# DENOISING OF ECG SIGNALS – A PRELIMINARY STUDY

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***Abstract*- The Electrocardiogram (ECG) is a non-invasive and graphic representation of electrical activity of the heart. It is obtained by placing electrodes at specific locations on the body surface. These ECG signals help in the diagnosis of cardiovascular diseases. The slight variation in the signal need to be noticed in order to identify any problem in the heart as ECG signals vary from 0.05 to 100 Hz. The acquired ECG signal may have noises such as baseline wander, power line interference, motion artifacts, muscle contraction, instrumentation noise and electrode-contact noise. The ECG signal is to be preprocessed to remove these noises. In this work, the signal is de-noised to remove the baseline wandering in MATLAB environment by various techniques such as Infinite Impulse Response, Independent Component Analysis, Interpolation and Successive Subtraction of Median values in RR interval, Least Mean Square Adaptive Filter and Moving Average Filter. Performance measures such as Mean absolute error, Mean Square Error, Signal to Noise Ratio, Percentage Signal to Noise Ratio, Percent Root Mean Square Difference are computed to find the method that is suitable for the acquired ECG signal.***

***Keywords—Baseline wandering, IIR filter, Denoising, Performance metrics, ECG signal.***

## I. INTRODUCTION

Electrocardiogram (ECG) is a non-invasive technique, which is a graphical recording of the heart's electrical activity during each of its cycle. It is the most common investigation of the heart performed by physicians and is extremely useful. The ECG signals are obtained by placing electrodes over the skin nearer to heart muscles. The electro physiologic pattern of depolarizing and re-polarizing of heart muscles for each heartbeat can be detected by placing these electrodes on the skin. It is very commonly performed to detect any cardiac problems [1].

The ECG signal is typically characterized by maximum amplitude of 1 mV and bandwidth of 0.05 Hz to 100 Hz [2]. There are three types of ECG recordings done. They are rest mode ECG, ambulatory ECG and exercise ECG. The resting ECG recordings are done when the subjects lay in a comfortable position, which are short duration ECG signals. The ambulatory ECG are recorded using the portable ECG monitors that are to be worn for 24 hours or more to give an extended picture of the heart's rhythm, particularly when symptoms occur intermittently. Exercise ECG recording is done when the subject exercise on a treadmill or exercise bike. This helps in showing the presence of narrowing of the coronary arteries [3]. These ECG signals cannot always predict future condition of the heart as they can only show the exact condition and working of the heart at the time of recordings. But they are valuable in diagnosing abnormalities of conducting pathway, enlargement of heart, myocardial infarction and electrolyte & hormonal imbalances [4].

The ECG signals acquired by exercise or in ambulatory way contain noises in them. These noises in an ECG signal make it difficult for the physicians to provide proper diagnosis for the patient. Some of the noises observed when recording an ECG signal are power line interference (50 Hz), baseline wandering, motion artifacts and electrode contact noise. The 50 Hz pickup and harmonics constitutes the power line interference in an ECG signal, which is mainly caused by electromagnetic interference over the power line and improper grounding of ECG machine. The 50 Hz signals are induced in to the input circuits of the ECG machine due to these interferences.

Baseline wander is the drift of ECG signals from the reference line caused due to respiration and body movements. They are low frequency noise that causes problem in detection and analysis of QRS peak. The voluntary and involuntary movement by patients during signal acquisition causes motion artifact. Improper contact of electrode between patient and the electrode thus disconnecting the measuring system from the patient results in electrode contact noise. The noise duration is of 1 sec [5]. The denoising of ECG signal from baseline wandering is essential, as a small drift in the signal can determine the condition of heart actions.

Recent literature reveals the importance of denoising of ECG signals. Silva, et al. (2014) suggested the importance of bio-signals such as ECG and Electroencephalography. The usage of these bio-signals is developing in a fast pace to provide advancements and potential applications in the medical world [6].

Kumar, et al. (2015) proposed in removing the baseline wandering noise using various techniques such as Finite Impulse Response filters like Rectangular, Hann, Blackman, Hamming and Kaiser window techniques. They also used Infinite Impulse Response (IIR) filters like Butterworth, Chebyshev I, Chebyshev II and Elliptic filters for denoising ECG signal. They concluded that digital FIR filter with Kaiser window of order 56 shows high performance as compared to the other windowing techniques and digital IIR filter approximation methods [7].

