International Journal of Electronics Communication and Computer Engineering
Volume 3, Issue 6, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

An Implementation of Signal Denoising of ECG Signal using Wavelet Transforms

Prof. Vikas Gupta
Technocrats Institute of Technology
Email : vgup24@yahoo.com

Ms. Dipmala M. Patil
Technocrats Institute of Technology
Email : jadhavdipmala@gmail.com

***Abstract* – Now days, we have seen that many cardiac diseases are diagnosed by Electrocardiogram test. Therefore ECG analysis is widely studied and applied in clinic. The recorded ECG signal in clinical information is corrupted by various kinds of noises. To obtain true ECG signal from noisy observations can be formulated as problem of signal denoising. In this paper a new threshold function is proposed. There were different thresholding functions introduced by the authors. In this paper proposed method is compared with the existing methods. SNR is the powerful parameter to decide the quality of signal. By using this proposed method the SNR is obtained highest after comparing the results of different methods used for denoising the ECG signal. As well as RMSE is reduced to obtain the true ECG signal.**

***Keywords* – ECG signal, AWGN, wavelet transform, denoising, thresholds, SNR & RMSE.**

I. INTRODUCTION

Electrocardiogram signal is one of the biomedical signals, which reflects electrical activity of the heart. ECG signals are widely studied and applied in clinic. ECG signal is obtained by recording produced by an electrocardiographic device and collected by skin electrodes placed at designated locations on body [1]. The ECG signal is characterized by five peaks and valleys, which are traditionally labeled P, Q, R, S, & T as shown in fig.1.

The ECG signal is time varying signal, includes the valuable information related to heart diseases, but frequently this valuable information is corrupted by various noises. Motion artifact: this comes from variation of electrode-skin contact impedance. Electromyograpic noise: caused by noise caused by muscle motion. Power line interference: from 50-60 Hz pickup & harmonics from power mains. Baseline wonders: caused by variable contact between electrode and skin and respiration. Electromagnetic interference: from other electronic devices [3] & noise coupled from other electronic devices, usually at high frequencies.

As noise corrupts the ECG signal it is very important as well as difficult task to suppress noises from ECG signal. So denoising is the method of estimating the unknown signal from available noisy data. The wavelet transform provides description of signal, decomposing it at different time-frequency resolution. Wavelet transform is well suited tool for analysis of non-stationary signals like ECG. At first step, the signal is decomposed into transform domain where filtering procedures are applied.

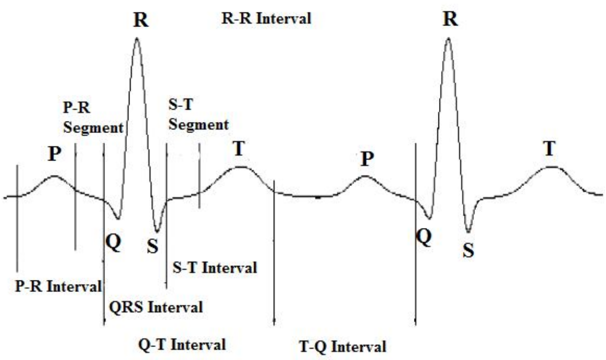

Fig.1. Normal ECG signal

The noise free signal is then obtained by inverse transform. The wavelet based signal denoising is performed using technique called wavelet shrinkage & thresholding that David Donoho has worked on several years. In this technique, when we decompose a data set using wavelet, we use filters that act as averaging filters & others that produce details. Some of resulting wavelet wavelet coefficients corresponds to detail in data set. If details are small, they might be omitted without substantially affecting the main features of data set. Then thresholding is used to set to zero all coefficients that are less than particular threshold. These coefficients are used in an inverse wavelet transformation to reconstruct data set. Hence with the help of WT the noise is removed from the ECG signal.

