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Analysis of ECG Signaling Using Wavelet Transform

O.P. Singh, K.K Singh, G.R. Mishra, Deepak Tiwari, Saumya Dubey
Department of Electronics & Communication Engineering
Amity School of Engineering & Technology
Amity University Uttar Pradesh, Lucknow Campus, India

***Abstract* - Analysis and monitoring of ElectroCardioGram (ECG) gives information about the activities of the heart. Phenomena such as ECG contraction movement of body, respiration, power line interference, high frequency interference generate noise in signaling, which restricts the extraction of information from generated signal. For de-noising of ECG, wavelet transform technique has been implemented. ECG signal sampled at 500 Hz is taken as an input signal which has to be de-noised using Discrete Wavelet Transform (DWT) technique. In this paper, we have decomposed the ECG signal up to the level three and then threshold the signal. The ECG signals with noise and without noise have been plotted. The de-noised ECG signal give better clearity as compared to noisy one that would help the experts to diagnose the patient in better ways. The simulation of the results is done with the help of MATLAB.**

***Keyword* - ECG Signal, DWT, Threshold, De-noising, MATLAB, MSE, PSNR.**

I. Introduction

Bio-medical signal processing is very important for de-noising of ECG signals [1]. Electrocardiography is the technique with the help of which we can easily monitor the activity of the heart. An ECG signal is a random signal because its statistical properties vary with time. A noiseless ECG signal provides lots of information to the doctors; sometimes it is superimposed by unwanted signal that corrupts the ECG signals. The electrocardiography is the process in which we measure the electric potential generated by the contraction of heart on the surface of the body [2]. Noise occurs in the ECG signals due to several causes in the ECG signals, but some main causes are the respiration, movement of the body, interference of high frequency [3]. De-noising of ECG signal becomes important and necessary for extracting the useful information to get the detail of any human body. In the bio-medical signal processing, we can de-noise the ECG signal with many techniques [4]. In this paper, the discrete wavelet transform theory is used for de-noising the ECG signal. DWT is more efficient as compared to CWT for the ECG because it removes the redundancy. DWT can be computed by passing a signal through a pair of high and low pass filters.

DWT:- Discrete Wavelet Transform transforms the discrete time signal to the discrete wavelet representation. It changes the input signal series into the series of a low pass and a high pass series of wavelet co-efficient. It is represented by following expressions,

$$H_i = \sum_{m=0}^{k-1} x_{2i-m} \cdot s_m(z)$$

$$L_i = \sum_{m=0}^{k-1} x_{2i-m} \cdot t_m(z)$$

Where, $s_m(z)$ and $t_m(z)$ are the wavelet filters, K is the length of the filter and i=[0,…..,, n/2]-1.

II. Methodology

This section describes the methods and processes which are used for analyzing and de-noising the ECG signal. In which we can decompose the signal into three levels of Wavelet Transform using the Symlet (sym4) [5], Sym4 is the Symmetric Wavelet family which reduces the computational complexity and produces a symmetric shape in output [6]. Using the soft thresholding technique in the wavelet domain, the de-noised ECG signal will be restored from the noisy one. Simulation has been done using MATLAB R2010a. Process of de-noising the signal is shown in fig.1 which has been simulated with the help of MATLAB10.

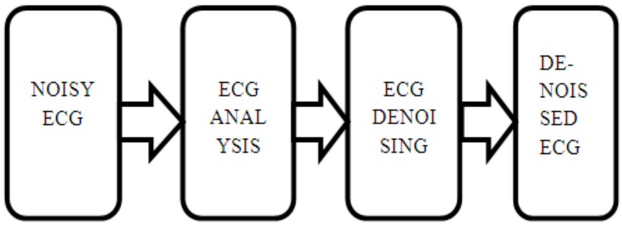

Fig.1. Steps for enhancing the signal

The method is divided into the following steps:-
1. Signal Analysis:- ECG signal is de-noised using the DWT technique. In wavelet transform, there are many wavelet families such as Symlet, Haar, Daubechies etc. for analysis and synthesis of signals. De-noising can be done with different wavelet families [7]. In this paper, we have used the de-trending technique for proper analysis of the ECG signal.
De-trending: if we study any time series then the change with slow rate in some properties of the series are called as trends. Trends show the nature of the series. Sometimes it is also called that trends are the long term change in the mean of the series. In many series it is very useful and important to study about the trends, irregular fluctuations and some other parameters separately. The linear tendency of any time series can be reduced using the de-trending

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technique and obscure information automatically filtered [8]. De-trending computes the least-mean square value and then subtract from the time series data which gives better accuracy.

