ECG Signal De-noising using Discrete Wavelet Transform for Removal of AWGN Noise by Daubenchies Technique

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Abstract— An Electrocardiogram (ECG) describes the electrical activity of the heart recorded by electrodes placed on the body surface. ECG is a non-linear, non-stationary signal. Electrocardiogram is an important electrical activity as it is used for the primary diagnosis of heart abnormalities like the myocardial infarction, conduction defects, and arrhythmia. But real ECG signal is often contaminated by different noises. For the purpose of quality diagnosis, the ECG signal must be clearly de-noised to remove all noises. This paper presents a method for De-noising the noisy real ECG signal using wavelet transform. Different ECG signals from MIT/BIH arrhythmia database are used with added Additive White Gaussian Noise (AWGN) which is common in ECG signal and effect on all frequency signals. The results were evaluated using MATLAB software. De-noised ECG signal is compared with original signal using Mean Square Error (MSE) and Signal to Noise ratio (SNR). MSE and SNR improvements for different noise coverage were calculated and compared for different filtering method from db4-db10 wavelet transform method.

I. INTRODUCTION

A. *The ECG Signal*

The ECG is nothing but the recording of the heart's electrical activity. The deviations in the normal electrical patterns indicate various cardiac disorders. Cardiac cells, in the normal state are electrically polarized. Their inner sides are negatively charged relative to their outer sides. These cardiac cells can lose their normal negativity in a process called depolarization, which is the fundamental electrical activity of the heart. This depolarization is propagated from cell to cell, producing a wave of depolarization that can be transmitted across the entire heart. This wave of depolarization produces a flow of electric current and it can be detected by keeping the electrodes on the surface of the body. Once the depolarization is complete, the cardiac cells are able to restore their normal polarity by a process called re-polarization. This is also sensed by the electrodes.

Normally, the frequency range of an ECG signal is of 50–100 Hz and its dynamic range – of 1–10 mV. The ECG signal is characterized by five peaks and valleys labelled by the letters P, Q, R, S, T. In some cases we also use another peak called U. The performance of ECG analyzing system depends mainly on the accurate and reliable detection of the QRS complex, as well as T- and P waves. The P-wave represents the activation of the upper chambers of the heart, the atria, while the QRS complex and T-wave represent the excitation of the ventricles or the lower chamber of the heart. The detection of the QRS complex is the most important task in automatic ECG signal analysis. Once the QRS complex has been identified a more detailed examination of ECG signal including the heart rate, the ST segment *etc.* can be performed [3].

In the normal sinus rhythm (normal state of the heart) the P-R interval is in the range of 0.12 to 0.2 seconds. The QRS interval is from 0.04 to 0.12 seconds. The Q-T interval is less than 0.42 seconds and the normal rate of the heart is from 60 to 100 beats per minute. So, from the recorded shape of the ECG, we can say whether the heart activity is normal or abnormal.