II. WAVELET TRANSFORM

ECG signal may be corrupted by different types of noises. That will be challenging to recover the true ECG from noisy observed data. The basic idea of wavelet threshold denoising was proposed by Donoho [2]: the signals can be decomposed into high and low frequency sub bands by WT, and the low frequency ones can be operated in this way repeatedly by the scale number. In fact, when representing a signal contaminated by additive “unstructured” noise using WT, some larger WT coefficients should mostly result from the signal components, while the noise part may in general; contribute to almost all the small-valued ones. The fact stated above therefore leads to the idea of denoising a signal in wavelet domain [3]. In threshold denoising, each coefficient is compared against threshold, if it is smaller than threshold, set to zero; otherwise it is kept or modified. Replacing those small noisy coefficients by zero and inversing WT on the threshold result may lead to reconstruction with the essential signal characteristics and less noise ECG signal may be corrupted by different types

Copyright © 2012 IJECCE, All right reserved

International Journal of Electronics Communication and Computer Engineering
Volume 3, Issue 6, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

of noises. That will be challenging to recover the true ECG from noisy observed data. In this paper, additive white Gaussian noise is added to obtain noisy ECG. Therefore the basic need is to remove that noise, this is known as signal denoising. Denoising is the method of estimating unknown signal from available noisy data. An effective denoising technique should minimize the noise content in the signal & also ensure that the important details in the signal are not lost or altered. The general de-noising procedure involves three steps. The basic version of the procedure follows the steps described below.

i) Decomposition: Choose a wavelet & choose a level N. Compute the wavelet decomposition of the signal s at level N.

ii) Thresholding detail coefficients: For each level from 1 to N, select a threshold and apply either soft or hard thresholding to the detail coefficients.

iii) Reconstruction: Compute wavelet reconstruction using the original approximation coefficients of level N and the modified detail coefficients of levels from 1 to N. The algorithm of wavelet signal decomposition is illustrated in Fig.2

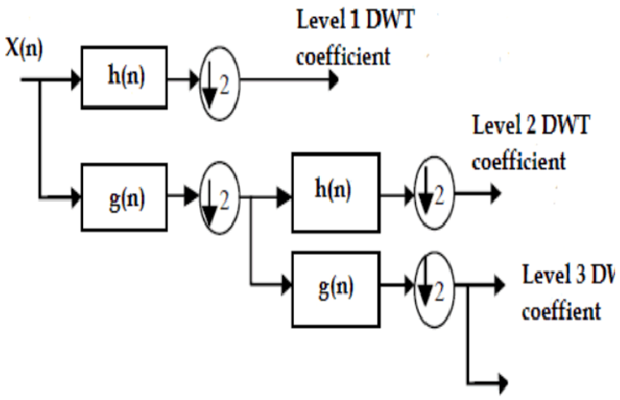

Fig.2. Filters banks used for DWT decomposition

III. Materials & Methods

DWT of a signal is two variables function, the time translation k and the scaling index j, which makes it difficult to illustrate [6].

To understand how wavelet transforms works, several articles are published. Recent works by Donoho and Johnston gives a better understanding of how wavelet transforms work. This new understanding combined with nonlinear processing solves currently problems and gives the potential of formulating and solving completely new problems. The basic steps of the method are shown in fig.3. First, we perform the DWT of the signal. Second we pass the transform through a threshold to remove the coefficients below a certain value. Third, we take the Inverse DWT (IDWT) [7].

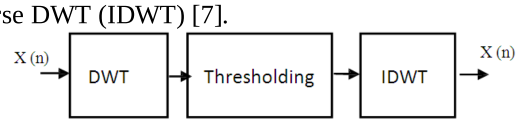

Fig.3. Basic steps for filtration method

This able to remove noise and achieve high Signal-to-Noise ratios (SNR) because of the concentrating ability of the wavelet transform. The signal has coefficients relatively large compared to any other signal or noise that has its energy spread over a large number of coefficient. Thresholding or shrinking the wavelet transform will remove the low amplitude noise or undesired signals and any noise overlap as little as possible in the frequency domain and linear time-invariant filtering will approximately spare them. It is the localizing or concentrating properties of the wavelet transform that make it particularly effective when used with this nonlinear method.

IV. Proposed Method

While registering the ECG signal it may get contaminated by random noises uncorrelated with the ECG signal. These noises can be approximated by white Gaussian noise. Thresholding is used in wavelet domain to smooth out or to remove some coefficients of wavelet transform of sub signals of the measured signal. This reduces the noise content of the signal under the nonstationary environment. The proposed method is implemented using following steps.

1) The additive white Gaussian noise is added to original signal to obtain noisy ECG & mathematically it is given by,

$$ns = s + an$$

Where, s is the noise free ECG signal, an is the white Gaussian noise and ns is the noisy ECG signal.

