Implementation of different wavelet transforms and threshold combinations for ECG De-noising

Kandarpa.S.V.S.Sriharsha¹, Akhila John²

M.Tech Student, Department of ECE, University College of Engineering and Technology,
Acharya Nagarjuna University, Guntur, India¹
Assistant Professor, Department of ECE, University College of Engineering and Technology,
Acharya Nagarjuna University, Guntur, India²

Abstract: An Electro Cardiogram is the observation and recording of electrical information in the heart. Technological developments in the medical industry and non-aggressive monitoring of critical biological functions is an important need to provide appropriate care to patients and leads to their improved health. ECG signal analysis has been in use for a long time for cardiac problems. Technological advancements made the ECG observation quite easy but quite often, they get corrupted by different type of noises. Hence De-noising of ECG signal has gained a lot of importance. This paper deals with de-noising of three majorly encountered ECG disturbances viz. Power Line Interference, Wide Band Stochastic noise (EMG noise) and Base Line Wander noise. The De-noising is performed using various wavelet Transform techniques applying different types of threshold functions. Performance is measured using SNR and MSE and optimized combinations of Wavelet with a Threshold functions for different noises are suggested. The analysis is also done on real ECG signals obtained from Physionet medical database.

Keywords: Electro Cardiogram (ECG), Power Line interference, Electromyography (EMG) noise, Base line wander noise, Wavelet Transform, Signal to Noise ratio (SNR), Mean Square Error (MSE), Physionet.

I. INTRODUCTION
The Electrical activity of the heart is described by Electro Cardiogram, which is decomposed in characteristic components namely P, Q, R, S and waves. The rare cardiac events, anomalies like arrhythmias can be detected, predicted and monitored using ECG. The major concern of biomedical signal processing is need for reliable techniques to exclude the major distortions like noise contamination, artifacts and interference from other signals.

The non stationary behavior of ECG signal gives a tough challenge to denoise it. There are many approaches in the literature developed so far for the task of denoising. There are a no of approaches in ECG denoising like Linear Filters, Adaptive Filters and Kalman Filters, but all of them have their own limitations. The limitations include poor SNR, MSE and complexity.

Research results proved that WTs can be an effective tool in handling the non-stationary nature of signals. Donoho et al combined wavelet de noising and threshold estimations which laid a path to use the technique in ECG de-noising. Many hybrid algorithms came up combining Wavelet with different other techniques giving out proven results.

In this paper by combining Wavelet filtering with Threshold, some of the wavelet coefficients are removed, hence smoothing out the signal. Donoho’s method has been the inspiration for de-noising and works well for a wide class of one-dimensional and two-dimensional signals. The noise content of the signal is reduced, effectively, under the non-stationary environment.

In this paper a wide variety combinations of Wavelets and Thresholds are deployed and the appreciable combinations for a particular noise are suggested. The most disturbing noises for ECG like Power Line Interference, EMG noise and Base line drift are removed using the techniques.

II. WAVELET TRANSFORMS
A wavelet is a small wave whose energy is concentrated in time, which is useful for the analysis of transient, non-stationary or time-varying phenomena. Such a wave can be expressed and analyzed as a linear decomposition of the sums and products of the coefficient and function.

For Example, any signal x(n) decomposition can be done by simultaneously passing it through a series of high and low pass filters with impulse responses as h(n) and g(n) respectively. The outputs of high and low pass filters are named as detailed and approximate coefficients respectively.

Fig. 1. Wavelet Decomposition

In the decomposition process, the down-sampling by 2 divides the input frequency by 2, thus doubling the
frequency resolution further making the time resolution half. Increasing the levels of decomposition, which is user defined and application specific, will increase the frequency resolution further. Typically 3 to 5 levels are cascaded.

In the wavelet transform, the original signal (1-D, 2-D, 3-D) is transformed using predefined wavelets. The wavelets are orthogonal, orthonormal, or biorthogonal, scalar or multiwavelets. In discrete case, the wavelet transform is modified to a filter bank tree using the Decomposition/ reconstruction given in Fig. 2.