Romero, et al. (2018) analysed ECG data obtained from Noise Stress Test Database (NSTD) and synthetic ECG signals for different techniques and stated that FIR high pass filter with cut off frequency of 0.67 Hz provided best results [8].

Alhelal, et al. (2015) implemented denoising and beat detection of the ECG signals. They converted the MATLAB counterpart into Field Programmable Gate Array (FPGA) to handheld and portable ECG equipment. It should also be noted that FPGA usage is very beneficial when compared to digital signal processors as they are of low cost, high speed devices and are reprogrammable [9].

In this work, the various denoising methods for the ECG signals are performed. The method that performs best is chosen from the performance metrics. All the processing and analysis of the signals are done in R2014a MATLAB environment.

## II. METHODOLOGY

The ECG signals are obtained by ambulatory or stress tests may be corrupted by various kinds of noise. It is essential to remove these noise signals for the meaningful extraction of the ECG signal.

So the preprocessing stage is done by using digital filters, which can easily eliminate the noises in the ECG signal. Though there are different methods present to eliminate these noises care should be taken in choosing a proper method.

Figure 1 shows the basic block diagram to denoise the ECG signals. The acquired ECG signals are preprocessed and their performance measures are studied.

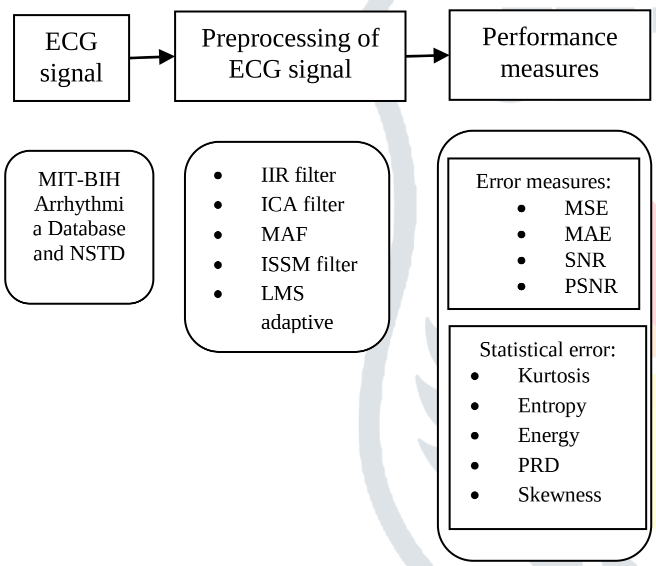



Fig. 1. Basic block diagram to denoise ECG signals

### A. *ECG signal database*

The ECG signal is obtained by non-invasive method, where the electrodes are attached to the skin to measure the signal. In the present work the ECG signals from Physionet MIT-BIH Arrhythmia database is used for analysis where these signals are obtained as a binary file (.dat) file whose necessary details are obtained from its corresponding text header file (.hea) and binary annotated file (.atr).

The header file consists of detailed information such as number of samples, sampling frequency, format of ECG signal, type and number of ECG leads, patient's history and the detailed clinical information.

The database contains 48 records; each record is in digital format, which is sampled at a rate of 360 Hz with 11- bit resolution. These signals are clear signals. The bw.mat file contains the baseline wandering noise is obtained from the NSTD [10, 11].

So the clear signal and the noise signals are added such that the de-noised ECG signal is obtained and is used for further processing.

### B. *Preprocessing of ECG signal*

The preprocessing is done with the help of various techniques and the best method is chosen based on the performance metrics. Though each technique is unique and has its own strength and weakness, it should be chosen based on the performance metrics.