2. Signal De-noising:- The process of de-noising is summarized in following three steps namely decomposition, thresholding and reconstruction [9].

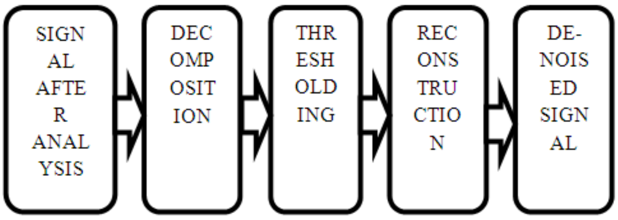


Fig.2. ECG De-noising Process

A) ECG Decomposition:- Discrete wavelet transform decomposes the signal by wavelet filter banks. DWT uses two filters, first is a low pass filter (G_0) and another one is a high pass filter (H_0) for decomposing the signal into different scale [10]. The obtained output coefficients of low pass filter are called approximation co-efficients and from the high pass filter are called detail co-efficients [11]. Both coefficients are down sampled by a factor of 2 at each level.

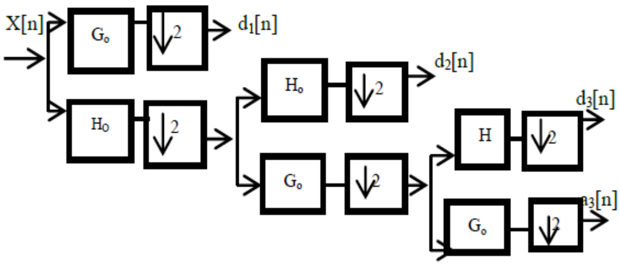


Fig. 3 Three Level Decomposition Tree

Using the DWT mother wavelet, the noisy signal is decomposed, up to a factor of 3. So we obtain approximation coefficients $a_j[n]$ and detail coefficients $d_j[n]$, where j is denoting no. of levels.

B) Thresholding:- Then thresholding process is applied to the noisy ECG signal after passing through the decomposing step to remove the coefficients below a certain value, and it removes the low amplitude noise and additional noise occurred during the process.

Selection of Type of thresholding:- Basically, there are two types of thresholding namely soft and hard thresholding and can be used depending on the type of applications [12]. Fig.4 indicates the two types of thresholding, which can be mathematically expressed as follows,

Hard threshold: $$\begin{cases} dj' = dj & \text{if} |dj| > T \\ dj' = 0 & \text{if} |dj| =< T \end{cases}$$

Soft threshold: $$\begin{cases} dj' = \text{sign}(dj)(|dj| - T) & \text{if } |dj| > T \\ dj' = 0 & \text{if } |dj| =< T \end{cases}$$

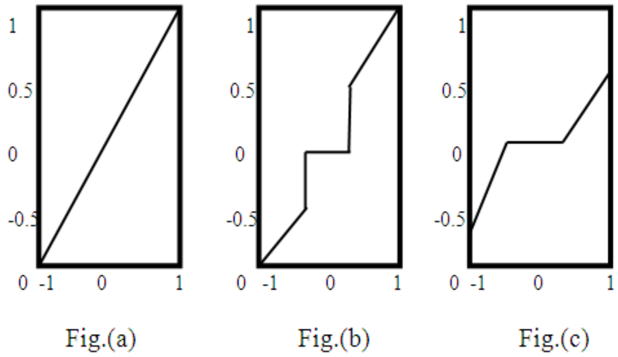


Fig.4. a) Original signal; (b) Hard threshold signal; (c) Soft threshold signal

Soft tresholding does not produce discontinuities in the signal but in hard thresholding it often appears. MATLAB by default use soft thresholding for de-noising the signal and hard thresholding for compression. By applying soft thresholding [13], we have obtained the estimated wavelet coefficients d_j. For each level a threshold value is found and this value is applied for detailed coefficients d_j by using Global Thresholding (GT) techniques [14].

Selection of Threshold value:- The selection of threshold value is another important step for proper thresholding. In this paper, we have used Global Thresholding (GT). This technique was proposed by D.Donoho's method [12]. The threshold value is calculated using the following relation,

$$T = \sigma\sqrt{(2\log L)}$$

Where T denotes the threshold value, L is no. of samples or the length of the signal and σ is the standard deviation of noise [16].