![DWT and IDWT Diagram](image_url)

**Fig. 2 DWT and IDWT**

The wavelet transform de-noising is based on the statement that most energy of a signal is concentrated in few coefficients whereas noise is spread over a large number of coefficients. The shrinkage step involves implementing a nonlinear threshold over these coefficients to retain the larger magnitude (signal) coefficients and nullifying the smaller magnitudes (noise).

### III. THRESHOLD ESTIMATION

Thresholds are usually applied only on the detailed coefficients as approximation coefficients contain low frequency components which are least affected by noise. The magnitude of coefficients is compared to a threshold level, denoted by 'λ'. An optimized value of λ is estimated. To estimate the threshold λ, we need to calculate the noise level σ. Among many methods for estimating value of σ, a popular one proposed by Donoho and Jonstone is based on the detail coefficients of the last level calculated with the help of median absolute deviation (MAD) as per the following formulae:

\[
σ = (|x − x'|)/ 0.6745 \tag{1}
\]

Where, 0.6745 is the scaling factor for a normally distributed data. Further, to estimate the threshold level 'λ', a universal threshold was used which is a function of noise level 'σ' and length of signal 'k', given as:

\[
λ = σ \sqrt{2 \log(k)} \tag{2}
\]

This shrinkage step is also referred as wavelet thresholding.

The thresholds implemented in this paper are Rigrsure, Heursure, Sqtwolog and Minimaxi under the cases of both soft and hard thresholding. Each and every threshold in their own case of hard and soft have their own set of advantages for a particular noise when used with a particular combination of wavelet. The various combinations of Thresholds with wavelets are performed and tabulated in the results.

#### A. Sqtwolog Threshold:

This is also known as fixed threshold or global thresholding method and it is calculated as:

\[
λ = σ \sqrt{2 \log(k)} \tag{3}
\]

Where ‘λ’ is the threshold level, ‘σ’ is the noise level and ‘k’ is the length of the signal.

#### B. Rigrsure Threshold:

Steins unbiased risk estimator (SURE) or rigrsure is an adaptive thresholding method which is proposed by Donoho and Jonstone.

#### C. Heursure Threshold:

Heursure threshold is a combination of SURE and global thresholding method. If the signal-to noise ratio of the signal is very small, then the SURE method estimation will account for more noises. In this kind of situation, the fixed form threshold is selected by means of global thresholding method.

#### D. Minimaxi Minimax:

Threshold is also used fixed threshold and it yields minmax performance for Mean Square Error (MSE) against an ideal procedures.

#### E. Hard Thresholding:

\[
S 𝜆(d) = d \cdot (\text{abs}(d) > 𝜆)
\]

#### F. Soft Thresholding:

\[
S 𝜆(d) = \begin{cases} 
0; & |d| < 𝜆;
|d| \geq 𝜆; & |d| < 𝜆
\end{cases}
\]

### IV. METHODOLOGY

An experimental setup is made and a broad comparison of various denoising techniques for variety combinations of wavelets and thresholds is made for each type of noise in ECG signal (viz. baseline drift noise, EMG noise and Powerline interference noise). The experimental setup is as follows.

![Experimental Setup](image_url)

**Fig. 3 Experimental Setup**

#### A. Removal of EMG/wideband stochastic noise

The whole process can be summarized in the following steps:-

*Step 1:* Decomposition of the noisy ECG signal is done into the wavelet coefficients using the wavelet decomposition tree. Any of the wavelet can be chosen from the wavelet family for this purpose.

*Step 2:* From the obtained wavelet coefficients the noise variance is estimated and thus threshold level λ is estimated using the universal threshold formulae as discussed earlier.
Step 3: Then the different thresholding schemes are implemented and finally modified coefficients are reconstructed using the IDWT.

