Removal of 50Hz PLI using Discrete Wavelet Transform for Quality Diagnosis of Biomedical ECG Signal

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ABSTRACT

Electrocardiogram (EKG or ECG) is an important electrical activity of the human Heart. ECG is used for the primary diagnosis of heart diseases since it shows the electrophysiology of the heart and the ischemic changes that may occur like the myocardial infarction, conduction defects, and arrhythmia. But, in real condition, ECG is often corrupted by different artifacts and noises. For the purpose of quality diagnosis, the ECG signal must be clearly de-noised to remove all noises and artifacts from the signal. In this paper, we present the Wavelet Transform, a new approach in digital signal processing to filter the ECG signal. Different ECG signals from MIT/BIH arrhythmia database are used with added 10dB, 5dB & 0dB Power Line Interference (PLI) noise which is common in ECG signal. The results were evaluated using MATLAB software. Basically, two synthesis parameters Mean Square Error (MSE) and Signal to Noise ratio (SNR) have been used. The prime aim of this paper is to adapt the discrete wavelet transform (DWT) to improve the (ECG) signal quality for better clinical diagnosis. The evaluated results have been compared with Butterworth IIR filter. The proposed method shows improvement in output SNRo for 5dB noise is 98.5% and for 10dB noise is 95.7%.

Keywords

Wavelet de-noising, ECG Signal and Noise, Discrete Wavelet Transform, Thresholding

1. INTRODUCTION

The electrical activity of Heart are represented by the Electrocardiogram (ECG) is easily susceptible to the various kinds o noise : the Electromygram (EMG) signal, Baseline Wander signal, 50/60 Hz Power Line Interference (PLI) etc. However, Noise contamination to these noises can degrade the ECG signal and cause to loss of clinical information. Thus, the filtering of ECG is necessary to conserve the useful information and to remove such noises. This work remains as a challenge. The American Heart Association (AHA) has defined standard filtering requirements for clinical ECG equipment [1]. Generally, adequate ECG de-noising algorithms and procedures should have properties: Improved signal to noise ratio (SNR) and Mean Square Error (MSE) for obtaining clean and readily observable recordings, yielding the subsequent use of straightforward approaches for automatic detection of characteristic points in the ECG signal and reorganization of its specific waves and complexes.

Many researchers have worked on the ECG signal de-noising. Power line interference (PLI) and Baseline wander in the ECG signal are the major problem in the diagnostic of ECG. Different researchers have worked on removal of AC interference (50/60 Hz) so as to retain basic ECG signal characteristics.

G. Umamaheswara Reddy et.al.[2] proposed a new thresholding technique compromise between hard and soft thresholding for ECG signal Denoising using evaluation criteria: Mean Square Error (MSE) and output SNR. Donoho and Johnstone [3] proposed a very simple thresholding procedure based on the Discrete Wavelet Transform with universal threshold for getting better signal from noisy data is very much suitable for Non-stationary ECG signal.

ECG signals are very low voltage amplitude (1mV) signals and easily susceptible to many noises and artifacts and one of them is Power Line Interference Noise. This noise causes the problem in analysis of low voltage level signals like ECG. Manpreet Kaur, Birmohan Singh [4] proposed a combination of Notch and Moving Average method for PLI reduction. Mahesh S. Chavan, R.A. Aggarwala, M.D.Uplane [5] has used Digital FIR Filters based on Rectangular window for the power line noise reduction. Removal of 60Hz PLI and ECG signal amplification of Remote ECG systems was developed by Ying-Wen Bai et.al. [6]. A novel method for elimination of PLI and BW in ECG signal was developed by Zhi-Dong Zhao et.al.[7]. Baseline wanders and power line interferences removing are the first step in quality diagnosis biomedical ECG signal [8-13]. Mikhled Alfaouri and Khaled Daqrouq [14] have proposed the combination technique to remove power line interference.

2. METHODS

The ECG signal is easily corrupted by noises such as Gaussian noise, baseline wander, EMG, Power line interference (PLI) and so on.

The method can be divided in into the following steps:

2.1 Noise Generation and Addition:

The 50/60 Hz Power line interference noise is generated and added into the original ECG signal samples taken from the MIT/BIH database. The process of adding noise to original signal is mathematically shown as:

$$F(n) = X(n) + D(n), \qquad n = 1, 2, 3\ldots N.$$

Where, $X(n)$ is the original ECG signal,
$D(n)$ is the 50/60 Hz PLI noise,
$F(n)$ is the Noisy ECG signal.