#### *1) Infinite Impulse Response (IIR) filter*

The values of both the past outputs and the present inputs are convoluted to produce a digital filter, which when subjected to an impulse input produces an output. This output is mandatorily not zero and has infinite impulse response. Such a filter is known as an Infinite Impulse Response filter or IIR filter. The infinite impulse response of the filter indicates that the system is prone to feedback and inconstancy. The IIR filter is determined by the equation below [7].

$$y[n] = \sum_{k=0}^{N-1} h(k).X(n-k) \quad (1)$$

#### *2) Least Mean Square (LMS) Adaptive Filter*

Two types of adaptive filter algorithms such as LMS and Normalized LMS (NLMS) are used in denoising of ECG signal. The basic block diagram of adaptive filtering process is given in Figure 2.

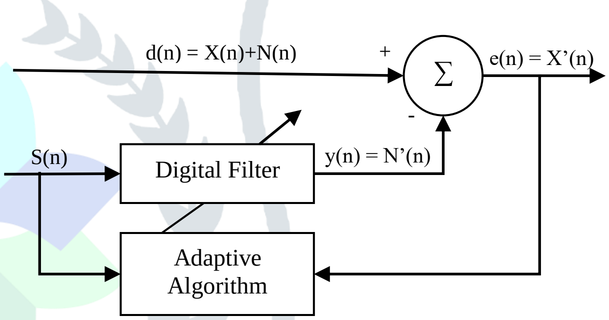



Fig. 2. Principle of adaptive filter

The block diagram presented in Figure 2 shows that the original signal X(n) could be obtained by subtracting the N(n) from the mixed signal d(n). This process is difficult due to presence of harmonics present in the noise signal. Digital filters and a measurable noise source S(n) is used to calculate the estimated noise signal N'(n) value. The desired signal X'(n) can be obtained from this which can be more close to the original signal X(n).

The least mean square of the error signal can be produced by changing the filter tap weight with appropriate step size for the coefficient in the LMS algorithm. As the coefficient fluctuate widely with larger step size causing the LMS algorithm to experience a problem with gradient noise amplification. This can be solved by normalizing the step size. This normalization of the step size in the LMS algorithm is called NLMS algorithm, whose coefficient is given by [12],

$$W_{k+1} = W_k + \beta \frac{X_k^*}{\alpha + \|X_k\|^2} e_k \quad (2)$$

where β is normalized step size for 0<β<2.

#### *3) Moving Average Filter (MAF)*

A moving average filter is also called rolling average, rolling mean or running average. It is a type of low pass Finite Impulse Response (FIR) filter. They are used to regulate an array of sampled data or signal. They create a series of averages of different subsets of a full data set to analyse a set of data points. If the length of the filter increases, the smoothening of the signal decreases. After extracting the estimated baseline wandering, it is subtracted from the original signal. There will be loss of samples in the baseline wandering due to the usage of sliding window which is rectified by filling zeros at the beginning and at the end [13].

*4) Interpolation and Successive Subtraction of Median (ISSM) values in RR interval*

In this approach, the signal samples from RR interval are subtracted from the calculated median value in this interval. This is a recursive process where the above step is repeated until there is a small definite threshold difference in the median values of all RR intervals. This process uses separate algorithm for QRS complex such that the baseline wandering is minimum, if all QRS complexes are not detected. The baseline wandering becomes zero if there is cent percent detection of QRS complexes [14].

*5) Independent Component Analysis (ICA)*

ICA is a statistical method to separate a signal from a mixture of signals. The ICA was first used to solve cocktail-party problems. This algorithm works based on two assumptions. One is that the signal source is independent of each other and another is that they have non-guassian distribution. The fastICA method is developed by combining the singular value decomposition and ICA method to provide fast convergence rate [15].

## C. Performance Metrics

The performance of the denoising methods are compared based on the following parameters: Signal to Noise Ratio (SNR), Mean Square Error (MSE), Percent Root mean square Difference (PRD), Percentage Signal to Noise Ratio (PSNR), Mean Average Error (MAE), energy, entropy, kurtosis, skewness. These parameters are defined in the following paragraphs.

*1) Signal to Noise Ratio*

In order to determine the strength of a signal it is necessary to calculate the signal to noise ratio (SNR). The higher the ratio, the easier it becomes to detect a true signal or extract useful information from the raw signal. SNR is inversely proportional to log (MSE). SNR can be defined as:

$$SNR = 10\log_{10}\frac{\sum_{n=1}^{N} x(n)^2}{\sum_{n=1}^{N}(x(n)-x'(n))^2} \quad (3)$$

A high value of SNR indicates good denoising [16].

