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A Review on Noise Analysis and Different Denoising Techniques of ECG Signal

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Abstract— Electrocardiogram (ECG) is an electrical signal used for measuring electrical activity of the heart on the body surface via electrodes (leads). As ECG signal is corrupted by different noises therefore in this study different noises like power line interference, baseline drift, electrode contact noise, muscle contraction and motion artifacts are analyzed. In this paper various techniques are presented such as adaptive filter algorithms, windowing methods and empirical mode decomposition for ECG signal denoising.
Keywords— Electrocardiogram(ECG), Least mean square(LMS), normalized least mean square(NLMS), Signal to noise ratio(SNR), Mean square error(MSE), Power spectral density(PSD), Percentage root mean square difference(%PRD).

I. INTRODUCTION

ECG is an electrical signal generated by the heart muscle and measured by the leads on the skin surface of the body. Due to the electrical abnormalities of the heart, the heart stops pumping and supplying of enough blood to the brain and body. when chest pain occurred such as heart attack, shortness of breath, faster heartbeats, high blood pressure, high cholesterol ECG is necessary to be done as ECG records the electrical activity of heart [1]. ECG signal lies in the range of 0.05-100Hz and 50Hz power line interference is the main source of interference in ECG signal [2]. 50Hz noise is removed by filtering the signal with a 50Hz notch filter [3]. the ECG recorder should have a frequency range of 3 db from 0.67Hz to 150Hz is recommended by American Heart Association [4]. ECG signal is affected by different types of noise and interference as ECG is very sensitive signal. ECG signals are mostly corrupted by colored noise, white noise electrode movement noise, muscle artifact noise, baseline wander, composite noise and power line interference (PLI). Due to these noises and interference correct diagnosis of the ECG signal does not take place. So, it is very important to remove these noises and interference from the ECG signal [1].

A. *Electrocardiographic Signal*

ECG signal can be analyzed and processed in two Domains ie, time domain and frequency domain. ECG signal is one of the biomedical signals which can be analyzed and worked in these two domains [5].

1) *Time Domain of An ECG Signal:* P, Q, R, S, T and U are specific wave forms identified in the time domain of an ECG signal. The P wave followed by QRS complex, formed by Q, R and S waves, represents a relevant wave form because the heart rate can be identified by locating two successive QRS complex. Figure 1 represents waves in an ECG signal [5].

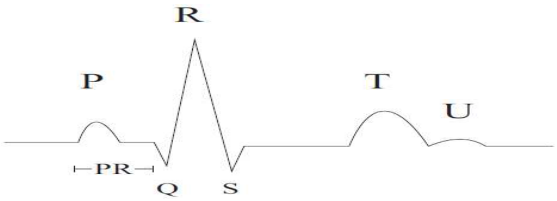

Fig. 1 Typical wave forms of an ECG signal [5]

2) *Frequency Domain Of An Ecg Signal:* Frequency values of an ECG signal vary from 0 Hz to 100Hz whereas the amplitude values vary from 0.02 mV to 5 mV. Table 1 describes the frequency and amplitude values of various biomedical signals ie, ECG, EMG (electromyogram), and EEG (electroencephalogram) signals [5].

Table 1

Amplitude and Frequency Range of Basic Biomedical Signals

Signal	Amplitude(mV)	Frequency(Hz)
ECG	0.02 - 5.0	0.05 – 100
EEG	0.0002 – 0.3	DC – 150
EMG	0.1 – 50	DC – 1000

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B. Digital ECG

Block diagram shows the typical digital ECG [5].

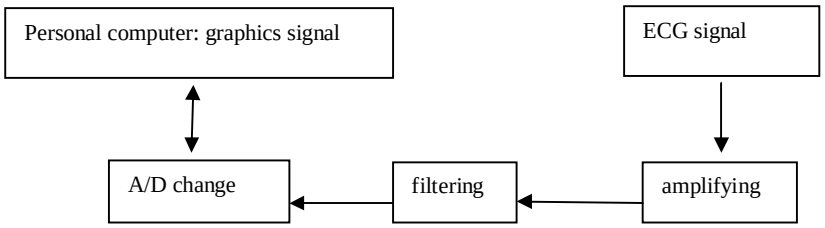

Fig. 2Blocks Diagram of a Digital ECG[5]

II. TYPES OF NOISE IN ECG

A. Power Line Interference

It consist of 50/60Hz pickup and harmonics. Amplitude and frequency contents are the characteristics which might to be changed in power line interference having 60 Hz components[6].The amplitude varies up to 50 percent of peak-to-peak ECG amplitude of signal, which is approximately equal to 25mv[7].

B. Base Line Drift

Baseline drift is defined as continuous drifting of ECG signal from base line. The frequency and amplitude of the sinusoidal component should be variable [6].patients movement and respiration causes the low frequency wander. It causes problem in detection and analysis of peak. amplitude variation is 15% of peak to peak ECG amplitude and variation in base line is 15% of ECG amplitude at 0.15 to 0.3 [7].