2.2 Basic Steps:

The basic blocks utilized in the proposed system are shown in Fig 1.

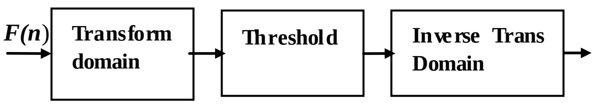

Fig 1: Proposed system blocks

In transform domain, we perform DWT of the signal. Second we pass the transform through a threshold to remove the coefficients below a certain value. In inverse transform domain, we take the Inverse DWT (IDWT) to reconstruct the original ECG signal. 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.

2.3 Wavelet Transform:

A wavelet is simply a small wave which has energy concentrated in time to give a tool for the analysis of transient, non-stationary or time-varying phenomena such a wave shown in figure 2.

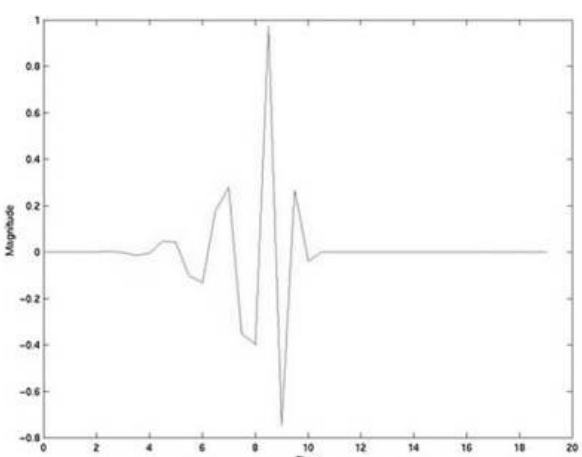

Fig 2: Wavelet function

Wavelet transform is an emerging tool for the de-noising of non-stationary signals like ECG. There are number of wavelet families like Haar, Daubechies (Db), Symlet etc for analysis and synthesis of signal. Proper selection of wavelet basis function is plays an vital in de-noising. Since Db is mostly morphologically similar to the ECG signal, so in present work Db is used in de-noising and its comparative results with IIR filter and HAAR wavelet are discussed. In Discrete Wavelet transform (DWT), original signal is decomposed and reconstructed using the low pass h(n) and high pass g(n) filter bank tree as shown in Fig 3.

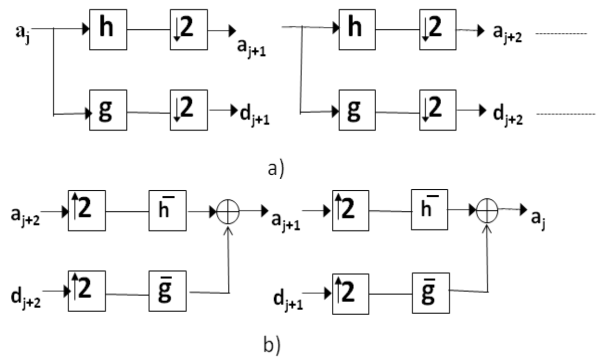

Fig 3: Filter bank tree a) Decomposition (DWT)

b) Reconstruction (IDWT)

2.3.1 *Thresholding Method*

In discrete wavelet transform, threshold is applied to the signal after passing through the DWT, and then IDWT is taken.

$$T = \sigma\sqrt{2\log N} \qquad (1)$$

Where T is the threshold, N is no. of samples,

σ, is the standard deviation of noise.

Two thresholding methods are used namely Hard threshold and Soft threshold.

2.4 Evaluation Criteria:

2.4.1 Estimation of Mean Square Error (MSE):

The MSE value is estimated between the de-noised ECG signal and original ECG signal taken from MIT/BIH database is given by eq. (2).

$$MSE = \frac{1}{N}\sum_{i=1}^{N}\left(\mathbf{x}(\mathbf{i}) - \bar{\mathbf{x}}(\mathbf{i})\right)^2 \qquad (2)$$

Where N is the length of ECG signal, $\mathbf{x}(i)$ is the original ECG signal and $\bar{\mathbf{x}}(i)$ is the de-noised ECG signal.

