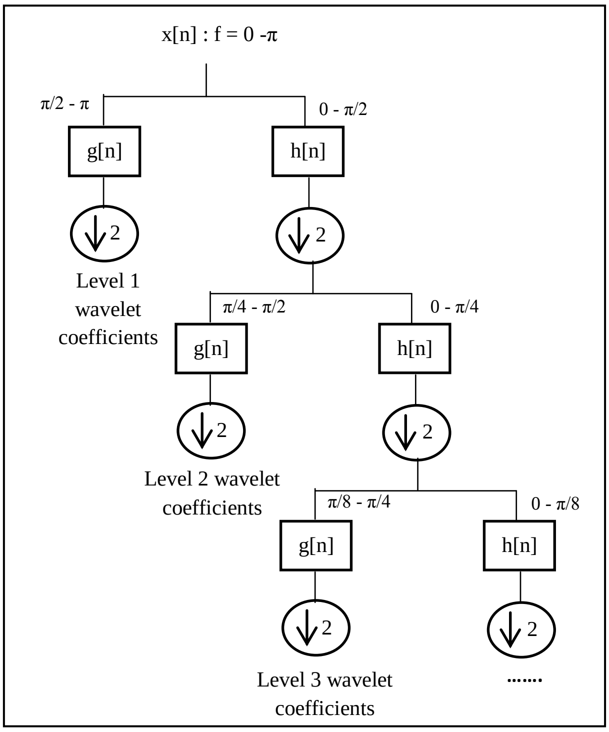
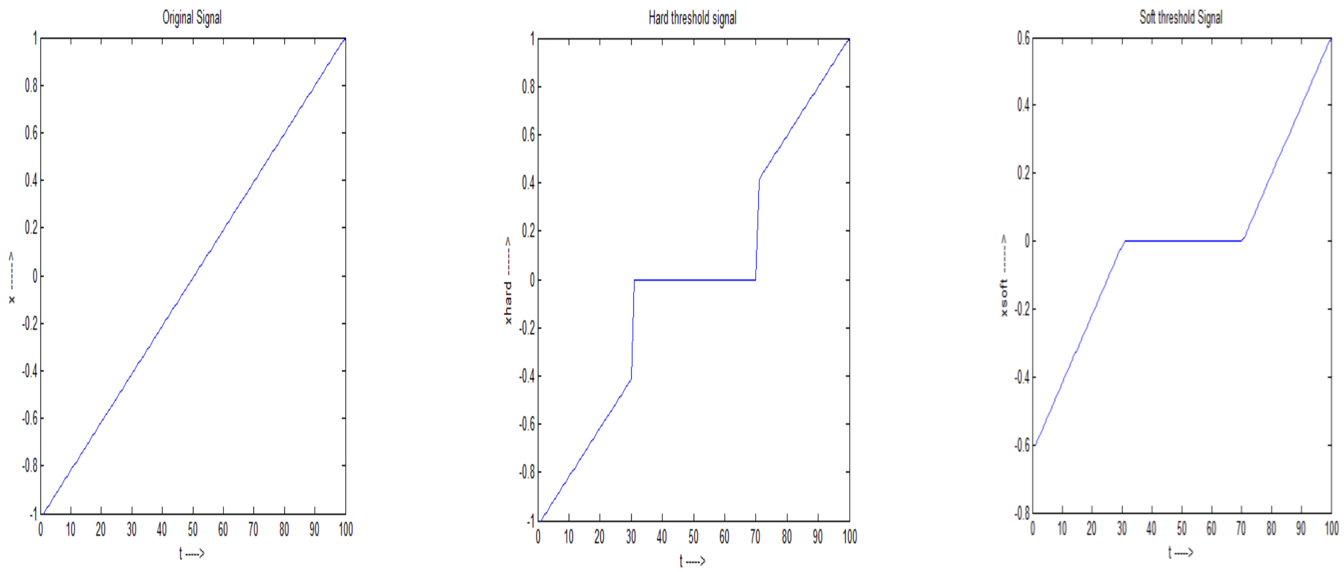


Fig -2: Decomposition of signal



a. Original signal

b. Hard threshold signal

c. Soft threshold signal

Fig -3: Thresholding of signal

Let x = signal, th = threshold

Hard threshold signal, $\hat{x} = \begin{cases} x; if\ |x| > th \\ 0; if\ |x| \leq th \end{cases}$

Soft threshold signal,

$$\hat{x} = \begin{cases} sign(x) * (|x| - t); if\ |x| > th \\ 0; \qquad\qquad\qquad if\ |x| \leq th \end{cases}$$

Fig- 3(b) and Fig- 3(c) show hard and soft thresholding of signal shown in Fig- 3(a).

3. IMPLEMENTATION USING MATLAB

3.1 Graphical user interface

Graphical user interface is developed in Matlab so that various methods can be easily selected from the dropdown list. There are four methods of threshold noise reduction: *rigrsure, heursure, minimaxi* and *sqtwolog*. Fig- 4 shows the window of GUI.

