NOISE REMOVAL FROM ECG SIGNAL USING VARIOUS FILTERS

Dissertation submitted in partial fulfillment of requirements of the degree of

MASTERS OF TECHNOLOGY

IN

ELECTRONICS & COMMUNICATION ENGINEERING

By

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May– 2017

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DECLARATION BY THE SCHOLAR

I hereby declare that the work reported in the M-Tech dissertation entitled **"NOISE REMOVAL FROM ECG SIGNAL USING VARIOUS FILTERS"** submitted at **Jaypee University of Information Technology, Waknaghat India,** is an authentic record of my work carried out under the supervision of **Dr. Meenakshi Sood**. I have not submitted this work elsewhere for any other degree or diploma.

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CERTIFICATE

This is to certify that the work reported in the M. Tech dissertation entitled **"NOISE REMOVAL FROM ECG SIGNAL USING VARIOUS FILTERS"** which is being submitted by **Bhawna Chandel** in fulfillment for the award of Masters of Technology in Electronics and Communication Engineering by the Jaypee University of Information Technology, is the record of candidate's own work carried out by her under my supervision. This work is original and has not been submitted partially or fully anywhere else for any other degree or diploma.

1/5/17

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ACKNOWLEDGEMENT

A dissertation cannot be completed without the help of many people who contribute directly or indirectly through there constructive criticism in the evolution and preparation of this work. It would not be fair on my part, if I do not say a word of thanks to all those whose sincere advice made this period a real educative, enlightening, pleasurable and memorable one.

First and foremost, I would like to express my deepest appreciation to my project supervisor, **Dr. Meenakshi Sood** for their gracious efforts and keep pursuits, which has remained as a valuable asset for the successful instrument in keeping my spirit high.

Finally, I am very much thankful to **God** for the shower of warm blessings and **my parents** for their moral support and continuous encouragement while carrying out this study.

Bhawna Chandel

Date: 01 May 2017

ABSTRACT

Electrocardiogram signal is noninvasive technique that has great importance in the detection of cardiac abnormalities. The analysis of ECG signal is preferred for conveying information as it preserves the electrical performance of heart. ECG signals are very sensitive and characteristics of ECG signals get contaminated due to different types of noise. In many of the biomedical applications, for real time heart monitoring system, it is necessary to remove the noise from ECG recordings to achieve faithful signals for further processing. In this thesis, various filters are used results to reduce and remove the effect of noise to get refined signal. The power spectral density and average power are performance metrics used before and after filtration. Adaptive filter is used for noise cancellation of ECG signal. Adaptive filter function is based on error minimization between input signal which is noisy ECG signal and its reference input. There are many adaptive algorithms such as Least Mean Square (LMS), Recursive Least Square (RLS), and Normalized Least Mean Square (NLMS) etc.

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ABBREVIATIONS

AV	Atria Ventricular
BPM	Beats Per Minute
CWT	Continuous Wavelet Transform
DWT	Discrete Wavelet Transform
ECG	Electrocardiogram
FIR	Finite Impulse Response
IIR	Infinite Impulse Response
LMS	Least Mean Square
MA	Muscle Artifacts
MSE	Mean Square Error
NLMS	Normalized Least Mean Square
PLI	Power Line Interference
PQRST	P,Q,R,S,T Wave of the heart beat
QRS	QRS Complex in ECG Signal
RLS	Recursive Least Square
SA	Sino Atrial
WT	Wavelet Transform

CHAPTER – 1

INTRODUCTION

1.1 Electrocardiogram (ECG)

Electrocardiogram (ECG) represents electrical activity of heart. In this electrodes are detected which are attached to the surface of the skin. ECG signal shows heart information and cardiovascular condition. ECG signal is used to measure the electrical activity is produced by polarization and depolarization of cardiac tissue and converted into waveform. This waveform measure the heart beat rate, size and position of chambers [1]. ECG belongs to five waves P, Q, R, S, T. ECG signal is mostly used biomedical signal. It records electrical pulses which are produce in the human heart at different parts of body by placing electrodes. ECG signals are sensitive. ECG signals get corrupted due to different type of noise. In many of the biomedical applications, it is necessary to reduce the noise from ECG recordings by filtering the signal. The power spectral density and average power are used for the comparison for before and after filtration using different filters. The amplitude of P-QRS-T wave holds useful information. The electrical wave is used for depolarization and repolarization. The ECG signal provides this information:

- heart position of human
- relative chamber size of chamber
- impulse origin
- propagation
- Drug effects on the human heart.

Filters techniques are used for reduce the noises which are presented on ECG signal. ECG signal detect and amplify the potential changes on the skin. ECG can be affected by voltage.

1.2 ECG Signal Generations:

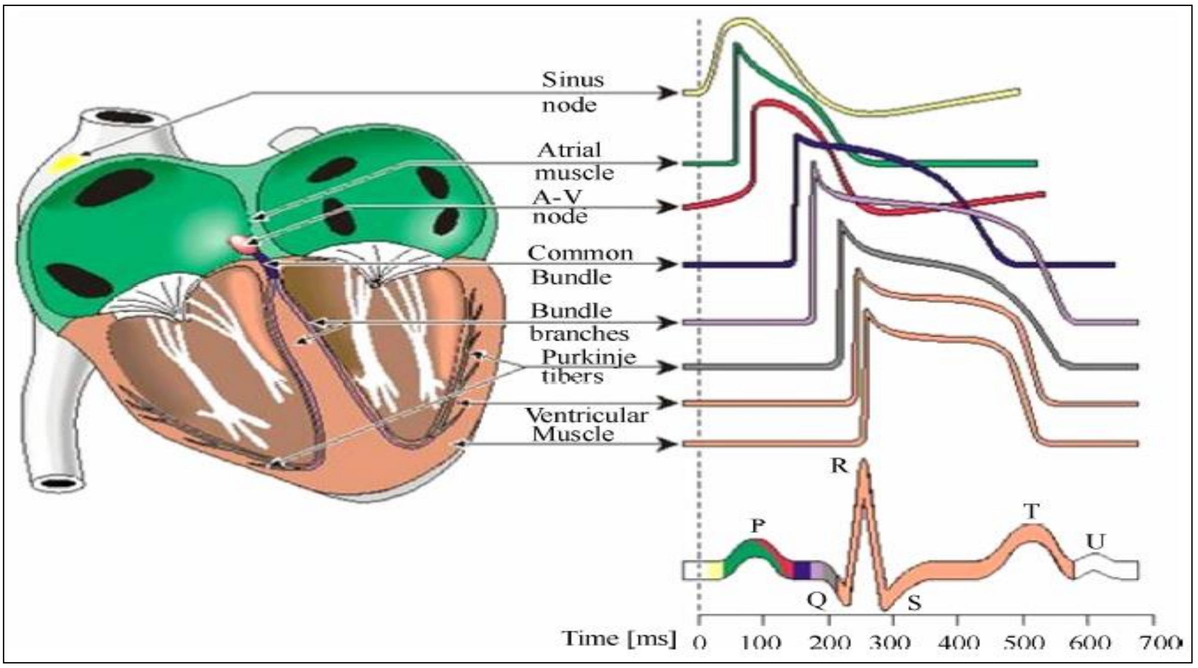

Figure 1.1: ECG pulse

It is divided into two halves that are left half and right half. It consists of arteries, veins, and capillaries. It has four chambers two at the top and two at the bottom. In human heart Sino Atrial node is the top chamber. The right ventricle is used to pump blood. Sino atrial (SA) node is the normal pacemaker of heart which is located in right atrium. Electrical impulse propagation through excitable tissue is achieved through a method known depolarization. Depolarization spreads from SA node across atria and results in the P wave. Purkinje fibers are terminal bundle branches. Fig. 1.1 represents the various chambers of the heart as describe.