2.4.2 Estimation of Signal to Noise ratio (SNR):

The output SNR is given by eq. (3).

$$SNRo = 10\,log \frac{\sum_{i=1}^{N} x(i)^2}{\sum_{i=1}^{N} (x(i) - \tilde{x}(i))^2} \qquad (3)$$

SNRo values to determine the wavelet function for Denoising ECG signal.

2.5 Butterworth IIR Notch Filter:

The Butterworth IIR Notch filter is designed using the MATLAB FDATool and it is required to specify the sampling frequency Fs, Filter order and cut-off frequency (Fc1 and Fc2).

3. RESULTS

In this section, we discussed on the result obtained with the experimental work done. In the proposed de-noising algorithm, the five set of ECG records of MIT/BIH database were used and sampling frequency is set to 360Hz and added with 50 Hz Power line Interference noise with different input SNR values. The effectiveness of proposed algorithm was determined by the MSE and output SNRo values. The IIR notch filter, Haar wavelet transform and Daubechies wavelet transform filters were used in proposed algorithm to obtain quality de-noised ECG signal for diagnosis and analysis. The obtained results were discussed in below sub-section.

3.1 Simulation Study

We explore our proposed algorithm result done in MATLAB®7.1 simulations to 0dB and 5 dB noisy ECG data segments. The Fig 4 shows the simulated results of IIR notch filter with 5dB noisy ECG signal but it unable to minimize the ringing effect seen. The Table 1 shows the MSE and SNRo values for input SNR values 0dB and 5dB noisy ECG signal. These average results clearly shows that as noise level goes on increasing from 5dB to 10db, MSE increases and SNRo decreases. When input SNR increases from 5dB to 10dB, we found 49.1% output SNRo values.

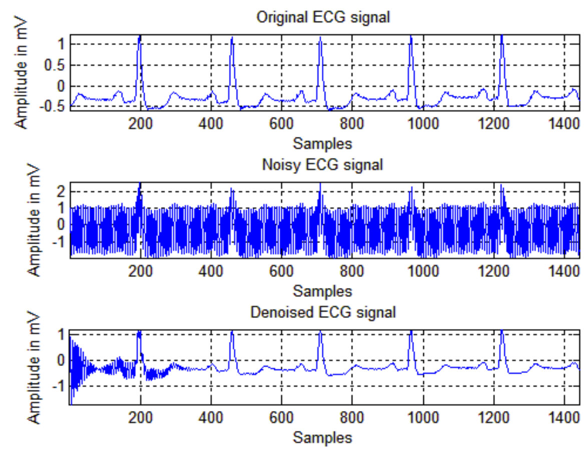

Fig 4: De-noising of ECG signal using IIR Notch Filter.

Table 1: The MSE and SNR values for the de-noising algorithm using IIR Notch filter:

ECG Data	I/P SNR = 5 dB		I/P SNR =10dB	
	MSE	**SNR**	**MSE**	**SNR**
Sample1	0.001747	15.059091	0.013322	6.235842
Sample2	0.003732	15.480584	0.018024	8.641819
Sample3	0.000659	15.242976	0.007164	4.880675
Sample4	0.004091	13.006576	0.011408	8.552229
Sample5	0.00156	15.784318	0.012796	6.64485
Sample6	0.003327	13.965597	0.01149	8.582474
Average	**0.0025193**	**14.7565237**	**0.0123673**	**7.2563148**

Next step in our work, we apply the Haar wavelet transform on the 5dB and 10dB noisy ECG signal. Fig 5 shows the simulated result of the same algorithm and Table 2 shows the MSE and SNRo values for the same transform. Obtained result clearly shows that when input SNR values increases from 5dB to 10dB, we found 65.1% output SNRo. Also, we observe there is no ringing effect as seen in IIR notch filter shown in Fig 4.

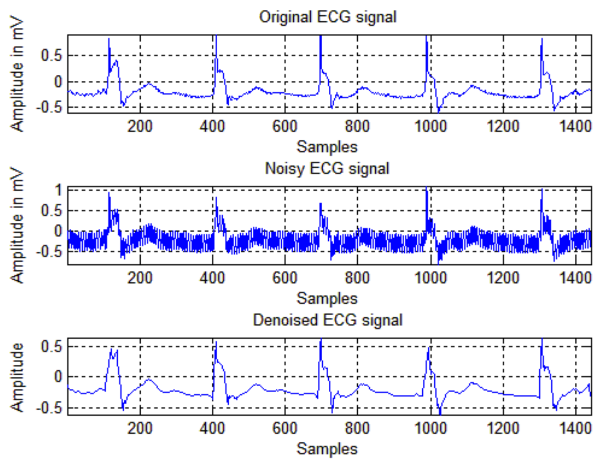

Fig 5: De-noising of ECG signal using Haar wavelet transform.