C. Electrode Contact Noise

Improper contact of electrode between patient and the measuring system for a short time results in electrode contact noise. The noise is of duration 1 sec [7].

D. Muscles Contraction

The MA (Muscle Artifacts) originally had a sampling frequency of 360Hz. Muscle contraction generates artifactual mV level potentials. The base line electromyogram is the microvolt range and therefore is usually insignificant. It is simulated by adding random noise to the ECG signal [7]. the standard deviation of muscle contraction noise is 10% peak to peak ECG amplitude having 50ms duration and frequency content is from dc to 10 kHz [8].

E. Motion Artifacts

Motion artifacts are transient base line changes caused by changes in the electrode-skin impedance with electrode motion. As this impedance changes, the ECG amplifier sees a different source impedance which forms a voltage divider with the amplifier input impedance therefore the amplifier input voltage depends upon the source impedance which changes as the electrode position changes [8].

III. DIFFERENT DENOISING TECHNIQUES IN ECG SIGNAL

A. Uzzal Biswas, Anup Das, Saurov Debnath and Isabela Oishee

This paper describes the two adaptive filters: Least mean square **(** LMS) and normalized least mean square **(**NLMS) for denoising of ECG signal. In this paper different noises are studied for denoising of real ECG signal. Real ECG signal is taken from the benchmark MIT-BIH arrhythmia database and different types of noises are generated using MATLAB.

In this paper, For LMS algorithm, the coefficient update equation is

$$W_{k+1} = W_k + 2\mu e_k X_k$$

Where μ is appropriate step size. It ranges from 0<μ<0.2 for convergence. Due to larger step size coefficients fluctuate extensively. Therefore to overcome the problems of LMS algorithm normalization of step size is done using normalized least mean square algorithm **(**NLMS).

Coefficient update equation for NLMS algorithm is

$$W_{k+1} = W_k + \beta \frac{x_k^*}{\alpha + \|x_k\|^2} e_k$$

Where β is the normalized step size for 0<β<2. It include the visual parameters such as power spectral density **(** PSD), spectrogram, frequency spectrum and convergence. Also estimate different performance parameters such as SNR, % PRD and MSE. At last this paper concluded that NLMS filter removes noise more significantly and is a suitable method for noise removal in ECG signal [1].

B. Uzzal Biswas and Md. Maniruzzaman

The paper presents the removal of power line interference from the ECG signal by comparing the performance of two adaptive filters: normalized least-mean-square **(**NLMS) adaptive filter and recursive-least- square adaptive filter with a traditional notch filter in both time and frequency domain. Real ECG signal is taken from the MIT-BIH database and the 50 Hz Power line interference is generated by using MATLAB. For performance measurement different parameters are used such as power spectral density **(**PSD), spectrogram, signal to noise ratio **(**SNR), percent root mean square difference **(**%PRD) and mean square error **(**MSE) .comparison is made between the adaptive filters and notch filter. The high SNR, low %PRD and low MSE and better PSD of adaptive NLMS shows the effectiveness of this filter as compared to others. This paper concluded that adaptive NLMS filter performs better than adaptive RLS and notch filter for removing 50Hz noise properly [2].

C. Md. Maniruzzaman, Kazi Md. Shimul Billah, Uzzal Biswas and Bablu Gain

This paper uses different adaptive filter algorithms: least-mean-square **(**LMS), Block LMS **(**BLMS), delay LMS **(**DLMS), adjoint LMS, filtered-X **(**XLMS), normalized LMS **(**NLMS) and fast fourier transform BLMS **(**FFT BLMS) for the removal of power line interference from the ECG signal. The real ECG signal and the 50Hz power line interference is generated by using MATLAB. Different performance parameters such as power, SNR, %PRD, ESD are compared. This paper concluded that LMS and NLMS are appropriate than other adaptive filters. As the SNR of LMS filter is lower than NLMS filter. Therefore performance of NLMS is better than LMS for removing 50Hz PLI [9].

D. Rinky Lakhwani, Shahanaz Ayub, J.P Saini

This paper proposed work on removal of low frequency interference ie base line wandering in ECG signal. It also tells about the designing of different digital filters with different windowing methods: rectangular, Gaussian, hamming & Kaiser. Filter designing is done in FDA tool in MATLAB. Digital filters are used as compared to analog filters because of advantage of size, cost, tolerance, speed etc. It included four steps of designing FIR filters:

Approximation
Synthesis and realization
Performance analysis
Implementation

Comparison was made on the basis of waveform and power spectrum before and after filtering for different windowing and for different orders. The Kaiser window at order of 56 shows the best result [10].