*2) Percent Root Mean Square Difference*

The PRD is widely used as it is a principle error criterion. The PRD is given by [17],

$$PRD = \sqrt{\frac{\sum_{n=1}^{N}(x[n]-x'[n])^2}{\sum_{n=1}^{N}x[n]^2}} \quad (4)$$

where x[$n$] = Clean ECG signal, $y[n]$= Noisy ECG signal, $x'[n]$ = Reconstructed ECG signal using Denoising techniques and N = Number of ECG samples.

*3) Mean Square Error*

MSE is a metric that is used to evaluate the accuracy of denoising. The lower the value of MSE, the closer is the denoised signal to the original, hence better denoising. Let x(n) represent the clean ECG signal , x'(n) the denoised signal and N the length of the signal. Let 'n' represent the sample number, where n=1, 2, 3..N . MSE can be defined as [16],

$$MSE = \frac{\sum_{n=1}^{N}(x(n)-x'(n))^2}{N} \quad (5)$$

A small value of MSE indicates that the denoised signal is similar to the clean signal and is hence accurately denoised.

*4) Mean Absolute Error*

MAE measures the average magnitude of the errors in a set of predictions, without considering their direction. It's the average over the test sample of the absolute differences between prediction and actual observation where all individual differences have equal weight. The lower the value of MAE, the better is the denoising [16].

$$MAE = \frac{\sum_{n=1}^{N}|x(n)-x'(n)|^2}{N} \quad (6)$$

*5) Statistical measures*

Some of statistical measures include entropy, energy, skewness and kurtosis. These measures are also used to evaluate the performance of the denoising methods.

# III. RESULTS AND DISCUSSION

## A. Denoising of ECG signals

Figure 3 shows a typical ECG signal with baseline wandering. An attempt has been made to correct the baseline wandering by the following methods such as, ICA, IIR filter, MAF, ISSM values in R-R interval and LMS adaptive filter.

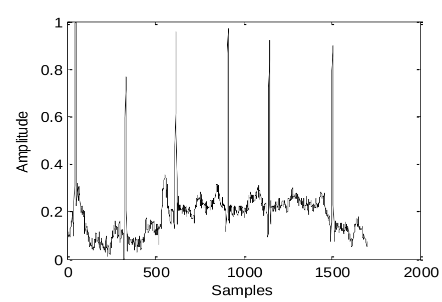



Fig. 3. Noisy ECG signal

Figure 4 (a) shows the denoised ECG signal using ICA. Similarly Figure 4 (b), (c), (d) and (e) shows the denoised ECG signal by IIR filter, MAF, ISSM values in R-R interval and LMS adaptive filter.

