ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 8, August 2015

Study of Different ECG Signal Denoising Techniques

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ABSTRACT: This paper deals with the study of different ECG signal denoising techniques and different performance evaluation parameters.ECG signal is a biomedical signal that conveys information about the electrical activities of the heart. But different noises of high frequencies and low frequencies are contaminated with ECG signal that may lead wrong interpretations. To overcome this problem, we use different ECG signal denoising techniques..

KEYWORDS: Electrocardiogram (ECG), Denoising techniques, Empirical mode decomposition (EMD), DWT, Filtering Techniques, Filtered Residue method

I. INTRODUCTION

Electrocardiogram (ECG),is used to monitor the cardiac activity of a person. It conveys information about structure and function of heart. A typical ECG tracing is consists of repeating cycle of three electrical entities: a P wave (atrial depolarization), a QRS complex (ventricular depolarization) and a T wave (ventricular repolarization). There is a U wave in ECG signal which is having a very low amplitude or even more often is absent

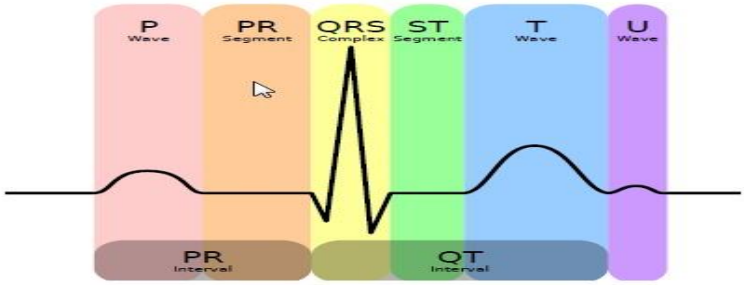

Fig.1. An ECG signal representation

Different noises are affected by the ECG signal. Mainly two types of noises are present. Noises with high frequency include Electromyogram noise, Additive white Gaussian noise, and power line interference .Noises with low frequency include baseline wandering .The noises contaminated in the ECG signal may lead wrong interpretation. There are different denoising techniques are available in the literature. In this paper some of these techniques are discussed.

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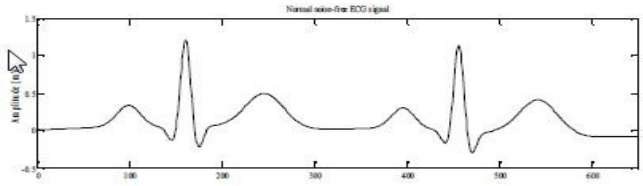

Fig.2 Human's ECG Signal: Normal noise-free [1]

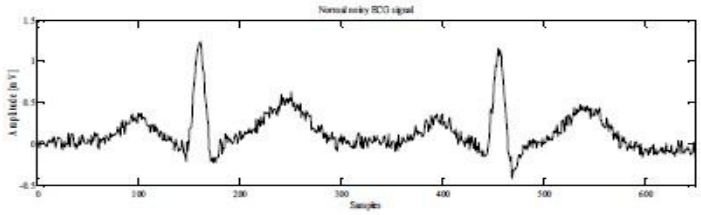

Fig.3. Human's ECG Signal: Normal noisy ECG [1]

The rest of the paper is organized as follows. Different ECG signal denoising techniques are presented in Section II, different performance evaluation parameters are discussed in section III ,simulation results are discussed in section IV and section V concludes the paper.

II. DIFFERENT ECG SIGNAL DENOISING TECHNIQUES

1 .Empirical Mode Decomposition (EMD)

In this method the noisy ECG signal is decomposed in to different intrinsic mode functions (IMFs) .Then we must find the width of the QRS complex, to preserve it. Therefore sum of first 3 IMFs were taken and their sum is calculated. With the help of this and R point location QRS width is calculated. Then an adaptive window (Tapered cosine window) of size equal to width of the QRS complex is designed to preserve the QRS complex from the noisy IMFs. Mainly lower order IMFs are noisy. Then the signal can be reconstructed by adding these windowed IMFs and the remaining IMFs [2]

An enhancement to this method can be done by using a moving average filter for the smoothening of windowed IMFs. Thus we have to increase the QRS complex quality. Here residue got after empirical mode decomposition is also considered. EMD is an adaptive and data driven technique, thus suitable for any non stationary signal [3].And the denoised ECG signal is very much similar to the original clean ECG signal. The ECG signal with high frequency Additive white Gaussian noise can be reduced using this technique

2. Filtering Techniques – To Remove power line interference (PLI)

A. IIR NOTCH FILTER

IIR filter is a simple filter .The stationary power line interference can be removed using a notch filter. If a notch filter has higher attenuation level, it will be able to remove PLI noise to a greater extent from ECG signal [4].But practically it eliminates power line interference at 50Hz frequency.