1.3 ECG Waveform and its components:

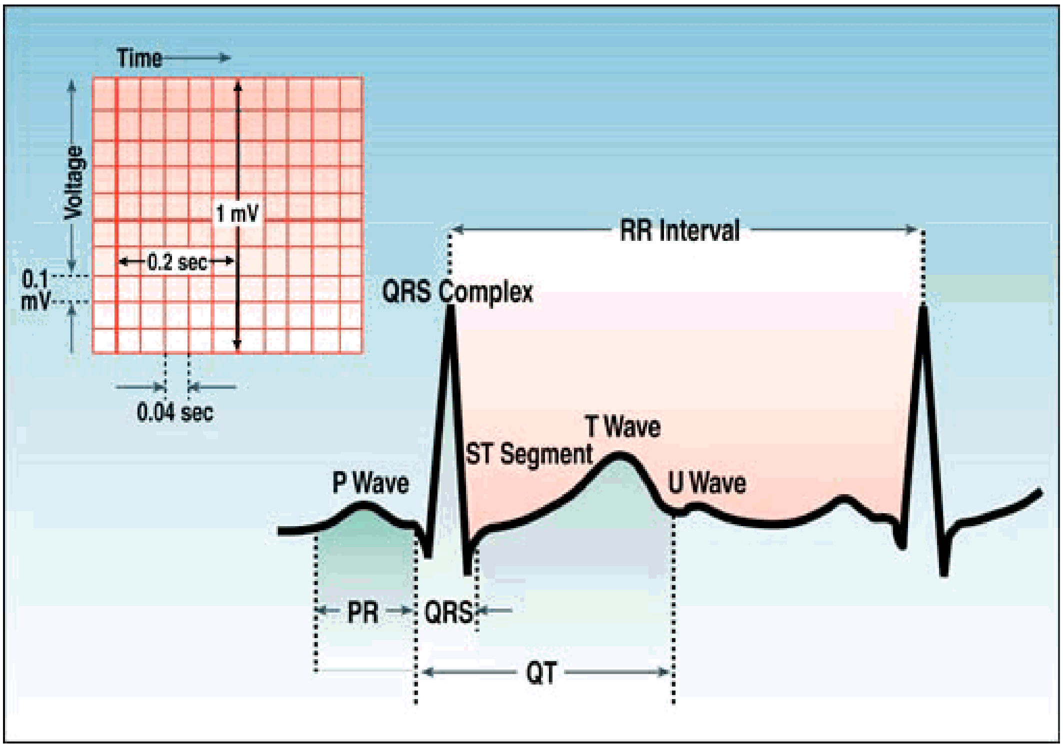

Figure 1.2: ECG Waveform

Each portion of a heartbeat spread a diverse sweep on the ECG. These sweeps may be negative and positive. ECG has five waves P-QRS-T wave. U wave is not always recorded in the ECG signal [2]. Brief description of the waves is given below and depicted in figure 1.2.

P Wave – The first small upward deflection of heartbeat is called P wave. Atrial depolarization is indicated by P wave. There flection of right atrial depolarization is initial portion of P wave and terminal portion P largely a reflection of left atrial depolarization.

Q Wave – After P wave, Q wave is any initial downward deflection. It represents the ventricle depolarization.

R Wave – After P wave, R wave is the first upward deflection. The R wave is identified on the ECG and indicates ventricular depolarization.

S wave – After R wave, S wave is the first negative deflection. It indicates the ventricular depolarization.

T Wave – The T wave indicates repolarization of the ventricles.

QRS Complex – It is used to observe muscle contraction rate in the heart and identify problems in the regularity of the heart rate. R wave is the highest point of the QRS complex. This is because it is changing with time.

1.4 Acquisition of ECG

ECG machines are monitored patient's heart rate. The electrical activity of lead is represented between the electrode and reference point. The clinical information is required for choice of location for the electrodes [3].

In ECG fine data for P wave is obtained from lead II and IV. In ECG signal leads I, II, aVL, V5, V6 are obtain from Q wave.

3-Lead ECG

3-lead ECG equipment is fine in all the ECG equipment's in which 4 electrodes are used for heart monitoring.

5-Lead ECG

5- Lead ECG consumes five electrodes in which 1 are used in chest and 4 are used in heart limb. It is commonly used in surgical operations.

12-Lead ECG

The 12-lead ECG consumes 10 electrodes, in which six are used 1 chest and 4 are used in limb.

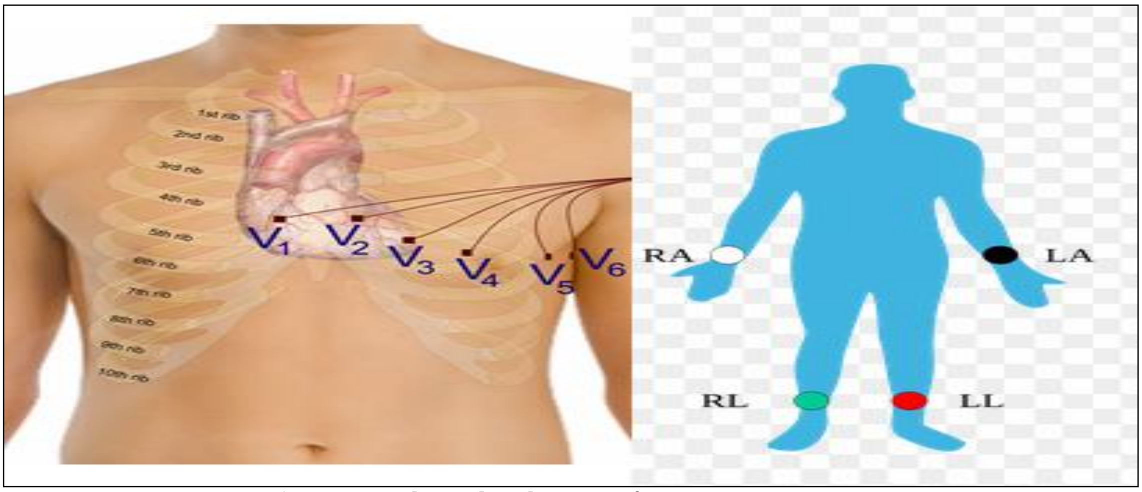

Figure 1.3: Electrodes placement for ECG measurement

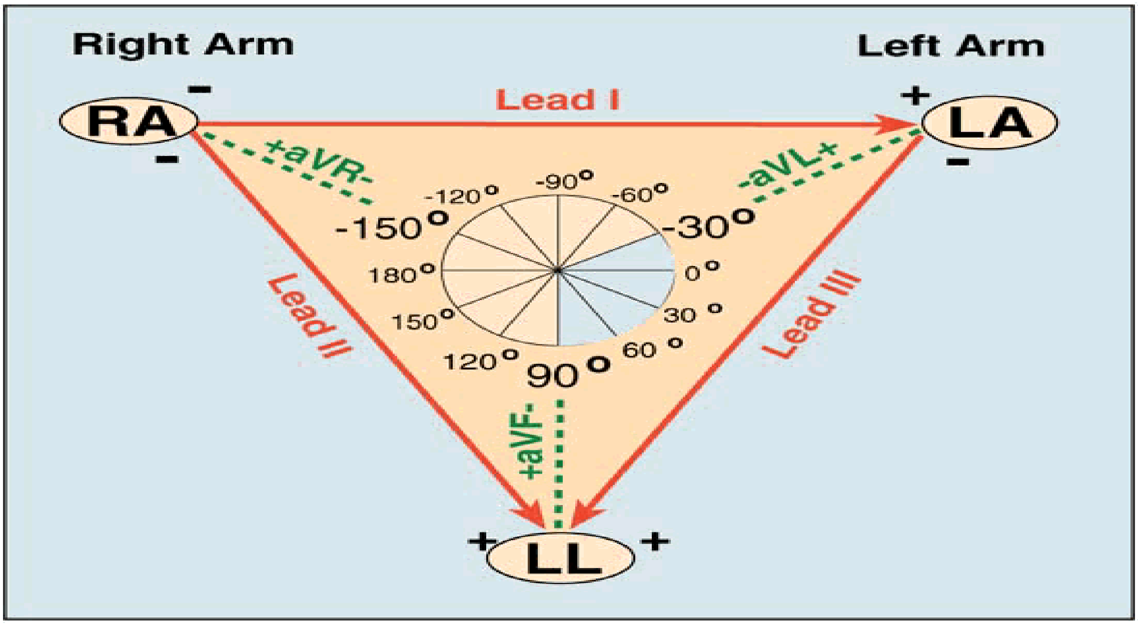

Figure 1.4: Einthoven equilateral triangle. RA and LA are the right and left arms and LL is the left leg.

Limb Leads:

Leads I, II and III are called limb leads. The combination of right arm, Left arm and Left leg point is called Einthoven equilateral triangle. Figure 1.4 represents the Einthoven equilateral triangle [4].

1.5 Outline of the work

The chapter 1 of the thesis explains basic of Electrocardiogram and Electrocardiogram signal. Electrocardiogram wave and its elements are mentioned. This chapter additionally explains the acquisition of Electrocardiogram.

The chapter 2 literature review is discussed.

In chapter 3 noises in ECG signal are discussed and also filters and window techniques are discussed.

In chapter 4 continuous and discrete wavelet transform are discussed and also mother wavelet and wavelet selection for QRS detection and Haar Wavelet is discussed.

Chapter 5 gives the results of the thesis.

Chapter 6 gives the conclusion of the thesis.

CHAPTER – 2

LITERATURE REVIEW

2.1 Literature Review

The first ECG recording is made by Willem Einthoven in 1895 and P, Q, R, S, T waves are also first define by Willem Einthoven in 1895. He first published his normal and abnormal ECG recording in 1906.