C) ECG Reconstruction:- After thresholding process the coefficients are reconstructed using Inverse Discrete Wavelet Transform (IDWT)[17]. Reconstruction is a reverse process of decomposition such as high pass and low pass filters. The approximation co-efficient $a_j[n]$ and detailed co-efficient $d_j[n]$ are up sampled by a factor of 2 at each level, passed through the both synthesis filters and then added. In this paper, the procedure for reconstruction is vice-versa of the decomposition however the level has remained same in both the process.

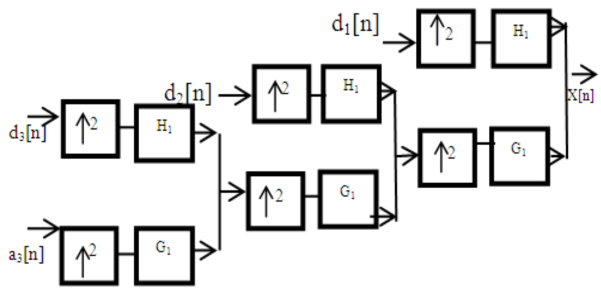
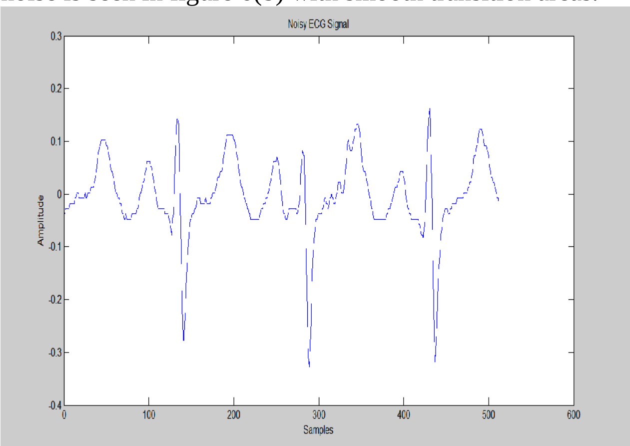


Fig.5. Three Level Reconstruction Tree

III. Simulation Results

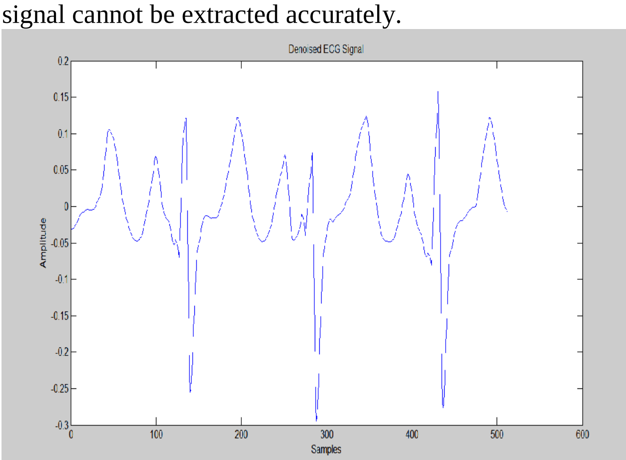
*A) Result and Discussion:-*De-noising of ECG signals have been done using the wavelet transform having 500 Hz sample rate, using the MATLAB simulator [18]. The original signal and de-noised signals have been shown in figure 6(a) and 6(b) respectively.

Often the noise or the unwanted signal occurred at sharp transition. Figure 6(a) approving this concept, this is easily seen that everywhere at the peaks the signal is superimposed by the noise and also the removal of the noise is seen in figure 6(b) with smooth transition areas.



6. (a) Noised ECG Signal

This is easily seen in the fig. 6(a) that the samples are distorted. Due to this distortion the information of the signal cannot be extracted accurately.



6. (b) De–noised ECG Signal

Fig.6. Plots of simulation in MATLAB

In figure 6(b) the smoothened signal which is de-noised is shown. The result obtained in fig. 6(b) is better in almost all points especially sharp transition compared to the original signal in fig. 6(a). The amplitude of decreased signal is also improved in reference of the original signal. The result obtained in de-noised signal helps the experts to diagnose the diseases more accurately.

B) Tabulation of Results:- Two measurements are computed for comparing the original and de-noised ECG signal in MATLAB by using predefined equations. The value of Mean Squared Error (MSE) has been tabulated in Table 1 and the value of Peak Signal to Noise Ratio (PSNR) is given in Table 2.