E. S. A. Anapagamini and R. Rajavel

The paper proposed the empirical mode decomposition method. Decomposition (EMD) of signal into sum of intrinsic mode functions **(**IMF) with a final residue is the important feature of EMD. Shifting process is used to estimate the IMFs. In this paper both FIR filter and EMD are used for removing PLI by passing the first IMF through FIR low pass filter and proposes a new technique for removing base line wander. In this technique first determine the number of IMFs that are affected by base line wander noise and then subtract those IMF and final residue from noise ECG signal. The ECG signal is taken from the MIT- BIH database. Parameter used in this paper is RMSE which is calculated for both EMD based method and filter based method and concluded that EMD based method is better and appropriate than filter based method and also have reduced computational complexity [11].

Table 2: Comparison of adaptive filter algorithm

Noise	**Adaptive filter Algorithm**	**MSE**	**PSD**	**%PRD**	**SNR**
Power Line Interference	LMS	High	Low	High	Low
	NLMS	Low	High	Low	High
		[1]	[1]	[1][2]	[1] [2]

IV. CONCLUSIONS

The different techniques for removing various types of noises in ECG signal have been discussed. Studied various types of noises such as power line interference, baseline drift, electrode contact noise, muscle contraction and motion artifacts.

Denoising of real ECG signal has been studied in this paper. The various parameters showed the good result of smoothed ECG waveform for better diagnosis of an heart diseases.

V. ACKNOWLEDGMENT

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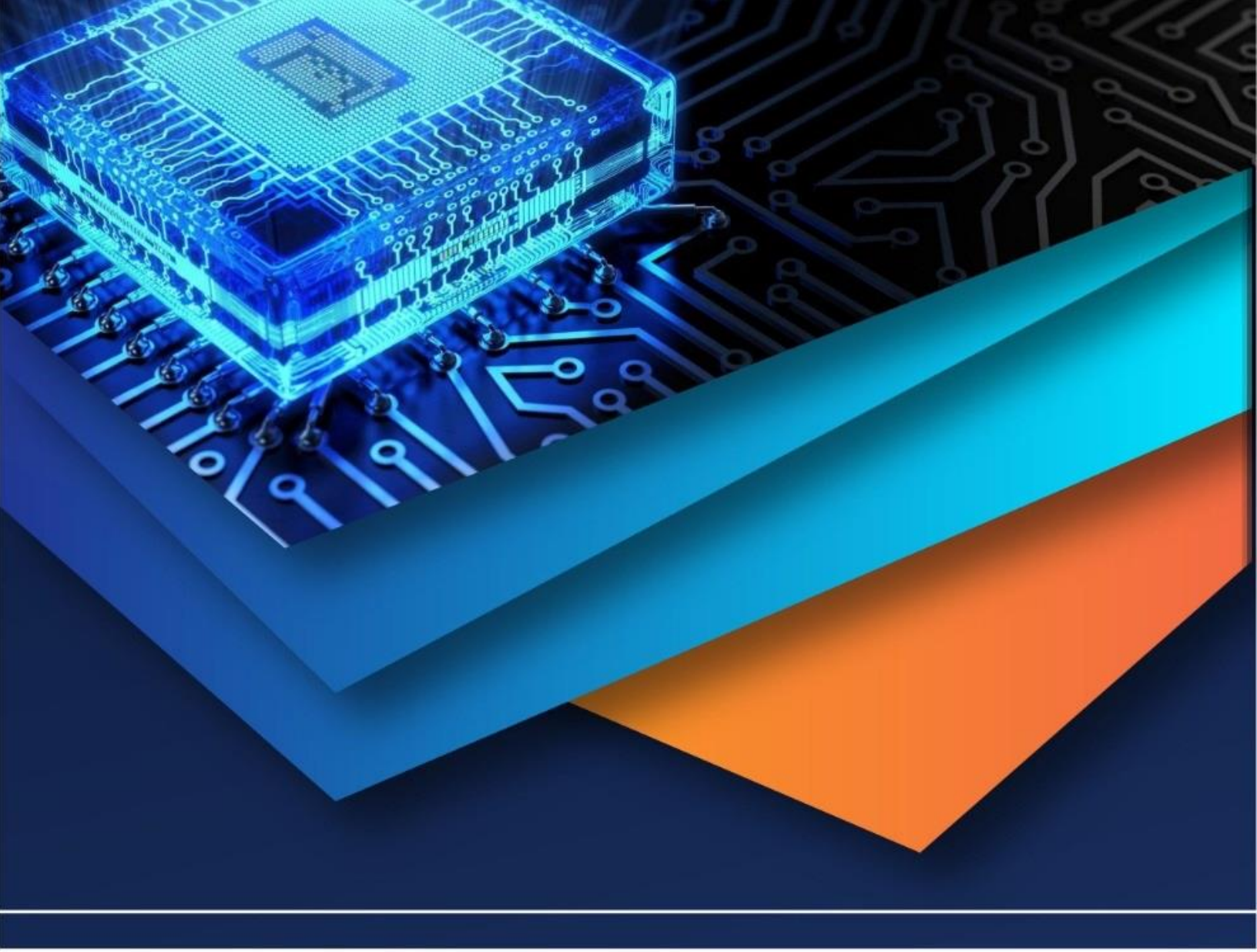

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