The literature review of the research work provides an overview of the technical appearance of various researchers on the topic of noise removal from ECG signal using various filters. ShahanazAyub and J P Saini [5] proposed technique supported signal process correlation technique to search out whether or not the ECG is traditional or abnormal. Few of abnormal ECG referred to as heart condition. The correlation analysis is the simple and best method to find the ECG is normal or abnormal. S.Karpagachelvi et al. [6] Described an approach for ECG feature extraction. ECG has been comprehensively used for identification several cardiac diseases. The feature ejection tool is used for fast ejection of element from ECG signal. Poonam Sao et al in [7] proposed artificial neural network as a classifier for identifying the abnormalities of heart disease. Artificial neural networks are biologically inspired networks that are useful in application areas such as pattern recognition, classification. Various supervised and unsupervised artificial neural network model have been proposed in the feature extraction and classification. Qi Haibing et al in [8] described ECG signal is denoise process. This method has a fine and sweeping effect for the ECG signal. Abdul Qayoom Bhat et al. [9] discussed 12 lead ECG systems in which 10 are used on the patient's body. In this low acquisition system is used with increased energy. Rajesh D. Wagh et al. [10] used ECG to diagnosis the heart disease. ECG signal contains various noisy signals which can be reduced by various filter techniques. Wilfried Philips [11] formulated time wraped polynomial filter, a new interval-adaptive filter for removing stationary noise from non-stationary biomedical signals. The interval-adaptive time wraped polynomial filter is a new method for adaptively removing noise from biomedical signals.

Yatindra Kumar et al. [12] concluded that ECG signal is sensible, when small noise is miscible with original signal characteristics of various signal changes.

CHAPTER – 3

METHODS AND TECHNIQUES

3.1 Noise in ECG signal: There are different types of noise present in ECG few are discussed below.

3.1.1 Power line interference.
3.1.2 Base line drift with respiration.
3.1.3 Electrode contact noise.
3.1.4 Muscle contraction.
3.1.5 Motion artifacts Noise in ECG signal

3.1.1 Power line interference–Power line interface lies in 50/60Hz pickup and harmonics [13].

3.1.2 Base line drift with respiration- It can be represented by a sinusoidal component at the frequency of respiration that can be removed by decomposing the signal.

3.1.3 Electrode contact noise -Electrode contact noise is associate interference caused by loss of contact between the conductor and skin. The loss of contact may be permanent, or may be discontinuous. The length of noise is one second.

3.1.4 Muscle contraction– Muscle Contraction noise generates mv level potentials having a sampling frequency of 360Hz.

3.1.5 Motion artifacts- Motion artifacts are caused by changes in the electrode-skin impedance with electrode motion [14]. The filtering of signal is not easy; hence it leads to unrecognizable QRS complex.

The electrocardiogram signal corrupted by these noises ends up in wrong judgment. Therefore, to scale back and take away the noises, digital filters area unit employed in medical specialty signal process. Analog filters can even be accustomed take away these noises, however nonlinear part shift is introduced by them [15].

3.2 Filters

Filter is a device that removes or reduces some unwanted components from a signal. Low pass filters on the ECG are used to remove highest frequency muscle artifacts and external interference. Digital filters are more accurate then analog filters. There are two types of filter response

3.2.1. Finite Impulse Response (FIR)

3.2.2. Infinite Impulse Response (IIR)

3.2.1. FIR FILTER: FIR filters have the impulse reply of finite period and might be enforced while not feedback [16]. Window techniques utilized in FIR filter are:-

(A) *Rectangular window :*- The window is given by

$$\omega_R(N) = \left\{ 1,\ for\ |N| \leq \frac{M-1}{2} \right\}$$

(B) *Kaiser window:*- To obtain original stop band attenuation, Kaiser window is used

$$\alpha = \begin{cases} 0; \beta \leq 21 \\ 0.5842(\beta-21)^{0.4} + 0.07886(\beta-21); 21 < \beta \leq 50 \\ 0.1102(\beta-8.7); \beta > 50 \end{cases}$$

(C) *Hamming window:*- The hamming window function can be expressed as

$$\omega(n) = \begin{cases} 0.54 - 0.46\cos\frac{2\prod n}{N-1}, 0 \leq n < N-1 \\ 0, otherwise \end{cases}$$

(D) Hanning window :- It can be import by

$$\omega(n)=\begin{cases}0.54-0.46\cos\dfrac{2\prod n}{N-1}, 0\le n<N-1\\ 0, otherwise\end{cases}$$

(E) *Blackman window:-* It can be obtained by

$$\omega_B(n)=\begin{cases}0.42-0.5\cos\dfrac{2\prod n}{N-1}+0.08\cos\dfrac{4\prod n}{N-1}; 0\le n\le N-1\\ 0, otherwise\end{cases}$$

3.2.2. IIR FILTER: IIR filters have the infinite impulse reply [17]

i. *Butterworth filter:* The Butterworth low pass filter is given as

$$|\mathrm{H}(j\Omega)|=\frac{G}{\left[1+\left(\dfrac{\Omega}{\Omega_C}\right)^{2N}\right]^{1/2}}$$

Where G is gain and ΩC cut off frequency ε is a constant.

ii. *Inverse Chebyshev filter* The magnitude response is given as

$$\mathrm{H}(j\Omega)|=\frac{G}{\left[1+\in^2 C_N{}^2\left(\dfrac{\Omega}{\Omega_C}\right)\right]^{1/2}}$$

Where G is gain and ΩC is cut off frequency.

iii. *Chebyshev filter:-* The Chebyshev filter can be expressed

$$|\mathrm{H}(j\Omega)|=\frac{\in C_N\left(\Omega_Z/\Omega_C\right)}{\left[1+\in^2 C_N{}^2\left(\dfrac{\Omega_Z}{\Omega}\right)\right]^{1/2}}$$

Ω cut off frequency ε is a constant [18].

3.2.3 Adaptive Filtering:

Adaptive filter is study of non-system and based on the recursive algorithm application [19]. The adaptive filter is basic fundamental of Mean Square Error (MSE). MSE is difference between signal output and reference signal. To minimize error, Least Mean Square (LMS) is used [20].

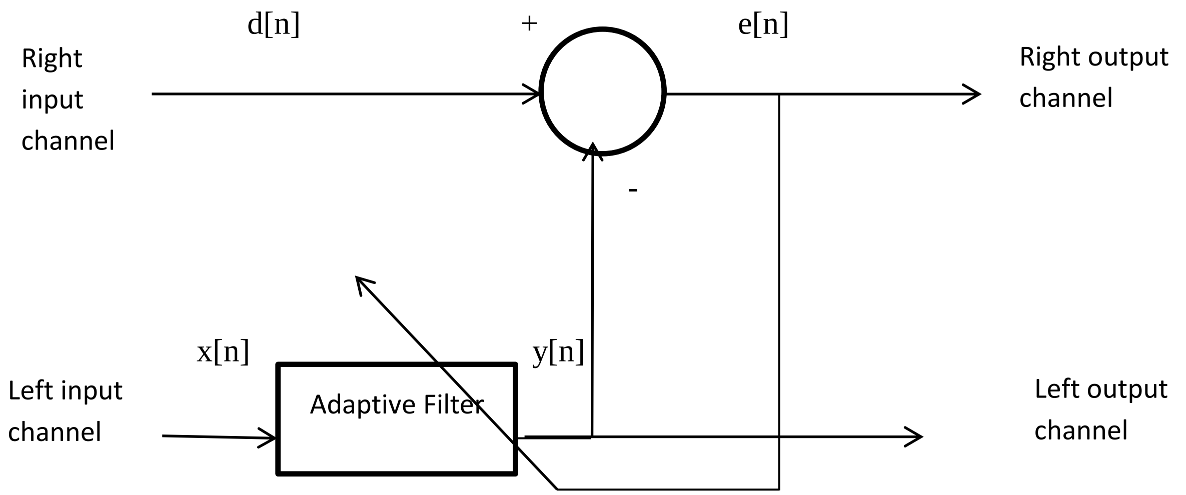

Figure 3.1: Adaptive Filter

LMS is used to reject noisy signal due to minute step size parameter. LMS adaptive filter reduce noise and obtains desired output with the help of adapting filter coefficients.

Consider a Least Mean Square filter where L is length

W(n+1) = W(n) +μ x(n) e(n) …………. (1)

Where W(n) is vector of nth term

x(n) = [x(n) x(n-1) x(n-L+1) ………… (2)

e(n) = d(n) – w(n) x(n)

d(n) is desired response

W(n+1) = W(n) + μ(n) x(n) e(n…...(3)

$$W(n+1) = W(n) + \left[\mu / \left(\mathrm{P} + \mathrm{X}^t(n)\Phi(n)\right)\right]\mathrm{X}(n)e(n) \quad \text{......................... (4)}$$

Variable step can be written as:

$$\mu(n) = \mu / \mathrm{P} + \mathrm{X}^t(n)\mathrm{X}(n) \quad \text{.................. (5)}$$

The NLMS can be expressed as:

W(n+1) = w(n) + μ(n) x(n) sgn {e(n)} (4)

Adaptive filter compares two parameters LMS and NLMS algorithm. In NLMS algorithm SNR is good as compared to LMS algorithm. LMS algorithm is mostly used for channel equalization, eco cancellation and noise cancellation. RLS algorithm is computationally complex. LMS is mostly used for filtering the signal.