Table 2: The MSE and SNR values for the de-noising algorithm using Haar wavelet transform:

ECG Data	I/P SNR = 5 dB		I/P SNR =10dB	
	MSE	SNR	MSE	SNR
Sample1	0.007364	8.810233	0.016133	5.40428
Sample2	0.010199	11.114828	0.022828	7.615621
Sample3	0.004035	7.373314	0.009739	3.547186
Sample4	0.015903	7.109659	0.023051	5.497628
Sample5	0.005688	10.166009	0.013983	6.259636
Sample6	0.007675	10.334941	0.015158	7.379248
Average	**0.0084773**	**9.1514973**	**0.0168153**	**5.9505998**

In the very next stage, we apply the Daubechies wavelet transform (Db2, Db3 and Db4) to obtain the noise free ECG signal. Fig 6, Fig 7, Fig 8 shows the simulated result of the Daubechies algorithm (Db2, Db3 and Db4). The Daubechies wavelet transforms results shows less distortion in original signal. Table 3, Table 4, Table 5 shows the MSE and SNR values for the Daubechies (Db2, Db3 and Db4) wavelet transform. Table 2 indicates that average SNRo values for 5dB is 10.84692 while for 10dB, it is 9.03848183. In Table 3, the Db3 transform shows that output SNRo of 12.14687 for 5dB and 11.6358998 for 10dB. Also Fig 7 shows the 98.5% de-noised ECG signal.

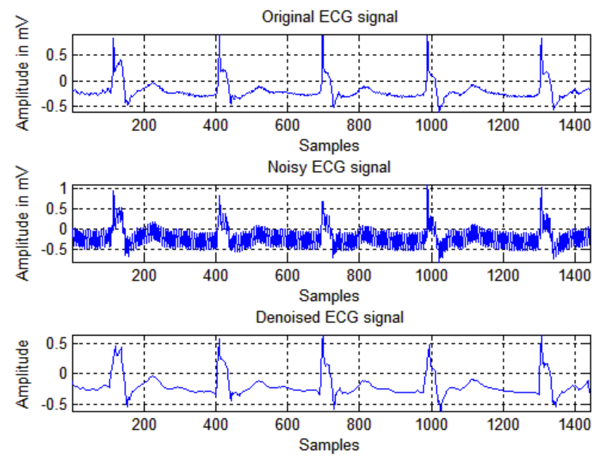

Fig 6: De-noising of ECG signal using Daubechies (Db2) wavelet transform.

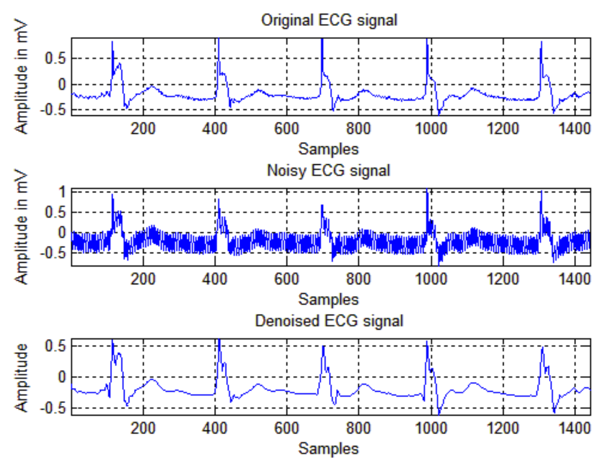

Fig 7: De-noising of ECG signal using Daubechies (Db3) wavelet transform.