B. Removal of Baseline Drift
Among the many proposed algorithms for removal of baseline drift noise, in this paper the adopted algorithm is based on wavelet approach for baseline wander suppression. This noise constitutes a frequency band of 0-0.5 Hz and thus for the purpose of denoising following steps are performed:

- **Step 1:** Signal is decomposed in a way that the final level of the approximation coefficients represents a frequency band of 0-0.5 Hz.
- **Step 2:** The noise variance is then estimated from this very level of the decomposed coefficients. For a 1 KHz signal, at a scale of 28, the approximation coefficient represents a frequency band of 0-0.5 Hz.
- **Step 3:** These coefficients are modified in accordance with the thresholding scheme.

C. Removal of Power Line Interference
The power-line signal is a narrow-band signal. For removing the PLI, whole process can be summarized in the following steps:

- **Step 1:** The noise is estimated using the 2nd level wavelet coefficients that correspond to the frequency band of this signal (50/60 Hz).
- **Step 2:** Once the signal noise estimation is done, the threshold value is estimated and further the detailed coefficients are modified accordingly.
- **Step 3:** The updated wavelet coefficients are then reconstructed to give the denoised signal.

V. RESULTS
The implementation is done on various types of noises using various wavelets and thresholds to finalize the best wavelet and threshold combination for a particular type of noise. For generating power line interference (PLI) a power line signal of frequency 60Hz is added to the original signal so that the input SNR (PLI)=8.0437 dB is obtained as in fig. 5(a). For input ECG with EMG noise as in Fig 6(a), white noise (20-250 Hz broadband with 10% of maximum amplitude) is superimposed over pure ECG signal so as to obtain an SNR (EMG) of 6.1817 dB. For baseline wandered noisy ECG as in Fig. 4(b), low frequency (below 0.6 Hz) sinusoids are added to obtain the SNR of the input signal as SNR (BW) = 2.4526 db.

The performance is measured on the basis of the mean square Error (MSE) in accordance with the following formulae:

\[
MSE = \frac{1}{N} \sum_{i=1}^{N}(x(i) - d n(i))^2,
\]

And Signal to Noise ratio (SNR) of the input (noisy) ECG and SNR of output (denoised) ECG.

\[
SNR_{input} = 10 \log_{10}\left(1 + \frac{\sum_{i=1}^{N} x(i)^2}{\sum_{i=1}^{N} (x(i) - n(i))^2}\right)
\]

\[
SNR_{output} = 10 \log_{10}\left(1 + \frac{\sum_{i=1}^{N} x(i)^2}{\sum_{i=1}^{N} (x(i) - dn(i))^2}\right)
\]

Where, \(x(i)\) is the pure ECG signal, \(n(i)\) is noisy ECG, \(dn(i)\) is denoised ECG and \(N\) is the total number of samples.
Table 1: SNR in denoised ECG in case of Power Line Interference (Input SNR = 21.31dB)

Table 2: SNR in denoised ECG in case of EMG Noise (Input SNR = 11.06)

Table 3: SNR in denoised ECG in case of Base Line Wander Noise (Input SNR = 8.68dB)

Table 4: MSE in denoised ECG in case of Power Line interference Noise (MSE Noisy signal = 0.000016)

Table 5: MSE in denoised ECG in case of EMG Noise (MSE Noisy signal = 0.00075)

Table 6: MSE in denoised ECG in case of Base Line wander noise (MSE Noisy signal = 0.00029)
The various types of wavelets and thresholds used in this paper are good in performance. But for a particular type of noise this paper comes out with a best combination of wavelet and threshold to be used. Power Line Interference noise is best removed using the bior6.8 wavelet with a threshold combination of minimaxi hard threshold. The Baseline Wander noise can be removed effectively using the db45 threshold and minimaxi soft threshold. EMG noise is removed using coif5 wavelet with a threshold combination of sgwtalog hard threshold. Hence this paper comes out with best combinations of Wavelet and threshold for a particular noise. This paper can be improved by working on more types of noises and finding the solutions to them. Even study can be done on realizing a new type of wavelet and a new threshold which can be useful to denoise any kind of ECG Noise. In this paper Real ECG signal from Physionet database is taken and denoised using some of the wavelet and threshold combinations available.

REFERENCES