Least mean squares (LMS): The LMS is belongs to the Wiener filter and minimizing the error criterion and does not rely on cross-correlations or auto-correlations. LMS filter is also used for minimize cost function. In this cost function is mean square error. In this no matrix operation is used. LMS algorithms are less complex than the RLS algorithms. The input matrix, or the matrix of the input sign is spread eigen value and affect the speed of convergence resulting in adaptive filter.

Normalized least mean squares (NLMS): The NLMS algorithm is standard and modified form LMS algorithm. The adaptive filter step size can improve by the convergence speed. The NLMS algorithm have faster converging algorithm as comparison to the LMS algorithm. The problem of LMS algorithm is that its input of scaling is sensitive. The LMS algorithm is variant of the NLMS and problem is solved by normalizing the power of the input. Adaptive filter is used for noise cancellation with the help of variation step size can be reduced. In adaptive filter Normalized Least Mean Square gives lowest mean square error.

Recursive least square (RLS) is an adaptive filter in which coefficients are find recursively and minimize a weighted linear least squares cost function which is relating to the input signals.

The RLS algorithm has high convergence speed and less steady state error as comparison to LMS and NLMS algorithm.

3.2.4 Notch Filtering:

Notch filter is also known as band stop filter with a narrow stop band frequency, in which all frequencies passes except those in stop band centered frequency and flat at all frequencies except stop band frequency and have greatest rate of change at the center frequency.

It can be used for reduce PLI. In notch filter Stationary means in which amplitude does not vary as well as frequency and phase. In second order notch filter, the band width is denoted by Δf, notch frequency is denoted by fo and Quality factor (means Q factor)

$$Q = fo/\Delta f$$

The Q factor is used to decrease in order to increase attenuation level. If attenuation level is high then power line interface is removed.

It affects location on -3db points. ECG processing for single notch filter, single notch filter cancels 60 HZ power frequency in ECG signal. In each beat there are 500 samples. Notch filter is used where unwanted frequency is present. In many applications notch filter is used where frequency components are eliminated. When the input frequency is higher than cutoff frequency the output is zero the net output is equal to output of high pass filter.

3.2.5 Butterworth Filtering:

The Butterworth filter is signal processing filter used to designed flat frequency response in pass band. The transition between the stop-band and pass-band of a first order filter with cut-off frequency $\omega c = 1/T$ the slope of 20 dB per decade of frequency change. For better selectivity, cascade a set of n such first order filters to form an nth order filter with a slope of 20n dB per decade. In Butterworth Low-pass filter provides a constant output response from DC and rejects all signals above that frequency. Butterworth filter there in no variation. The magnitude response low pass Butterworth filter is given by

$$|H(\Omega)|^2 = \frac{1}{1+\left[\dfrac{\Omega}{\Omega C}\right]^{2N}}$$

Where Ωc is cut off frequency

$|H(\Omega)|^2$ is the magnitude of low pass filter

N is order of Butterworth filter

3.3.6 Chebyshev Filter:

Chebyshev filter are digital and analog filter in which steeper roll off and pass band ripples are present. The property of chebyshev minimizes the error between idealized and actual filters. It is made up of sellen key circuits. It used as operational amplifier.

The Chebyshev implementation offers a far vessel roll-off, however has ripple within the pass band, therefore isn't any use in audio systems. These area units the foremost common Chebyshev filters. It's the steepest roll-off however exhibits in-band ripples. The kind two Chebyshev filter may additionally be called the inverse Chebyshev. It's less usually used than the kind one filter as a result of it doesn't reel off as quick, and additionally needs a lot of elements. However, its huge advantage is that it's no ripple within the pass-band, however will have what's termed equi-ripple within the stop band.

CHAPTER – 4

WAVELET TRANSFORM

4.1 Wavelets and Wavelet Transform:

Wavelets: Wavelets is mathematical equipment which can be used to reduce information from various data type [21]. For non-stationary signal it is powerful tool. In time interval its energy is concentrated. Different frequencies can be used tool to perform mathematical decomposition. The wavelet works on time domain representation [22].

Wavelet Transformation: A wavelet series is a complex and real value function. Wavelet transform are two types.

4.2Continuous Wavelet Transform:

In the continuous wavelet transform, finite energy of signal is extended on a continuous frequency band [23]. The wavelet transform of a continuous time signal is defined by x(t)

$$\mathrm{T}(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{\infty}x(t)\psi^{*}\left(\frac{t-b}{a}\right)dt \qquad \text{……………………………………... (4.1)}$$

Where $\psi^{*}(t)$ is the conjugate of the function

$$\mathrm{E}=\int_{-\infty}^{\infty}|\Psi(t)|^{2}\,dt<\infty \qquad \text{……………………………………………. (4.2)}$$

$$\Psi(\omega)=\int_{-\infty}^{\infty}\Psi(t)e^{-j\omega t}dt \qquad \text{………………………………………………... (4.3)}$$

:

$$C_{g}=\int_{-\infty}^{\infty}\frac{|d\omega|^{2}}{\omega}d\omega<\infty \qquad \text{………………………………………………. (4.4)}$$

It shows wavelet has no zero frequency components, that is Ψ (0)=0 where C_g is called 'Admissible constant'.

The chosen wavelet depends on C_g value. For complex wavelet, the Fourier transform must be both the real and hidden for negative frequencies. The total energy in the signal may be found from wavelet transform as follows:

$$\mathrm{E} = \frac{1}{C_g}\int_{-\infty}^{\infty}\int_{0}^{\infty}\frac{1}{a^2}|\mathrm{T}(a,b)|^2\, dadb \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (4.5)$$

4.3 Discrete Wavelet Transforms:

Discrete Wavelet Transform which transforms a discrete time signal to a discrete wavelet representation. It provides the complete information for examine and synthesis.

DWT can be written as:

$$\mathrm{T}_{m,n} = \int_{-\infty}^{\infty} x(t).\Psi_{m,n}(t)\,dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4.6)$$

The signal coefficient can be written as m and n form

$$S_{m,n} = \int_{-\infty}^{\infty} x(t).\Psi_{m,n}(t)\,dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4.7)$$

$$x_{0(t)} = x_M(t) + \Sigma_{m=1}^{M} d_m(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.8)$$

$$d_m(t) = \Sigma_{n=0}^{M-m} \mathrm{T}_{m,n}\Psi_{m,n}(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.9)$$

$$x_m = x_{m-1}(t) - d_m(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... (4.10)$$

4.4 Mother Wavelet:

Mother wavelets Ψ(t) are to be select according to their characteristics. Wavelets which are used for CWT are defined by mathematical functions. Wavelet which are characterized by individual filter bank, and used for DWT. Some wavelet can be describing by two ways and can be used for both types of transform, but in some cases there is only one possibility [24]. The CWT is calculated for all values of s the wavelet will dilate is s increases and compresses when s is decreased.

- The wavelet is multiplied with the signal and integrated time.
- The above step normalizes the energy so that the transformed signal has same scale.
- The wavelet at scale S = 1 is then shifted to the right by t and above steps are repeated until the wavelet reaches the signal [25].

4.5 Wavelet Selection for QRS Detection:

QRS has the very best slope and contains a characteristic form and also the event is localized in time. If the section shift is linear the form of signal is maintained. Time localization is vital as a result of the graphical record events are transient. Spline rippling could be a bi-orthogonal rippling. The primary derivatives of smoothing functions and symmetrical. Leads to the frequency response have higher order of spline rippling .

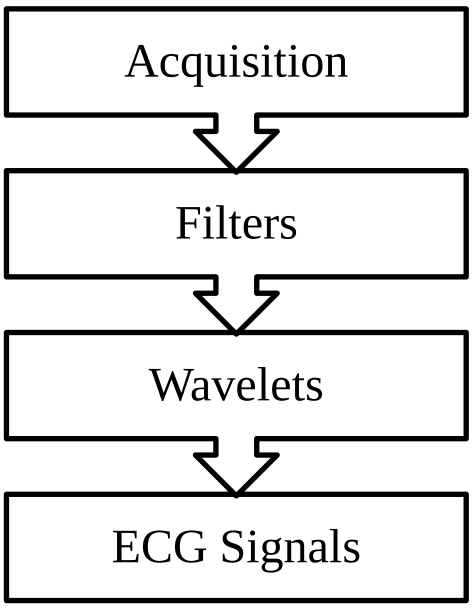

Figure 4.1: Flowchart

At high frequency Wavelet transform provides good time resolution. It provides efficient localization in both frequency and time domain. To extract approximation coefficient the discrete wavelet transform is applied on complex ECG signal. The original signal is transformed using predefined wavelet. These wavelets are orthogonal, orthonormal, scalar or multi wavelets [26]. Wavelet analysis allow the use of long time interval where more precise low frequency information and shorter regions. A wavelet time limited wave chosen as the "mother wavelet". This mother wavelet is limited in time and frequency.