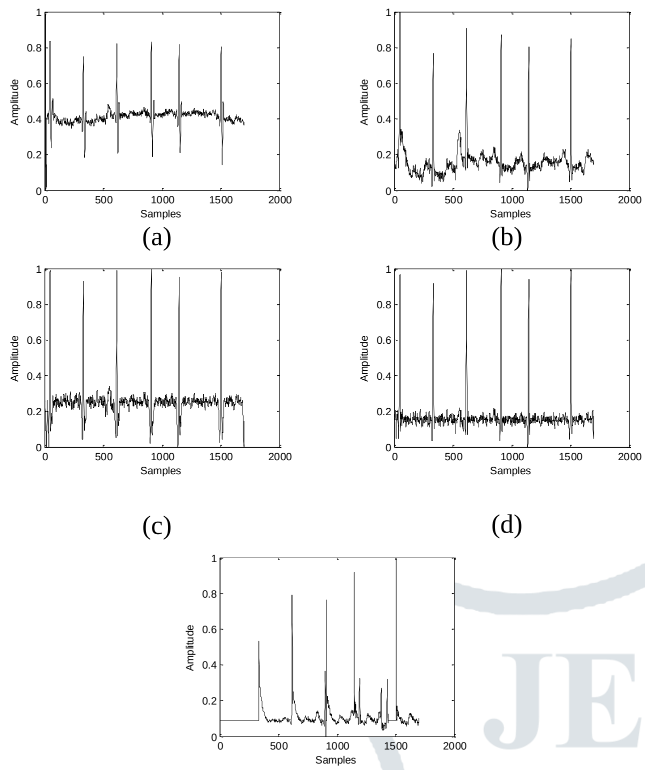



Fig. 4. Denoised ECG signal by (a) ICA (b) IIR (c) MAF (d) ISSM (e) LMS

Much of the baseline wandering issues are overcome in all the methods. It is difficult to find which method performs better in removing the baseline wandering problem as it may be subjective in nature. Also based on visual examination not much detailed conclusion could be arrived.

Hence in order to choose the best technique out of the five methods, performance measures are computed and are compared.

### B. *Performance Metrics*

The Table I shows the error measures such as MSE, MAE, SNR and PSNR determined for all five different techniques that are used in denoising the ECG signals.

TABLE I. MEAN AND STANDARD DEVIATION VALUES OF THE PERFORMANCE METRICS

| Method | Error measures | | | |
|---|---|---|---|---|
| | **MSE** | **MAE** | **SNR** | **PSNR** |
| **ICA** | 0.05 ± 0.02 | 0.19 ± 0.07 | 2.34 ± 5 | 13.78 ± 3.47 |
| **IIR** | 4e-3 ± 1e-3 | 0.06 ± 0.01 | 12 ± 0.60 | 23.43 ± 1.77 |
| **MAF** | 8e-3 ± 2e-3 | 0.07 ± 0.01 | 9.64 ± 2.30 | 21.06 ± 1.51 |
| **ISSM** | 11e-3 ± 6e-3 | 0.09 ± 0.02 | 8.36 ± 1.90 | 19.79 ± 2.38 |
| **LMS** | 12e-3 ± 4e-3 | 0.07 ± 0.01 | 7.71 ± 2.59 | 19.14 ± 1.47 |

Results demonstrate that from the error measures listed in Table I that both MSE and MAE are lower for IIR filter in denoising the ECG signal. It is observed that the SNR for ICA is 2.34 and the standard deviation is almost equal to 5. This shows the discrepancy of ICA in denoising the ECG signal.

It is also observed that SNR and PSNR values remain higher for IIR filter than other methods. Hence, it can be concluded that IIR filter method performs better in removing the baseline wandering in ECG signal.

The Table II shows the statistical measures such as entropy, kurtosis, skewness, energy and PRD determined for all the five denoising techniques.

TABLE II. MEAN AND STANDARD DEVIATION VALUES OF THE STATISTICAL MEASURES

| Method | Statistical measures | | | | |
|---|---|---|---|---|---|
| | **Entropy** | **Kurtosis** | **Skewness** | **Energy** | **PRD** |
| **ICA** | 5.22 ± 0.10 | 24.88 ± 7 | 2.57 ± 0.2 | 333 ± 51 | 66 ± 24 |
| **IIR** | 6.13 ± 0.20 | 16.23 ± 8 | 2.73 ± 1.5 | 118 ± 89 | 26 ± 3 |
| **MAF** | 5.41 ± 0.40 | 24.92 ± 8 | 3.38 ± 1 | 148 ± 37 | 33 ± 7 |
| **ISSM** | 4.6 ± 0.40 | 37.51 ± 9 | 5.25 ± 0.9 | 74 ± 34 | 47 ± 14 |
| **LMS** | 4.37 ± 0.72 | 45.2 ± 22 | 4.12 ± 2.1 | 108 ± 71 | 50 ± 22 |

It is observed from Table II that the entropy measure for IIR filter is high when compared to other techniques, which means that the information content present in the denoised ECG signal is more than other methods.