2) After obtaining noisy ECG, with the appropriate wavelet transform the ECG signal is decomposed & the appr oximate & detail coefficients are obtained.

3) There are number of methods for threshold estimation has been proposed. With the help of appropriate threshold function the denoising of ECG signal will be carried out. Hence selecting proper thresholding is important role in denoising ECG signal. In this paper, we have evaluated the performance of the following threshold estimators on the denoising of ECG signal [9].

(a) Universal Thresholding:

This is proposed by Donoho. The threshold value Thr is given by

$$\text{Thr} = \sqrt{2 \times \log(n)} \quad (1)$$

Where, n is the number of samples in the signal.

(b) Hard Thresholding:

This is proposed by Donoho. Due to the discontinuities of the shrinkage function, hard shrinkage estimates tend to have a bigger variance. In other words, it will be sensitive to small changes in the signal. And it is given by equation

$$\hat{y} = \begin{cases} 0 & |y| < Thr \\ y & |y| > Thr \end{cases} \quad (2)$$

(c) Soft Thresholding:

This method is proposed by Johnston. The derivation of standard soft shrinkage function is not continuous. The soft shrinkage estimates tend to have a bigger bias, due to the shrinkage of large coefficients. It is given by equation (3)

Copyright © 2012 IJECCE, All right reserved

$$\hat{y} = \begin{cases} 0 & |y| < Thr \\ y - Thr & y > Thr \\ y + Thr & y < Thr \end{cases} \quad (3)$$

(d) Firm Thresholding:

To overcome the drawbacks of hard and soft shrinkage, a firm shrinkage function was introduced by Gao and Bruce, given by equation (4)

$$\hat{y} = \begin{cases} 0 & |y| \le Thr_L \\ sgn(y)\left[\frac{Thr_H(|y|-Thr_L)}{(|y|-Thr_L)}\right] & Thr_L < |y| < Thr_H \\ y & |y| < Thr_H \end{cases} \quad (4)$$

Where, Thr2 is decided by formula (1), the scope of Thr1 is 0~Thr2. According to the previous experiments when Thr1 equals 2/3Thr2, the denoised results would be better. The shrinkage function is continuous and approaches the identity line as |y| increase. The firm shrinkage function provides a good compromise between the hard and the soft shrinkage function. The firm shrinkage is less sensitive than hard shrinkage to small fluctuations and less biased than soft shrinkage.

(e) Yasser Thresholding:

In 2006 Yasser presented an improved threshold shrinkage function as formula (5) & named Yasser shrinkage function.

$$\hat{y} = \begin{cases} y & |y| \ge Thr \\ \mathrm{sgn}(y).\frac{|y|^{\gamma}}{Thr^{\gamma-1}} & |y| < Thr \end{cases} \quad (5)$$

(d) Proposed Thresholding:

To overcome the drawbacks of the above implemented methods the proposed method is implemented in between these. It will give the better results while improving the SNR. It is given by

$$\hat{y} = \begin{cases} 0 & |y| \le Thr_L \\ sgn(y)\left[\frac{|y-Thr_L|^{\gamma}.Thr_H}{|Thr_H-Thr_L|^{\gamma}}\right] & Thr_L < |y| \le Thr_H \\ y & |y| > Thr_H \end{cases} \quad (6)$$

After estimation of threshold value, that threshold is applied to detail coefficients of wavelet for shrinkage. Normally there are two threshold & shrinkage functions used. Hard threshold & soft threshold functions. In hard threshold, coefficients below the threshold are set to zero. But in soft thresholding, in addition the remaining coefficients are also reduced linearly.

5) After thresholding the inverse discrete wavelet transform applied to estimate the original ECG signal.

6) To evaluate the performance of the proposed method, Signal to Noise Ratio (SNR) & Root mean square error (RMSE) between original signal and estimated signal is computed [4].