4.6 Haar Wavelet:

The Haar Wavelet is a sequence square-shaped functions that kind a wavelet family [27]. Wavelet associate to Fourier analysis that permits a target operate over an interval to be delineated in terms of orthonormal basis.

The Haar sequence is recognized in wavelet basis and used as a teaching example. The Haar wavelet is simple wavelet. Disadvantage of Haar wavelet is that it is not continuous.

The Haar transform has the following properties

1. There is no requirement for multiplications. It needs only additions and there are several components with zero value in the Haar matrix, thus there is short time computation. Haar wavelet is quicker than Walsh transform, and matrix consists of +1 and −1.
2. Same Input and output length. The length should be a power of 2.
3. It can be used to study the feature of signals. The orthogonal property of the Haar function, input signal can be analyzed in frequency elements.

Analysis to harmonic analysis that permits a target performs over an interval to be portrayed in terms of an orthonormal basis [28]. The Haar sequence is recognized in rippling basis and used as a teaching example. The Hare rippling is straight forward rippling.

Disadvantages:

1. There is no multiplication. There square measure several parts with zero with in the Haar matrix, therefore there is short time computation. Haar rippling is quicker than walsh remodel.

2. Same input and output length. The length to be influence in 2.

3. The orthogonal property of Haar perform, signal is analyzed in frequency elements.

CHAPTER – 5

RESULTS AND DISCUSSION

The input ECG signal is obtained from physionet (https://physionet.org/cgi-bin/atm/ATM).

5.1 Apnea ECG Database - Record apnea-ecg/a12 is taken and length is 3462000 sample intervals, sampling frequency 100 Hz. Gain is 200 adu/mv.

The plot of normal ECG signal before processing is shown in figure 5.1

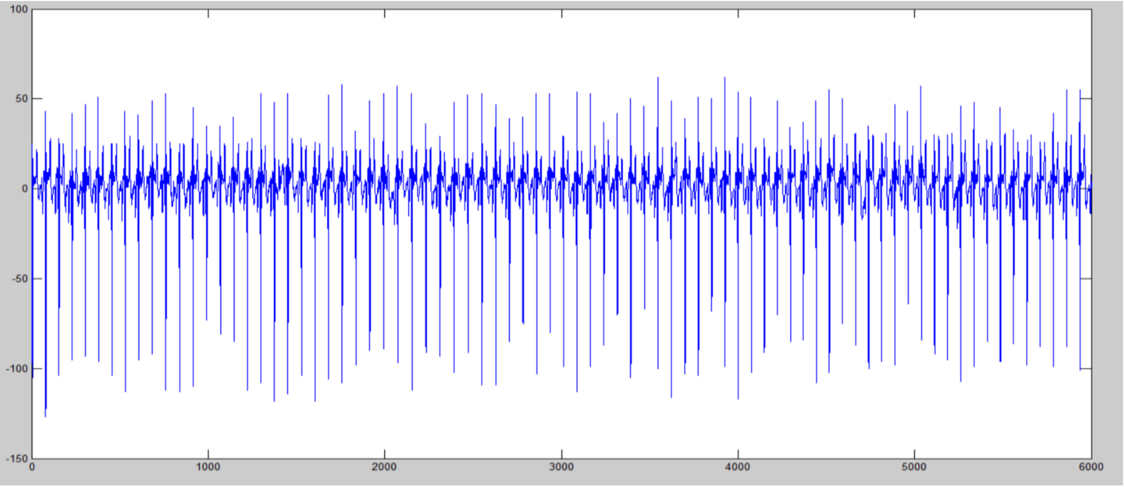

Figure 5.1: ECG original signal

Figure 5.2 shows the interval time series of apnea database

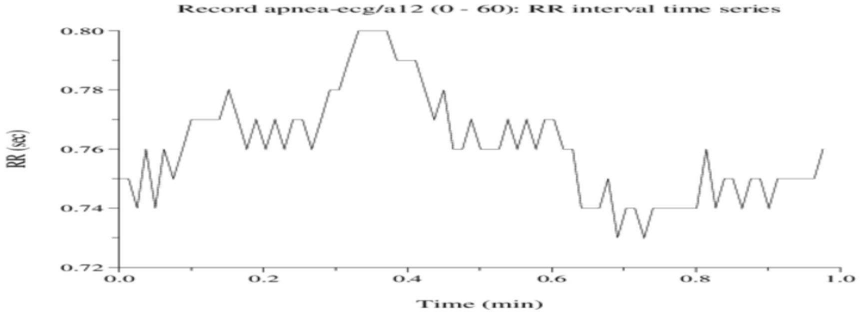

Figure 5.2: RR Interval Time Series

The RR interval histogram is shown in figure 5.3

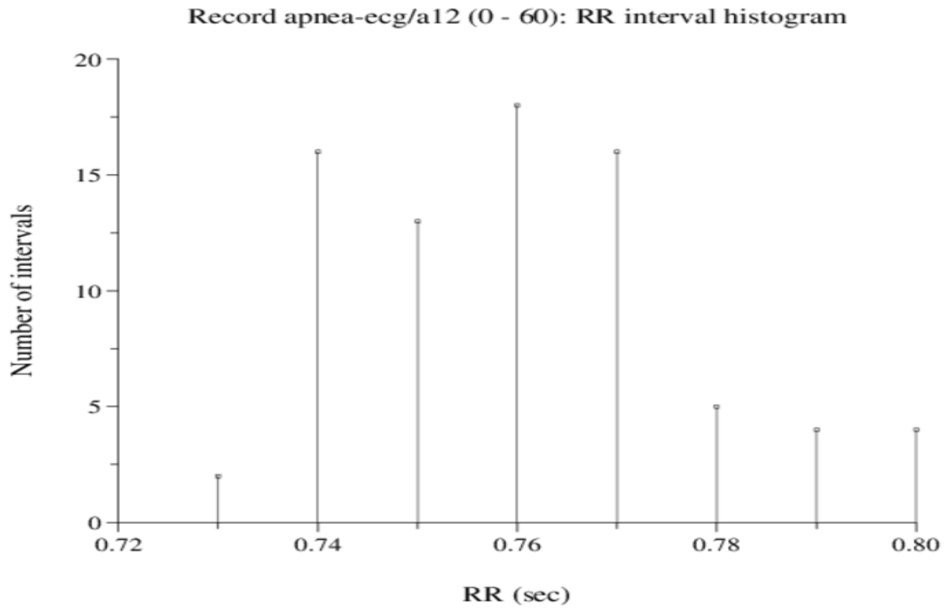

Figure 5.3: RR Histogram

The waveform apena ECG is shown in figure 5.4

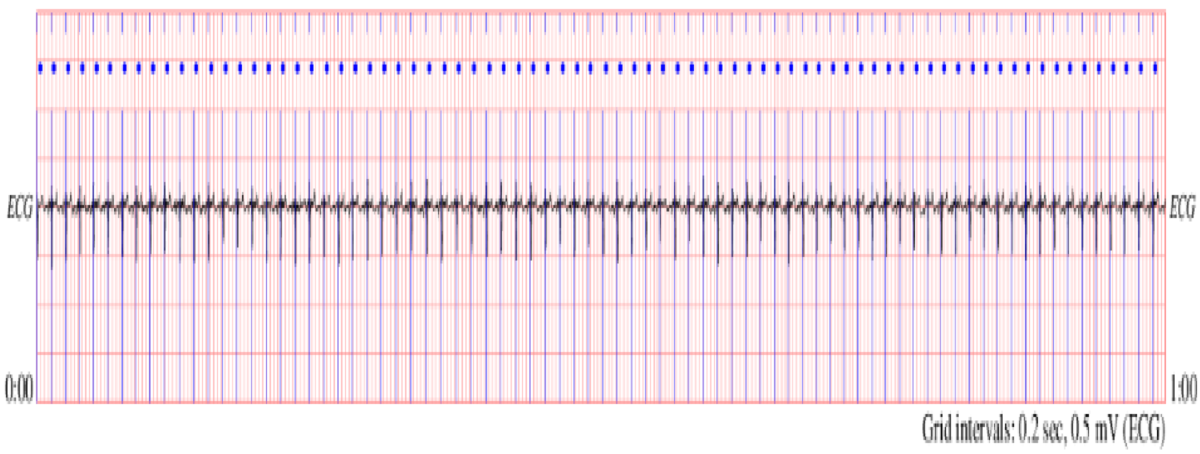

Figure 5.4: Waveform

5.2 MIT Arrhythmia Database - Record mitdb/100 is taken and length is 650000 sample intervals, sampling frequency 360 Hz. Gain is 200 adu/mv and baseline 1024.