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B. FIR FILTERING

FIR filters are simple and stable. Window method is the simplest FIR filter design method . Here all frequencies below the cut off frequency are passed with unity amplitude and others are blocked. The different windows used are

a) RECTANGULAR WINDOW

$$w(n) = \begin{cases} 1, & 0 \le n \le M-1 \\ 0, & otherwise \end{cases} \qquad eq.(1)$$

b) HANNING WINDOW

$$W(n) = \begin{cases} 0.5 - 0.5 * cos\left[\frac{2\pi n}{M-1}\right], 0 \le n \le M-1 \\ 0, \ otherwise \end{cases} \qquad eq.(2)$$

c) HAMMING WINDOW

$$W(n) = \begin{cases} 0.54 - 0.46 * \cos\left[\frac{2\pi n}{M-1}\right], & 0 \le 0 \le M-1 \\ 0, & otherwise \end{cases} \qquad \text{eq. (3)}$$

d) BLACKMAN WINDOW

$$W(n) = \begin{cases} 0.42 - 0.5 * cos\left[\frac{2\pi n}{M-1}\right], & 0 \le n \le M-1 \\ 0, \ otherwise \end{cases} \qquad eq.(4)$$

Using these windows High pass filter and Low pass filters are designed with cut off frequency 3Hz and 100Hz respectively. Then the noisy ECG signal is passed through these filters to remove noises

C. ADAPTIVE FILTER

The adaptive filter reduces the mean squared error between primary input (ECG signal) and the reference input (noise with ECG signal) [4]. An adaptive noise canceller is an efficient method to denoise noisy ECG signal .The algorithm used is Recursive least squares (RLS) [5].

Advantages of adaptive filter method are:

- Filtering response is fast
- Residual errors are small
- When working in time varying environment it has excellent performance

Drawback of adaptive filter method is:

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- This method requires reference signal (either signal or noise characteristics) information for the effective filtering process.[4]
- When RLS algorithm is used it has high computational complexity and stability problems

3. **Discrete Wavelet Transform (DWT)**

Wavelet transform (WT) is a powerful method for analysing non stationary signals. ECG signals are time varying and non-stationary signals so WT is suitable for analysing ECG signal. Wavelets allow both time and frequency analysis of signals. Discrete Wavelet Transform (DWT) analyse and a signal as a linear combination of the sum of the product of the wavelet coefficients and mother wavelet.

Generally 3 procedures are done in DWT

1. DWT is applied to the Noisy ECG signal to produce noisy wavelet coefficients
2. Thresholding of the DWT coefficients
3. Inverse wavelet transform of the thresholded wavelet coefficients to obtain denoised ECG signal

4.Filtered Residue (FR) Method

In this method the residue of the noisy ECG signal is calculated. The residue is given as the difference between the input ECG signal and the corresponding signal average at every point. This residue is then given to the Low pass FIR filter, thus we get a filtered residue .To reconstruct the final output this filtered residue should be added with the signal average.

The main advantages of this algorithm are simple to implement, stable, output is an accurate reconstruction of the actual signal, it preserves high frequency components, and it is fast. The main limitation of the filtered residue algorithm is that the misalignment of the beats has a blurring effect on the output and the FR algorithm is not iterative that is if it is applied to a signal, the measurement of the activation time in the output is not improved [6]

III. DIFFERENT PERFORMANCE EVALUATION PARAMETERS OF ECG SIGNAL DENOISING TECHNIQUES

1. Signal to Error Ratio (SER)

$$SER = \frac{\sum_{t=0}^{L-1} s^2(t)}{\sum_{t=0}^{L-1} [s(t) - \hat{s}(t)]^2} \qquad \text{eq. (5)}$$