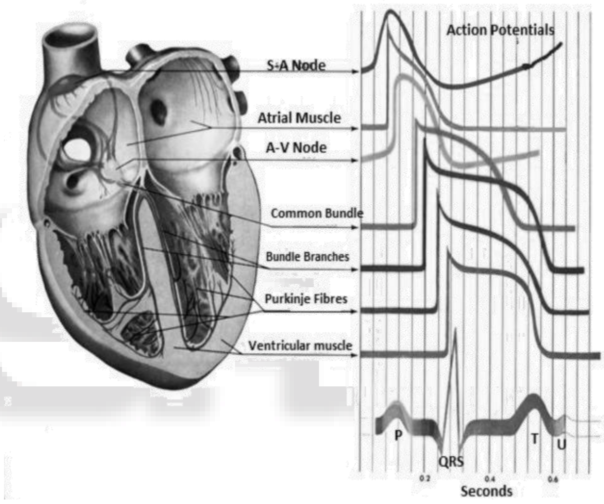

Fig. 1: The various views of ECG

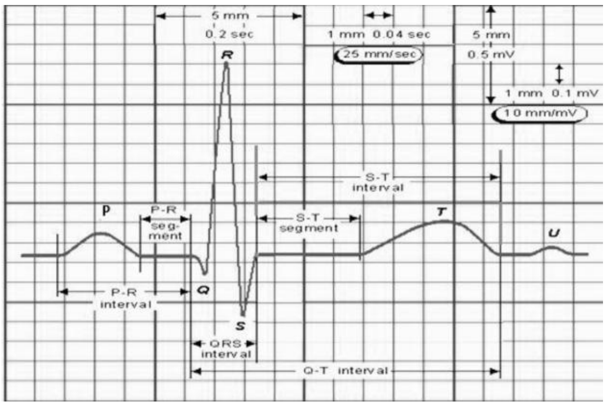

Fig. 2: Normal ECG Signal and its various components

The impulses of the heart are recorded as waves called P-QRS-T deflections.

The following is the description and significance of each deflection and segment [10].

P wave indicates atrial depolarization (and contraction).

PR Interval measures time during which a depolarization wave travels from the atria to the ventricles.

QRS Interval includes three deflections following P wave which indicates ventricular depolarization (and contraction). Q wave is the first negative deflection while R wave is the first positive deflection. S wave indicates the first negative deflection after R wave.

ST Segment measures the time between ventricular depolarization and beginning of repolarization.

T wave represents ventricular repolarization.

QT Interval represents total ventricular activity.

Noise contamination of the ECG such as baseline wander, power line interference and muscle activities can pollute the ECG and reduce the clinical value of an ECG signal. Thus, filtering of the ECG signal is a necessary pre- processing step to conserve the useful information and to remove such noises. American Heart Association (AHA) has defined standard filtering requirements for clinical ECG equipment [1]. ECG signal de-noising algorithms are evaluated based on improved signal to noise ratio (SNR) and Mean Square Error (MSE) for obtaining noise free and readily observable recordings.

A very simple thresholding procedure based on the Discrete Wavelet Transform with universal threshold is proposed by Donoho and Johnstone. [2] Which is very much suitable for Non-stationary ECG signal. A novel method for elimination of PLI and BW in ECG signal was developed by Zhi-Dong Zhao et.al. [5]. several wavelet de-noising ECG signal algorithms were developed, exploring each a particular parameter: the wavelet function, threshold calculus, and level decomposition. [7], [8].

II. METHOD

The ECG signal that is used in the paper is part of the MIT-BIH Arrhythmia Database, available online [3]. The recordings downloadable from there were digitized at 360 samples per second. For analysis MATLAB 12 is used.

The method can be divided into the following steps:

A. 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:

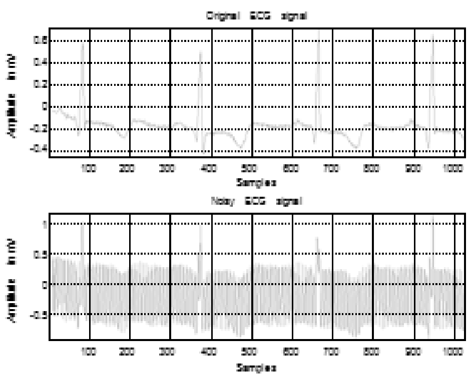

Fig. 3: Noisy ECG Signal

F (n) = X (n) + D (n), n = 1, 2, 3… N. Where,

X (*n*) is the original ECG signal,

D (*n*) is the 50/60 Hz AWGN noise,

F (n) is the Noisy ECG signal.

Above shows original ECG signal and Noisy ECG Signal with added noise

B. De-noising of Signal

Daubenchies methods are used and compared Db4-Db10 for De-noising of noisy ECG signal.

1) Wavelet Transform:

The wavelet transform (WT) is widely used for the analysis of non-stationary signals, because it provides an alternative to the classical Short-Time Fourier Transform (STFT) or Gabor transform. Wavelet Transform can be seen as signal decomposition into a set of basic functions called wavelets. They are obtained from a single prototype wavelet by dilations and contractions as well as shifts.

Discrete Wavelet transform is an emerging tool for the de-noising of non-stationary signals like ECG. There are Symlet etc for analysis and synthesis of signal. Proper selection of wavelet basis function plays a vital role in de- noising. Fig.4 shows Db4 wavelet function. 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 different daubenchies Db4-Db10 wavelet are discussed.