The plot of normal ECG signal before processing of MIT arrhythmia database is shown in figure 5.5

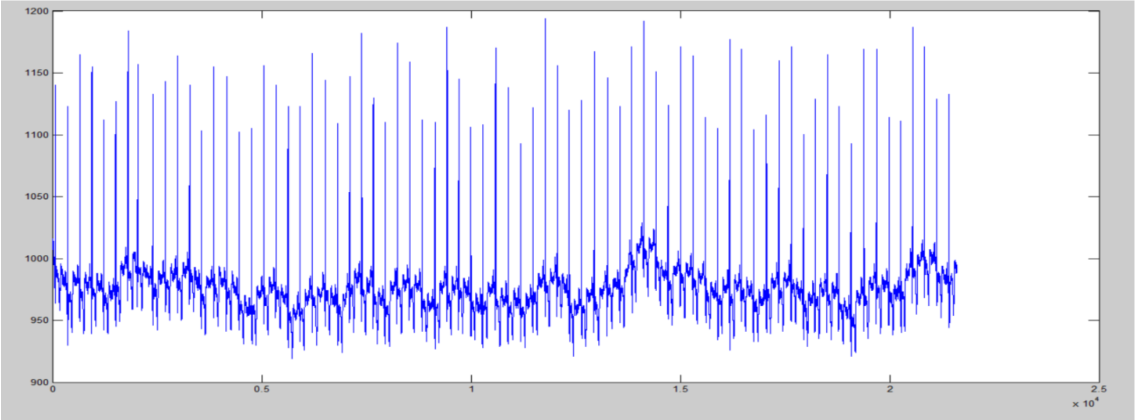

Figure 5.5: ECG original signals

The RR interval time series of MIT arrhythmia is shown in figure 5.6

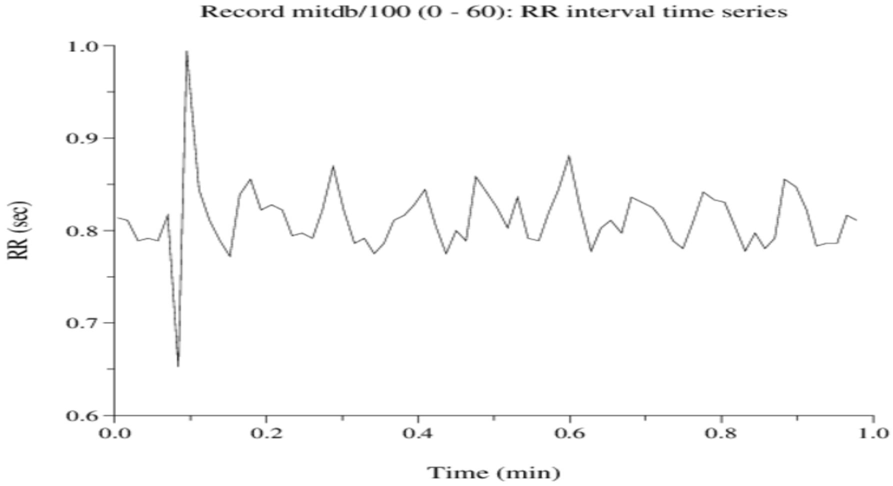

Figure 5.6: RR Interval Time Series

The RR interval histogram of MIT MIT arrhythmia is shown in figure 5.7

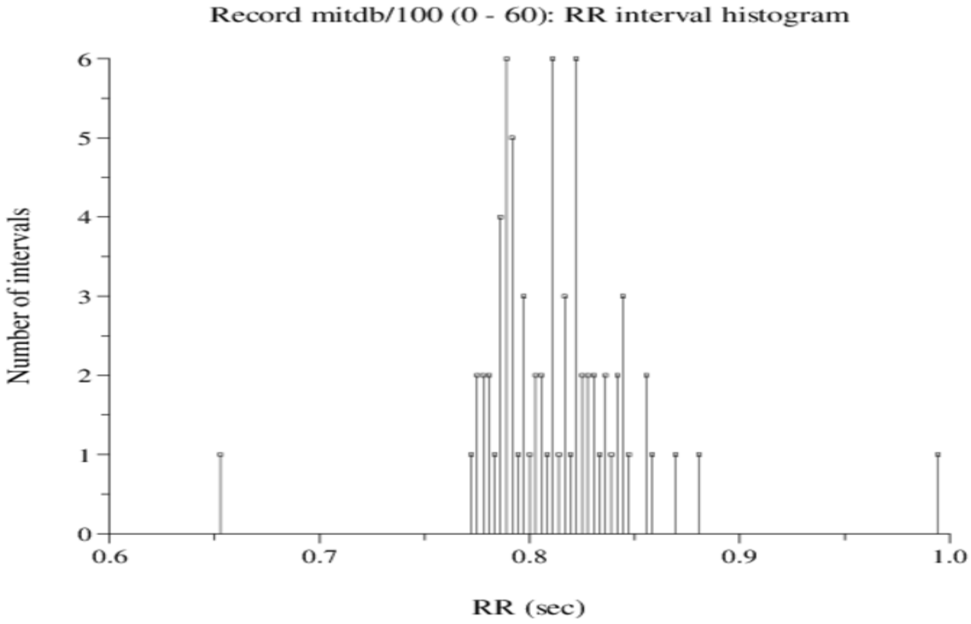

Figure 5.7: RR Histogram

The waveform MIT arrhythmia is shown 5.8

Figure 5.8: Waveform

5.3 MIT Noise Stress Test Database - Record nstdb/118e00 is taken and length is 650000 sample intervals, sampling frequency 360 Hz. Gain is 200 adu/mv and baseline 1024.

The plot of normal ECG signal before processing MIT noise stress database is shown in figure 5.9