V. Parameter Selection

SNR is an important parameter while evaluation or processing of any signal, which gives the information about quality of the signal. Higher the SNR better is the performance of the system and the signal to noise ratio is given by the following equation,

SRN

$$= 10\log_{10}\left[\frac{\sum_{i=1}^{N}(\text{filtered signal})^2}{\sum_{i=1}^{N}(\text{original signal} - \text{filtered signal})^2}\right]$$

Considering different contamination levels and making the pending signal more similar to the real signal, the variable range of WGN was set from 0~0.2. The range of γ is 0~10, the range of Thr_H is 0~2, the range of Thr_L is 0~. Thr_H The denoising process was performed in terms of formula of proposed threshold. The signal to noise ratio (SNR) of denoised ECG signals was calculated. Where, the calculation formula of SNR [5] is expressed as follows,

$$SNR = 10 \times log_{10}\left[\frac{\sum_{n-1}^{N} s^2(n)}{\sum_{n-1}^{N}|s(n) - \hat{s}(n)|^2}\right]$$

Where, s(n) is the sampling value of simulative ECG signal at the n^{th} point, $\hat{s}(n)$ is the sampling value of denoised ECG signal at the same point.

B. Root Mean Square Error (RMSE):

RMSE of original signal and denoised signal is given by the following equation

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Soriginal - Sdenoised)^2}$$

To evaluate the performance of proposed method, Root Mean Square Error (RMSE) [6] between original signal and estimated signal is computed. This is given by,

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x(n) - \tilde{x}(n))}$$

Where, $x(n)$ is the original ECG signal and $\tilde{x}(n)$ is denoised ECG signal.

VI. Simulation & Results

For the simulation of the proposed method, an ECG signal has been taken as original signal, shown in Fig. 4(a). The sampling frequency is 800Hz and 2048 samples of the signal are used. White Gaussian noise is added to the original ECG signal to introduce distortions. This noisy ECG signal shown in Fig. 4(b) is used as the test signal for the simulation of the proposed method. The symlets wavelet (sym6) and 5-level were also used in all the experiments. Fig. 4(b-f) shows the denoised results. The simulation is done using MATLAB10. The estimated signal from the noisy ECG signal using proposed method is shown in Fig. 4(f). From the figure it is clear that the noise has been greatly reduced. Denoising of ECG signal is performed using mentioned three threshold value estimators, discussed in section-IV, to compare their performance. Both hard and soft thresholding is used. To evaluate the performance of the proposed method RMSE is computed & also signal to noise ratio (SNR) is measured. The results obtained, from the simulation, are given in the Table 1.

Copyright © 2012 IJECCE, All right reserved

International Journal of Electronics Communication and Computer Engineering
Volume 3, Issue 6, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