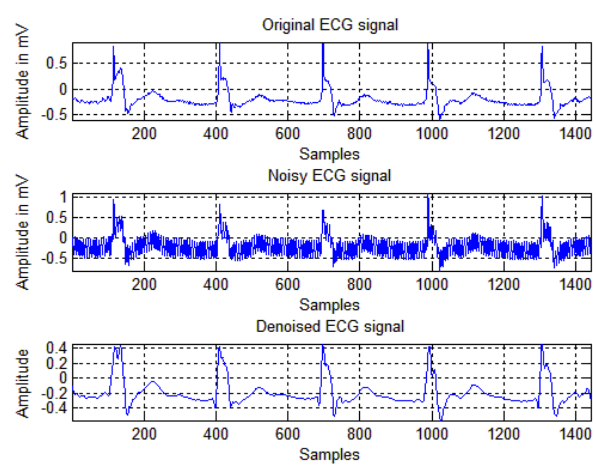

Fig 8: De-noising of ECG signal using Daubechies (Db4) wavelet transform

Table 3: The MSE and SNR values for the de-noising algorithm using Daubechies (Db2) wavelet transform.

ECG Data	I/P SNR = 5 dB		I/P SNR =10dB	
	MSE	**SNR**	**MSE**	**SNR**
Sample1	0.006164	9.583113	0.008672	8.100461
Sample2	0.004958	14.24753	0.008706	11.801883
Sample3	0.003126	8.482568	0.004959	6.47832
Sample4	0.012636	8.108472	0.014794	7.423701
Sample5	0.004296	11.38538	0.006858	9.353469
Sample6	0.003901	13.27448	0.006476	11.073057
Average	**0.00584683**	**10.84692**	**0.008411**	**9.03848183**

Table 4: The MSE and SNR values for the de-noising algorithm using Daubechies (Db3) wavelet transform.

ECG Data	I/P SNR = 5 dB		I/P SNR =10dB	
	MSE	**SNR**	**MSE**	**SNR**
Sample1	0.005685	9.934195	0.006016	9.687997
Sample2	0.005718	13.62801	0.006198	13.278012
Sample3	0.002995	8.668531	0.003244	8.320986
Sample4	0.009267	9.454963	0.009593	9.305106
Sample5	0.003197	12.6684	0.003593	12.161591
Sample6	0.001164	18.5271	0.001631	17.061707
Average	**0.004671**	**12.14687**	**0.005046**	**11.6358998**

Table 5: The MSE and SNR values for the de-noising algorithm using Daubechies (Db4) wavelet transform.

ECG Data	I/P SNR = 5 dB		I/P SNR =10dB	
	MSE	**SNR**	**MSE**	**SNR**
Sample1	0.005017	10.47674	0.006338	9.462156
Sample2	0.004271	14.89539	0.006111	13.339384
Sample3	0.0033	8.247336	0.004181	7.219191
Sample4	0.009445	9.37242	0.010577	8.880813
Sample5	0.004029	11.66326	0.005327	10.450469
Sample6	0.002339	15.49592	0.003661	13.549909
Average	**0.0047335**	**11.69185**	**0.006033**	**9.8704026**

Table 6 shows the experimental result obtained when the input signal SNR is increased from 0 dB to 5 dB, 5dB to 10 dB and also 0 dB to 10 dB. In this table, the calculated average value of output SNRo for the different ECG signals from the MIT/BIH database have been shown. The results clearly show that for IIR notch filter output SNRo varies from 51.9% to 25.53%. Similar to this, for Haar wavelet transform, output SNRo varies from 89.12% to 57.95%. This shows that Haar wavelet transform is better than IIR notch filter under noisy condition but it affects the shape of the signal and disturbs the wave. This problem is fixed with Daubechies wavelet transform Db3 found very good result and its output SNRo varies from 98.50% to 94.30%.

Table 6: The output SNRo values for different methods used for different input SNR values.

Method	input noise in dB		
	0-5 dB	**5-10 dB**	**0 - 10 dB**
IIR	51.90%	49.10%	25.53%
Haar	89.12%	65.10%	57.95%
Db2	95.22%	83.30%	79.34%
Db3	98.50%	95.70%	94.30%
Db4	96.60%	84.40%	81.50%

4. CONCLUSION

The proposed work illustrates the effect of the wavelet thresholding on the quality reconstruction of ECG signal. The IIR notch filter applied directly to the non-stationary signal like ECG has shown more ringing effect. Daubechies Db3 wavelet transform is the best method to de-noise the noisy ECG signals. For 5dB and 10dB input noise value, Db3 wavelet transform shows the output SNRo value 98.50% and 95.7% respectively with respect to other IIR, Haar, Db2 and Db4 to 95.70% which is very good for de-noising signal. We conclude that our work shows Daubechies wavelet transform performs the better than other methods. We can further illustrate this work by including other wavelets family to estimate the better quality de-noising of ECG signal.

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