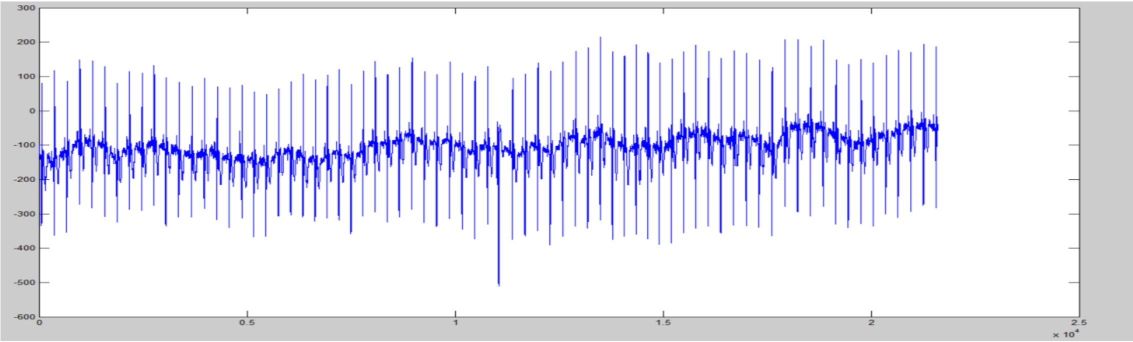

Figure 5.9: ECG original signal

The RR interval time series MIT noise stress database is shown in figure 5.10

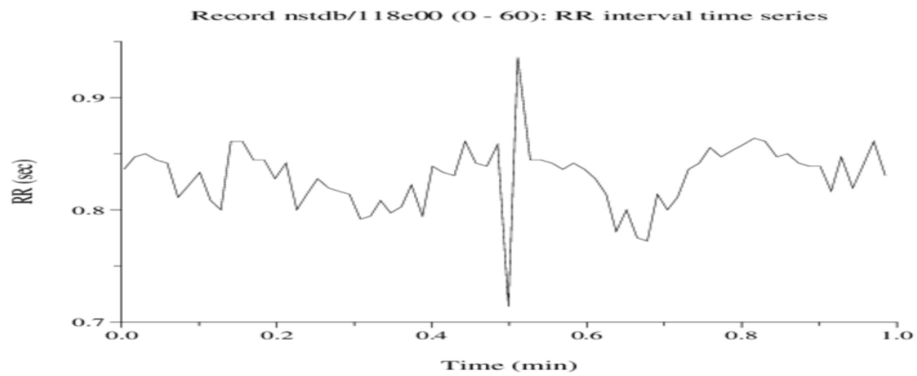

Figure 5.10: RR Interval Time Series

The RR interval histogram of MIT noise stress database is shown in figure 5.11

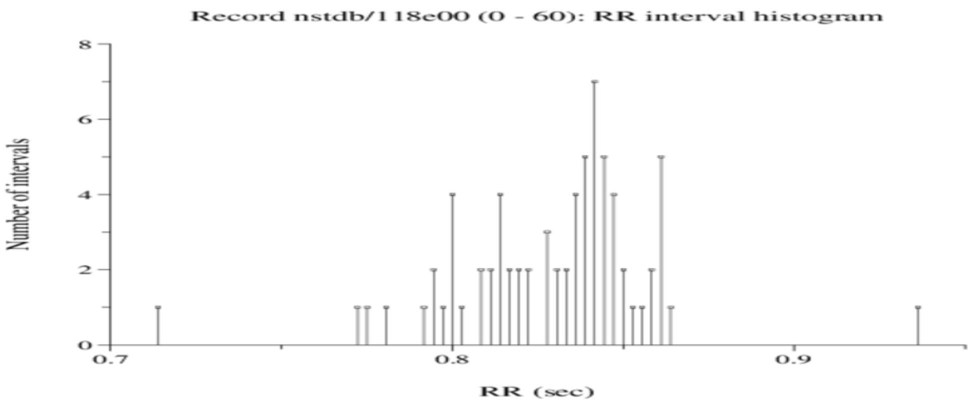

Figure 5.11: RR Histogram

The waveform MIT noise stress database is shown 5.12

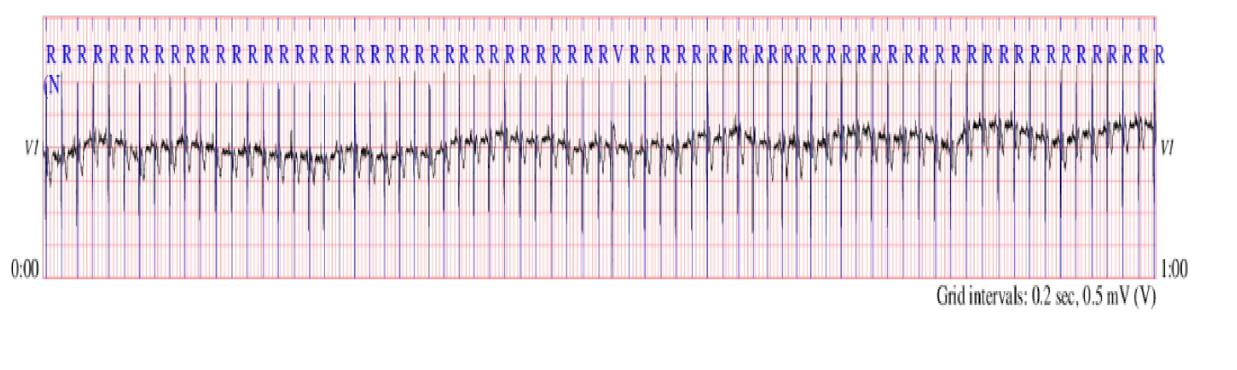

Figure 5.12: RR Waveform

MIT noise stress database Original ECG signal:

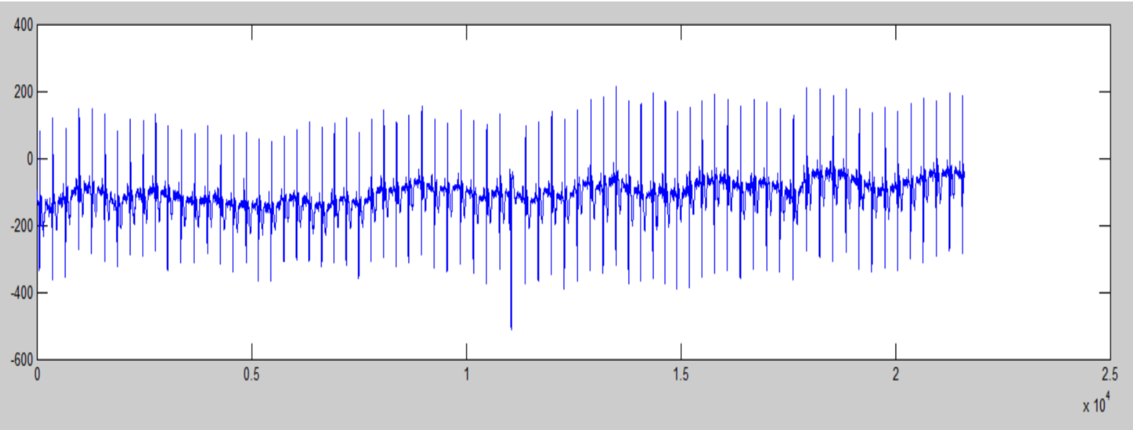

Figure 5.13: Original Signal

Notch Filtered signal

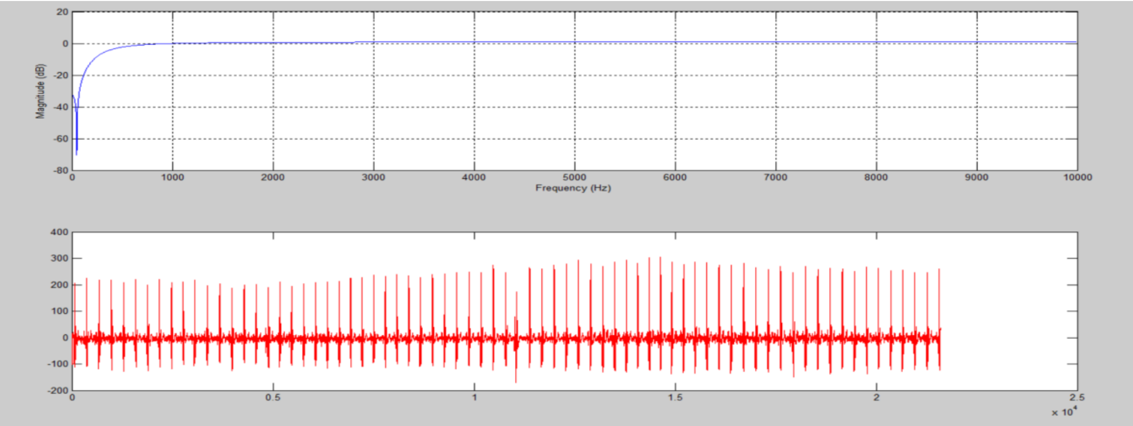

Figure 5.14: The notch filtered ECG signal.

5.4 Butterworth Filter

In figure 5.15 first ECG signal is generated and white noise is added in it and add ECG waveform and noise.

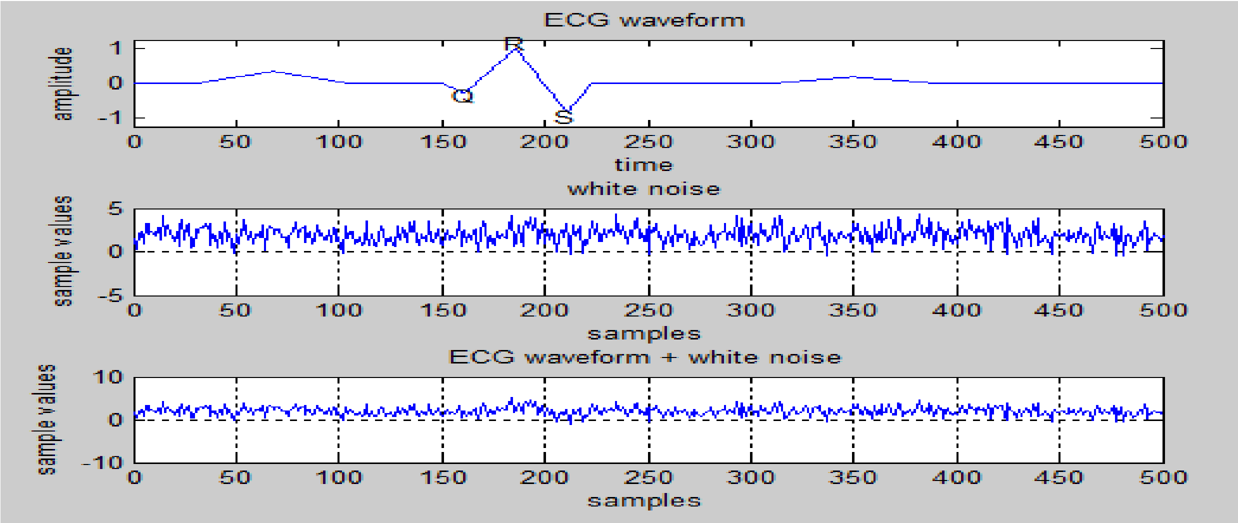

Figure 5.15: Butterworth ECG waveform and noise

In figure 5.16 shows noisy ECG signal and filtered ECG signal.