1. Mean Squared Error (MSE):- It computes the cumulative squared error between the de-noised and original ECG signal. The lower MSE value gives the lower error. MSE can be computed using the following equation:

$$MSE = \frac{\sum_{M,N} [I_1 - I_2]^2}{M * N}$$

Where M and N are the number of rows and columns in the original ECG signal, respectively. The computed MSE value is shown in Table 1, which is very small in magnitude.

Table 1: MSE Value

Error Between De-noised and Original Signal	MSE
	9.7344e-005

2. Peak Signal-to-Noise Ratio (PSNR):- It computes the PSNR, which is the measurement of quality between the original and de-noised ECG signal in decibel. The higher value of PSNR gives better quality of de-noised signal [19]. The PSNR can be computed using the following equation:

$$PSNR = 10 \log 10 \left(\frac{R^2}{MSE} \right)$$

Where R is the maximum fluctuation in the original ECG signal. The computed PSNR value is shown in Table 2.

Table 2: PSNR Value

Original ECG Signal vs. De-noised Signal	PSNR(db)
	38.9141

IV. Conclusion

The techniques for de-noising the ECG signal have been presented in this paper. The performance of DWT on ECG signals have been measured and found that the proposed technique is more efficient over other available techniques. A less complicated and more efficient method has been proposed to de-noise the random signals like an Electro Cardio Gram signals. The MSE and PSNR values of the de-noised ECG signal are also assuring the reliability of this technique. The de -noising process provides more accurate ECG pattern so, this technique is useful for medical practitioner in the process of diagnosis of complicated diseases.

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AUTHOR’S PROFILE

Dr. O. P. Singh

obtained his Ph. D in Electronics Engineering for IT, BHU. He has over sixteen years experience and presently working as Professor and Head Department of Electronics & Communication Engineering, Amity School of Engineering & Technology, Amity University Uttar Pradesh Lucknow Campus. He is life member of Indian Society of Remote Sensing (ISRS) and Material Research Society of India (MRSI).He has presented several papers in National Seminar/Conferences and also published papers in National/international Journals. His area of interest includes Microwave Remote Sensing Digital System, Signal Processing.
Email Id - opsingh@amity.edu

Kamlesh Kumar Singh

is presently Asstt .Prof. in the department of Electronics and Communication Engg., Amity University Uttar Pradesh, Lucknow,India. He received his M.Tech. Degree in Electronic Design and Technology from U.P. Technical University, Lucknow, India, in 2003.Before joining Amity University, he also worked in Integral University as an Asstt. Prof.in department of Electronics Engg. In 2000, he also worked at Central Scientific Instruments Organization (CSIO), Chandigarh, as an project scholar. He has been actively involved in the field of Technical Education as Academician, Researcher, Teacher, Planner and Administrator.He has guided several M.Tech. and B.Tech. students in Electronics Engg. discipline. He has also co-ordinated Front End VLSI design Programme. Email Id – kam2k_singh@yahoo.com

Dr. G.R. Mishra

obtained his d Ph. D in Electronics from Avadh University. He has over eleven years experience and presently working as faculty members in Department of Electronics & Communication Engineering, Amity School of Engineering & Technology, Amity University Uttar Pradesh Lucknow Campus. He is life member of Institution of Electronics & Telecommunication Engineers (IETE) and Material Research Society of India (MRSI).He has presented several papers in National Seminar/Conferences and also published papers in National/international Journals. His area of interest includes Digital System Design, Microprocessor Based System Design, Signal Processing, Embedded Systems and VLSI Design. Email Id - gr_mishra@rediffmail.com

Deepak Tiwari

is currently pursuing his M.Tech. Studies in the Department of Electronics and Communication Engg., Amity University Uttar Pradesh,Lucknow,India. He received his B. Tech. Degree in Electronics and Communication from PunjabTechnical University, Jalandhar, India, in 2011. He has been actively involved in the field of Technical Education as a research scholar. He has presented a paper on ‘Current Conveyor:A Novel Universal Block’ in National Seminar at Department of Electronics, DDU Gorakhpur University,Gorakhpur, he has published a paper in a reputed journal. Email Id-deepakbcet@gmail.com

Saumya Dubey

is currently pursuing her M.tech. Studies in the department of electronics and communication engg., amity university uttar Pradesh, lucknow, india. She has completed her M.Sc. in electronics from Kanpur University Pradesh, India, in 2010. She has been actively involved in the field of Technical Education as a research scholar.
Email Id- dubey.saumya2009@gmail.com