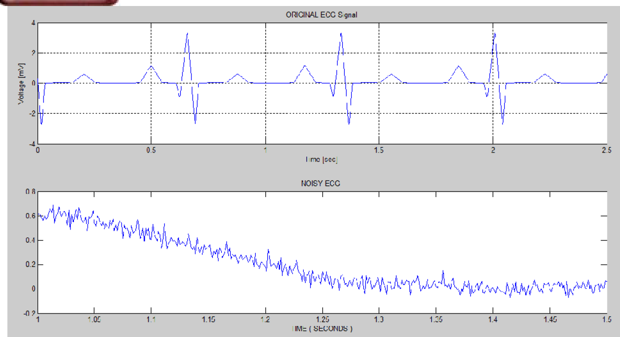

Fig.4 (a) Original ECG Signal & noisy ECG signal

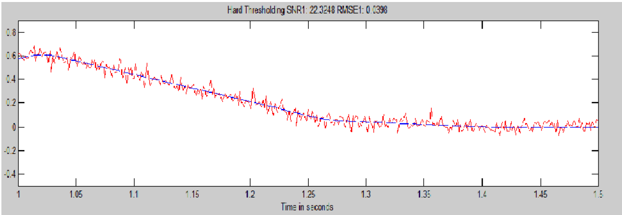

Fig.4(b) Estimated ECG Signal by Hard threshold method

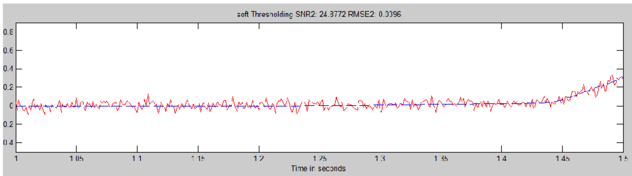

Fig.4(c) Estimated ECG Signal by Soft threshold method

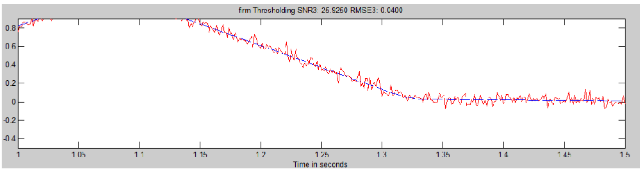

Fig.4(d) Estimated ECG Signal by Firm threshold method

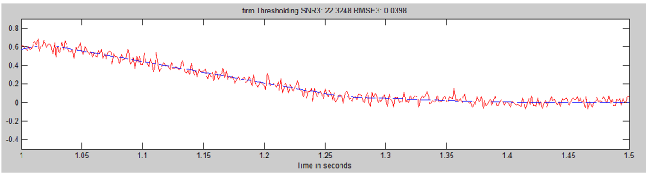

Fig.4(e) Estimated ECG Signal by Yasser threshold method

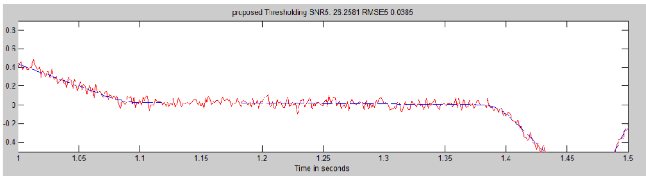

Fig.4(f) Estimated ECG Signal by Proposed method

Thresholding Methods	SNR in dbs	RMSE
Hard threshold	22.3248	0.0398
Soft threshold	25.8605	0.0400
Firm threshold	22.3248	0.0398
Yasser threshold	25.9250	0.0400
Proposed method	26.2581	0.0385

Tab. 1 shows that both SNR and RMSE of proposed method are better than the other two methods due to good similarity and smoothness.

VII. Conclusion

The denoising effects for noisy ECG signal using different functions were compared here. The results show that the shrinkage function proposed in this work is very good at noisy ECG signal denoising. Not only can it get the highest SNR, but also keep the similarity and smoothness of denoised signal. In fact, this function also can be used for all kinds of signals denoised. The improvement of signal to noise ratio for proposed method proves that this is powerful technique for denoising of non-stationary signals such as ECG signals.

VIII. References

[1] C. Saritha, V. Sukanya, Y. Narasimha Murthy, "ECG Signal Analysis Using Wavelet Transform", PACS number: 87.85.J; 02.30.Nw February 2008.

[2] D. L. Donoho, 1991. De-noising by soft thresholding, IEEE Transaction on Information Theory, Vol. 41, pp. 613–627, May 1995.

[3] Arman Sargolzaei, IEEE Student Member, “A New Robust Wavelet Based Algorithm for Baseline Wandering Cancellation in ECG Signals”, 2009 IEEE International Conference on Signal and Image Processing Applications

[4] Jeffery Z. A, “Performance Comparison of Wavelet Threshold Estimators for ECG Signal Denoising” 978-0-7695-4201-0/10 © 2010 IEEE

[5] Nagendra H. Research Scholar” Application of Wavelet Techniques in ECG Signal Processing: An Overview” International Journal of Engineering Science and Technology (IJEST) ISSN: 0975-5462 Vol. 3 No.10 October 2011

[6] J. Mallat: A theory of multiresolution signal decomposition using the wavelet representation, IEEE Transactions on pattern analysis and machine intelligence, Vol. 11, No. 7, pp. 674- 693, July, 1989.

[7] ABDEL-RAHMAN AL-QAWASMI AND KHALED DAQROUQ,” ECG Signal Enhancement Using Wavelet Transform” ISSN: 1109-9518 Issue 2, Volume 7, April 2010

[8] WANG Jie-Sheng, ZHANG Yong, ZHANG Ping, SUN Shi-Feng, Proceedings of the 29th Chinese Control Conference July 29-31, 2010, Beijing, China.”Research on Denoising Algorithm for ECG Signals”

[9] U. Kunzmann, G. vonWagner, J. Schöchlin, A. Bolz, “Parameter Extraction of ECG Signals in Real-Time”, Medical Information Technology, FZI Forschungszentrum Informatik Karlsruhe, Germany

Author’s Profile

Prof. Vikas Gupta

He is Head of Department at Technocrats Institute of Technology, Bhopal.

Ms. Dipmala M. Patil

She is a post graduate student at Technocrats Institute of Technology, Bhopal. She has completed B.E. in Electronics.

Copyright © 2012 IJECCE, All right reserved