Discrete Wavelet Transform is also referred to as decomposition by wavelet filter banks. This is because DWT uses two filters, a low pass filter (LPF) and a high pass filter (HPF) to decompose the signal into different scales. The output coefficients of the LPF are called approximations while the output coefficients of the HPF are called details.

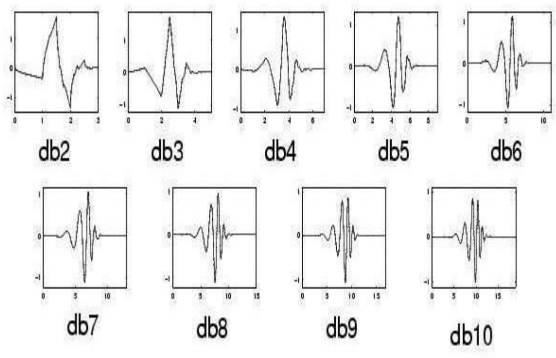

Fig. 4: Daubenchies Family

For wavelet analysis the Matlab program, which contains a very good ―wavelet toolbox‖ is used. The main steps of de-noising algorithms based on Wavelet Transform are:

1) ECG Decomposition using the discrete wavelet transforms. (DWT)
2) Thresholding.
3) ECG Reconstruction using the inverse DWT (IDWT).

First we perform DWT of the noisy ECG signal i.e. signal was decomposed using a wavelet decomposition. Then threshold is applied to the signal after passing through the DWT to remove the coefficients below a certain value, to remove the low amplitude noise or undesired signals and any noise overlap. Threshold is calculated using equation,

$$\mathbf{T = \sigma\sqrt{2\log N}}$$

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.

De-noising of ECG signal is performed using Daubechies wavelet transform (Db4) to obtain the noise free ECG signal. Fig.6 shows the simulated result of the Daubechies algorithm (Db4). The Daubechies wavelet transforms results shows less distortion in original signal

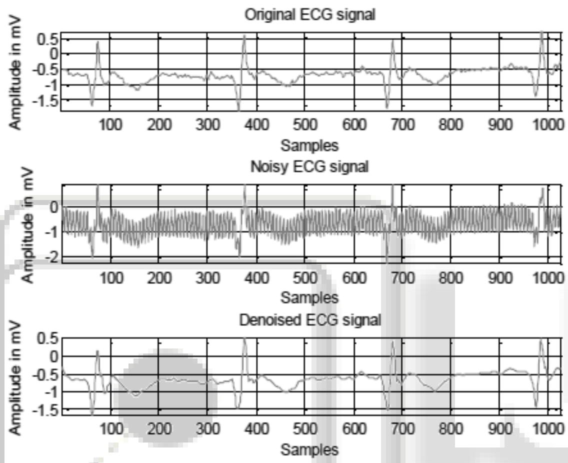

Fig. 5: De-noising of ECG signal using Db4 wavelet transform

C. *Evaluation Measures*

De-noised ECG signal is compared with the original ECG signal based upon following evaluation criteria.

1) *Estimation of Signal to Noise ratio (SNR):*

The output SNR is given by equation,

$$\mathbf{SNR = 10\log\left[\frac{\sum_{i-1}^{N} x(i)^2}{\sum_{i-1}^{N}(x(i) - \overline{x(i)}\,)^2}\right]}$$

Where, X (i) is the original ECG signal, $\overline{\mathbf{x(i)}}$ is the demised ECG signal and N is the length of ECG signal.

2) *Estimation of Mean Square Error (MSE):*

It is estimated between the de-noised ECG signal and original ECG signal given by equation,

$$\mathbf{MSE = \frac{1}{N}\sum_{i=1}^{N}(x(i) - \overline{x(i)}\,)^2}$$

Where, X (i) is the original ECG signal, $\overline{\mathbf{x(i)}}$ is the DE noised ECG signal and N is the length of ECG signal.