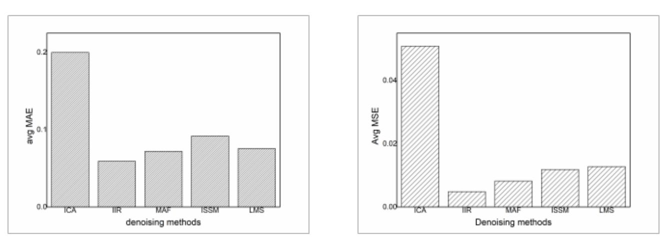
Similarly from the table it can be noted that the kurtosis value for IIR filter is less than other methods. This clearly states that the IIR method has gained all the required signals when filtering which means no interpolation of the signal is performed or no truncation is done while denoising.

Results demonstrate from the Table II that the skewness is not very high or not very low. Hence it can be concluded that IIR filter has not been biased in removing the wanted frequency components. The same is for the energy where it is moderate for IIR filter. The PRD for IIR filter is very less compared to other signal proving that the error present in the signal is lower than other methods.

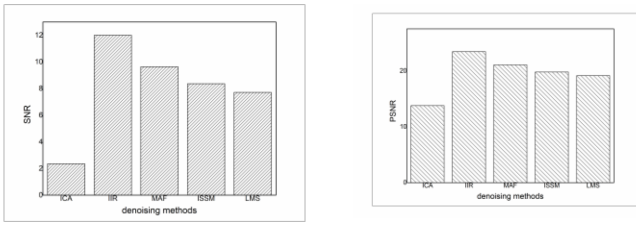
### C. *Graphical Representation of Performance Metrics*

The performance metrics is also graphically presentated as bar plots shown in Figure 5 and Figure 6. The error measures in Figure 5 and statistical measures are presented in Figure 6.

Figure 5 (a) shows the average value of MAE. Similarly Figure 5 (b), (c) and (d) shows the average MSE, SNR and PSNR.



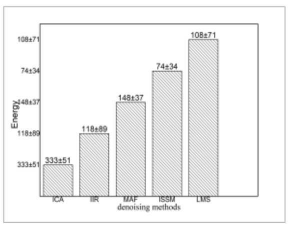

(a) (b)



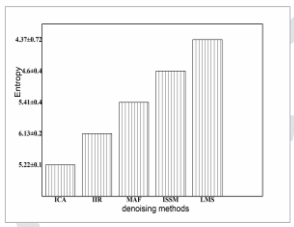

(c) (d)

Fig. 5. Error measures such as (a) MAE (b) MSE (c) SNR (d) PSNR

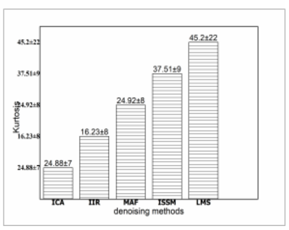
Figure 6 (a) shows the graphical representation of the measure energy for the denoised ECG signal. Similarly Figure 6 (b), (c), (d) and (e) shows the graphical representation of entropy, kurtosis, PRD and skewness computed for the denoised ECG signal.



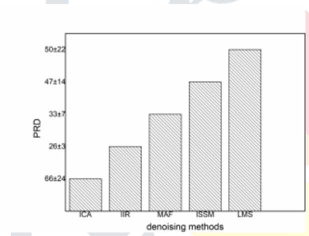

(a)



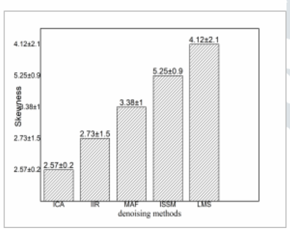

(b)




(c)




(d)




(e)

Fig. 6. Statistical measures such as (a) Energy (b) Entropy (c) Kurtosis (d) PRD (e) Skewness

Significant difference is observed for the IIR filters which leads to the conclusion that IIR filter suits best in removing the baseline wandering problem in the considered ECG signals.

## IV. CONCLUSION

The ECG signal is denoised to remove the baseline wandering, where the signals are not aligned with respect to base line. The five different techniques are used for preprocessing of the signals and their performances against various parameters are evaluated. Based on these measures the results demonstrate that the IIR filter is of best choice in removing the baseline wandering issue. It is observed that SNR and PSNR ratios are high and the error values such as MSE and MAE between the raw ECG and denoised signal is less. Hence the IIR filter is chosen as the best option for denoising the considered ECG signal in eliminating the baseline wandering.

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