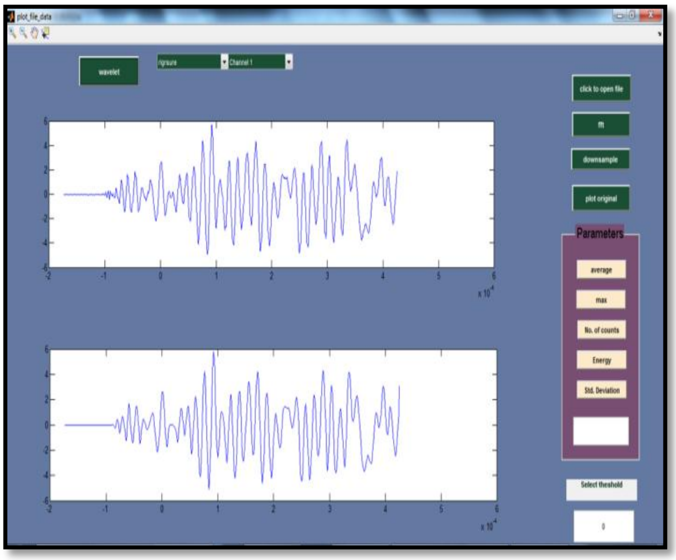


Fig -4: GUI developed for finding parameters and wavelet filtering

Following commands in Matlab [3] are used for filtering:

1. *fft:* This command is used to find frequency spectrum of signal. But it is frequency representation of signal.

2. *filter:filter* command filters input data sequence using digital filter like *Butterworth, Chebyshev*.

3. *wthresh:wthresh* command is used for selecting soft or hard thresholding method.

4. *wden:wden* is command for automatic denoising of the one dimensional signal.

In Fig- 4, there is parameters panel which shows different parameters which can be measured for signal. Peak, average, number of counts for noisy signal can be measured and energy, standard deviation can be measured for filtered signal. Also there is one drop-down menu list for selection of wavelet threshold denoising method and other for channel selection.

Energy and standard deviation are two parameters considered for the comparison of wavelet threshold denoising methods.

Energy is given by equation 4,

$$\text{Energy} = \sum |x(n)|^2 \quad (4)$$

Standard deviation [1] is given by equation 5,

$$\text{Standard deviation} = \sqrt{\frac{\sum_{n=1}^{l}[x(n)-y(n)]^2}{(l-1)}} \quad (5)$$

where,

x(n) = Noisy signal (Original signal)

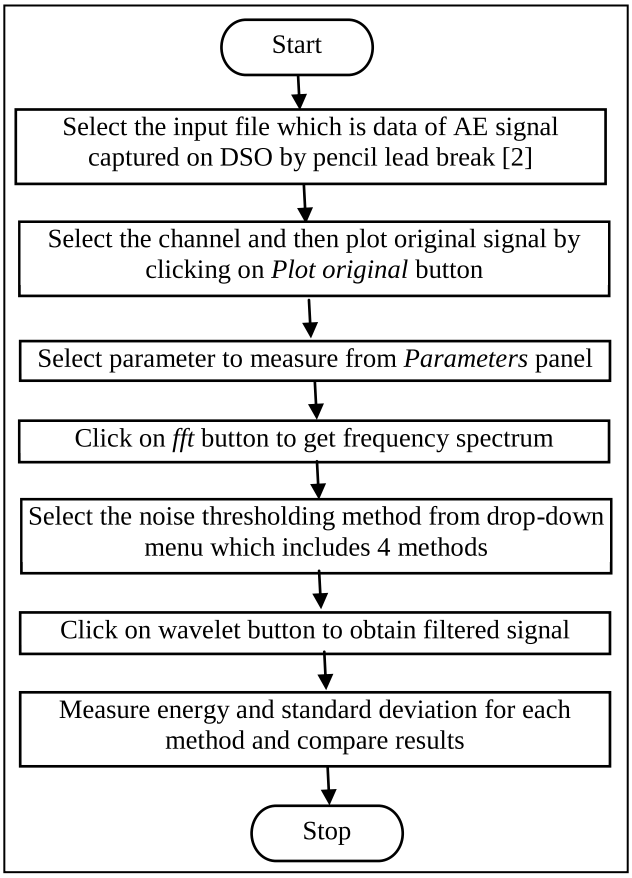
y(n) = Filtered signal

l = Length of signal

Attenuation is calculated for each method by using equation 6,

$$\text{Attenuation} = \frac{(Energy\ of\ original\ signal) - (Energy\ of\ filtered\ signal)}{(Energy\ of\ original\ signal)} \quad (6)$$

3.2 Flowchart



4. RESULTS AND DISCUSSION

Table -1 shows the comparison wavelet threshold denoising methods. The signal due to acoustic emission is noisy signal [4]. Here, the AE signal used is generated from the pencil lead break on metal sheet. Using wavelet filtering attenuation is less compared to conventional filtering.

Table -1: Comparison of wavelet threshold denoising methods

Wavelet Threshold Denoising Methods	Energy	Standard Deviation	Attenuation
heursure	4.16	0.32	1.16%
minimaxi	3.08	0.65	26.82%
rigrsure	4.18	0.30	0.68%
sqtwolog	2.66	0.93	36.80%

Different methods of wavelet threshold denoising decide the threshold based on certain algorithm. Threshold is automatically decided by these methods as per the signal given as input. From Table-1, it can be interpreted that *rigrsure* method gives very less attenuation and standard deviation.

5. CONCLUSION

Rigrsure is the best wavelet threshold denoising method for the acoustic signal obtained from pencil lead break. Attenuation in the filtered signal is 0.68% and standard deviation is 0.30 which is less as compared to other methods.

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