III. RESULTS

In this section, we discussed on the result obtained with the experimental work done. In the proposed de-noising algorithm, the three set of ECG records of MIT/BIH database were used and sampling frequency is set to 360Hz and added with AWGN noise with different input SNR values. The effectiveness of proposed algorithm was determined by the MSE and output SNR value

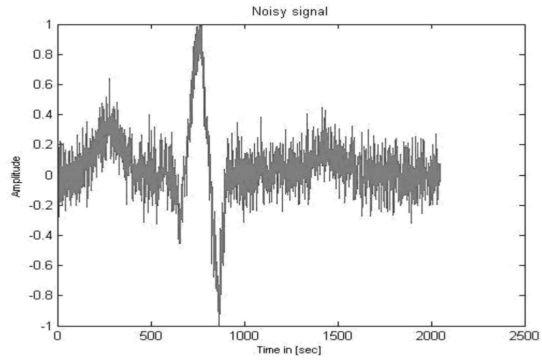

Fig. 6: Noisy ECG Signal (AWGN)

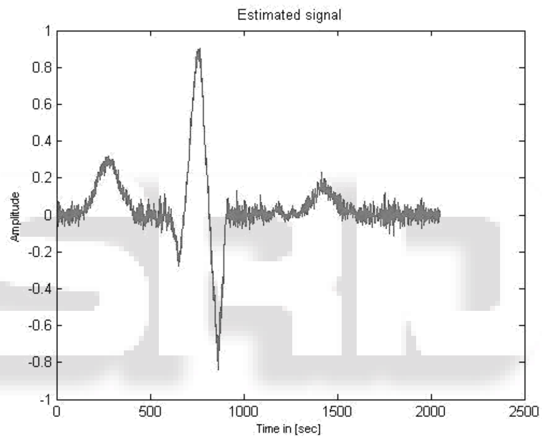

Fig. 7: De- Noisy ECG Signal

DAUBENCHIS TECHNIQUE	LEVEL	ORIGINAL RMSE	ENHANCED RMSE
db4	1	0.0025	0.0017
db4	2	0.0024	0.0013
db4	3	0.0025	0.0011
db4	4	0.0025	0.00096206
db4	5	0.0026	0.00086537
db6	1	0.0025	0.0017
db6	2	0.0025	0.0014
db6	3	0.0024	0.0011
db6	4	0.0025	0.00094707
db6	5	0.0025	0.00088221
db8	1	0.0026	0.0017

db8	2	0.0025	0.0013
db8	3	0.0026	0.0012
db8	4	0.0026	0.00096765
db8	5	0.0025	0.00089264
db10	1	0.0025	0.0017
db10	2	0.0024	0.0013
db10	3	0.0025	0.0011
db10	4	0.0025	0.00092031
db10	5	0.0025	0.0008049

Table. 1: MSE values for the de-noising algorithm using Daubechies (Db4-Db10) wavelet transform

DAUBENCHIS TECHNIQUE	LEVEL	I/P SNR	ENHANCED SNR
db4	1	5.2156	8.1873
db4	2	5.286	10.9112
db4	3	5.1934	12.3283
db4	4	4.9128	13.3646
db4	5	4.8971	14.2846
db6	1	5.0303	8.5379
db6	2	5.0646	10.3475
db6	3	5.2974	12.592
db6	4	4.9358	13.501
db6	5	4.9422	14.1173
db8	1	4.8266	8.3544
db8	2	5.167	10.5209
db8	3	4.8091	11.4459
db8	4	4.7372	13.3143
db8	5	5.1567	14.0152
db10	1	5.019	8.3753
db10	2	5.3441	10.5544
db10	3	4.9458	12.4799
db10	4	4.9198	13.75
db10	5	4.9498	14.9138

Table. 2: SNR values for the de-noising algorithm using Daubechies (Db4-Db10) wavelet transform

IV. CONCLUSION

Filtering is an important step in the processing of the ECG signal. The proposed work shows the effect of the wavelet thresholding on the quality reconstruction of an ECG signal. Comparison of RMSE & SNR of Daubechies Db4-Db10 wavelet transform using algorithm shows that RMSE will decrease and SNR will increase as increase technique and level of it. Also shows that Daubenchies technique performed better than the other methods to de-noise the noisy ECG signals.

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