Where $s(t)$ and $\hat{s}(t)$ are the clean ECG signal and the reconstructed ECG signal. L is the length of the ECG signal

2. Signal to Noise Ratio (SNR)

$$SNR = \frac{\sum_{t=0}^{L-1} s^2(t)}{\sum_{t=0}^{L-1} n^2(t)} \qquad eq.(6)$$

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3. Signal to noise ratio improvement (SNR imp)

$$SNR_{imp} = 10log_{10}\frac{\sum_{n=1}^{N}|y[n]-x[n]|^2}{\sum_{i=1}^{N}|\hat{x}\,[n]-x[n]|^2} \qquad eq.(7)$$

Where $x[n]$ denotes clean ECG signal, $y[n]$ means noisy ECG signal and $\hat{x}\,[n]$ is the reconstructed ECG signal using Denoising techniques. N is the number of ECG samples. SNR_{imp} should be larger for a better denoising method.

4. Mean square error (MSE)

MSE is defined as:

$$MSE = \frac{1}{N}\sum_{n=1}^{N}(\,x[n]-\hat{x}\,[n]\,)^2 \qquad eq.\ (8)$$

MSE should be small for better denoising technique

5. Percentage Root mean square Difference (PRD)

PRD measures the distortion between the actual signal and the reconstructed signal.

And it is given by

$$PRD = \sqrt{\frac{\sum_{n=1}^{N}(x[n]-\hat{x}[n])^2}{\sum_{i=1}^{N}x^2[n]}} * 100 \qquad \text{eq.(9)}$$

Denoising technique said to be better if it has a smaller PRD value

IV. SIMULATION RESULTS

The simulation studies involves the performance evaluation of different ECG signal denoising techniques. The Fig.4. shows the results of SNR and SER values of five records 100,103,105,119, and 213 chosen from the from the MIT-BIH database using Empirical mode decomposition. For each record, the SNR is changed from 6 to 18 dB. The horizontal axis corresponds to the SNR and the vertical axis shows the average SER . It shows that the SER improves when increasing the SNR [2]

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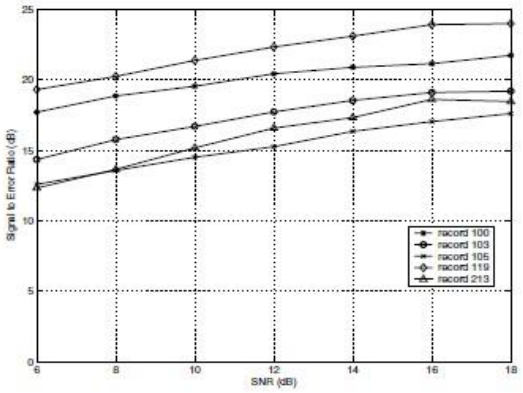

Fig.4. SER (dB) vs. SNR (dB) for five signal records: 100,103,105,119, and 213 in Gaussian noise case [2]

Table 1 shows signal to error ratio for different ECG records from MIT/BIH database using Empirical mode decomposition and moving average filter .Table 1 depicts that the SER consistently improves as the SNR increases and gives better result [3]

SNR Vs SER	**ECG Record 100**	**ECG Record 103**	**ECG Record 105**	**ECG Record 119**	**ECG Record 213**
SNR (dB)	**SER (dB)**	**SER (dB)**	**SER (dB)**	**SER (dB)**	**SER (dB)**
8	27.71	23.52	20.56	21.97	17.86
10	29.94	28.21	23.48	22.46	20.65
12	33.16	30.23	24.67	23.47	22.93
18	37.85	37.02	29.63	26.76	30.61

Table1. Signal to Error Ratio for different ECG records from MIT/BIH database [3]

V. CONCLUSION

The survey includes the works and findings done by various researchers on ECG signal denoising techniques. If the input signal has low frequency SNR adaptive filtering is the best choice .But if the amount of noise is moderate Filtered Residue algorithm provides better output. Wavelet denoising methods can be used for ECG signals with large beat to beat variation.EMD and moving average filter is an effective technique to suppress high frequency Additive white Gaussian noise. The survey also includes different performance evaluation parameters of ECG signal denoising techniques. For a better denoising method the SNR_{imp} should be larger, Mean square error and Percentage Root mean square Difference (PRD) should be small.

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BIOGRAPHY

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