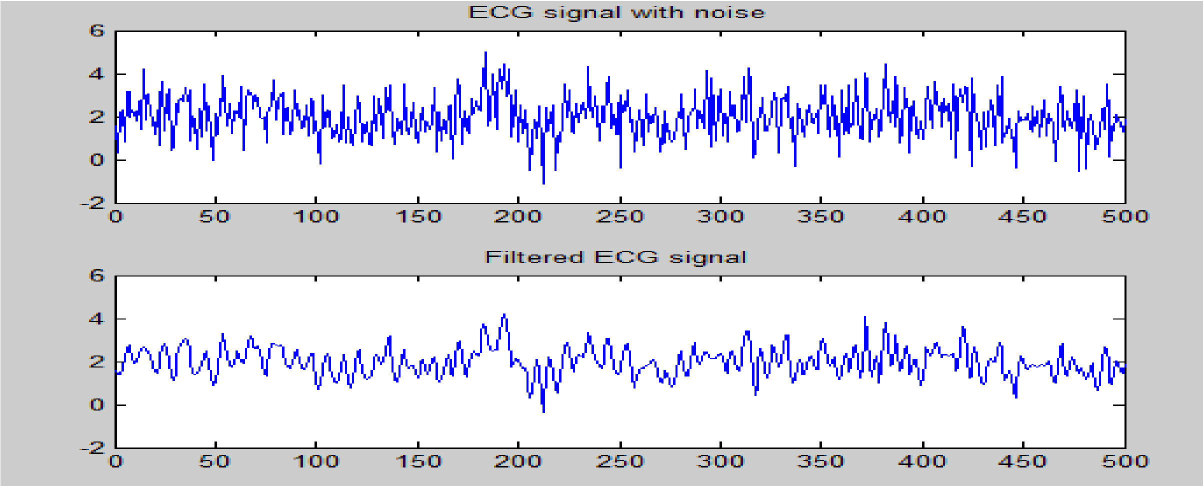

Figure 5.16: ECG signal and filtered ECG signal.

In figure 5.17 shows the Butterworth low pass coefficient

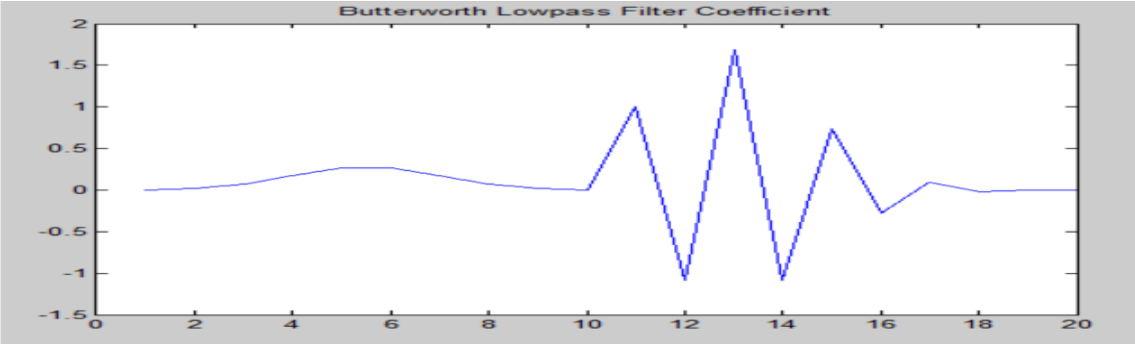

Figure 5.17: Butterworth low pass filter coefficient

Magnitude and Phase response of Butterworth filter

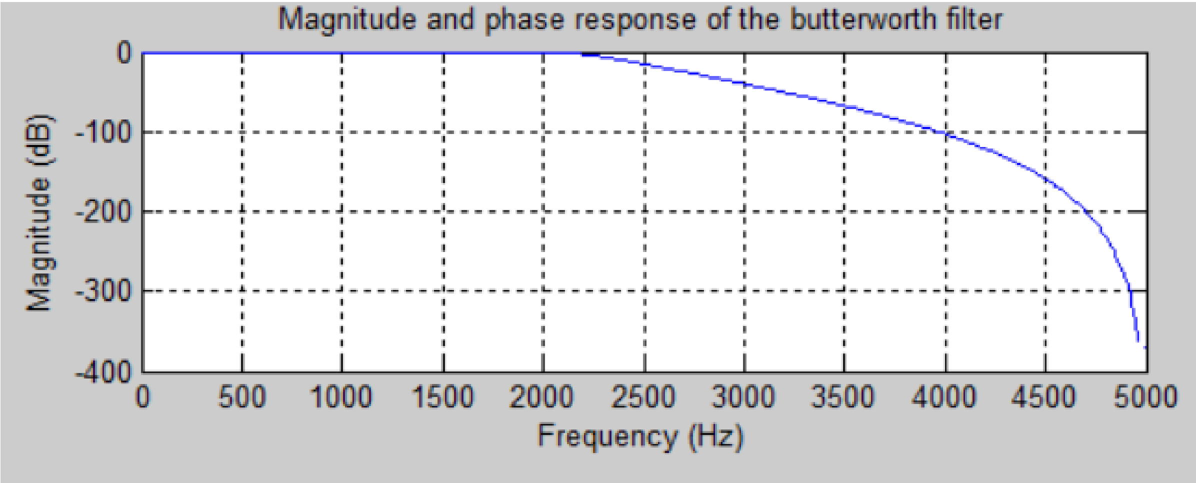

Figure 5.18: Magnitude response of the Butterworth filter.

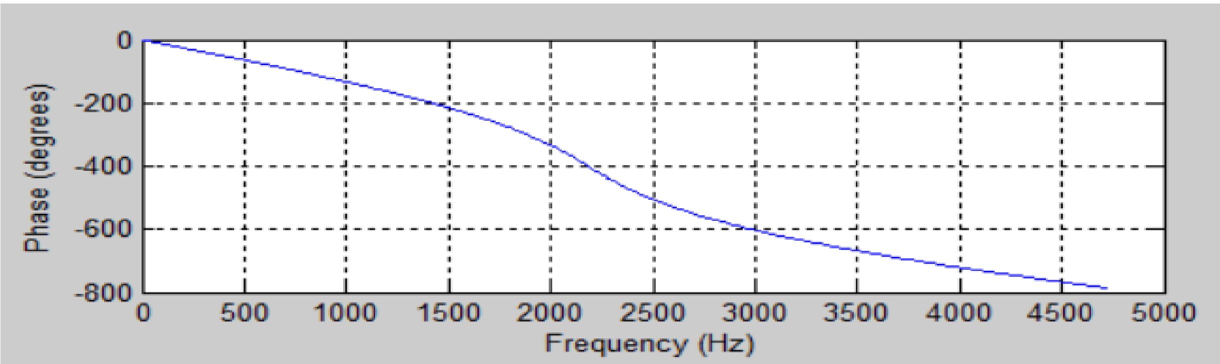

Figure 5.19: Phase response of the Butterworth filter.

5.5 Chebyshev Filter:

In this ECG original signal is taken after that noisy signal is added in it. Chebyshev filter is used to reduce noise. In Chebyshev filter two parameters are find in which value of SNR before filtering is decreased and after filtering value is increased. The value of MSE is increased before filtering and after filtering value is decreased.

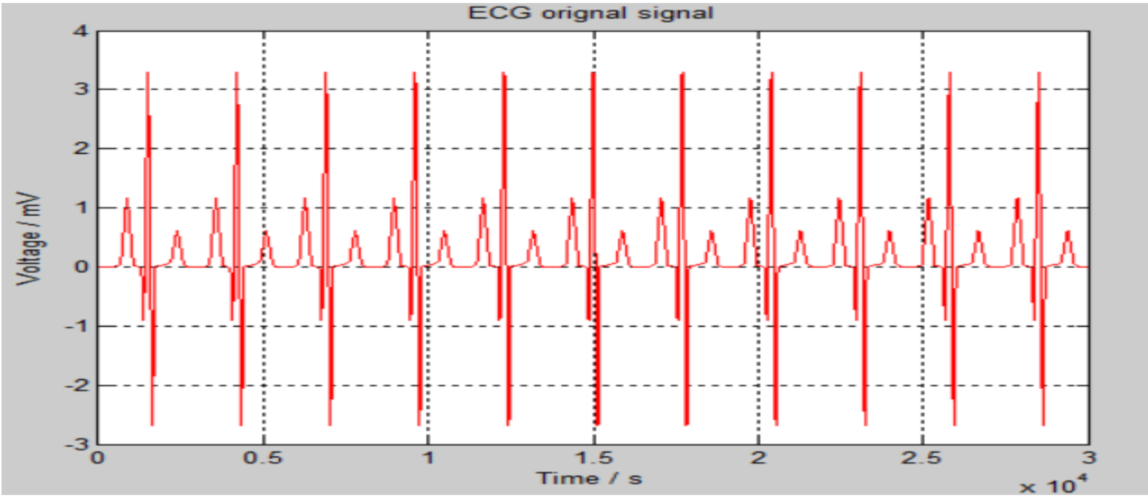

Figure 5.20: ECG original signal

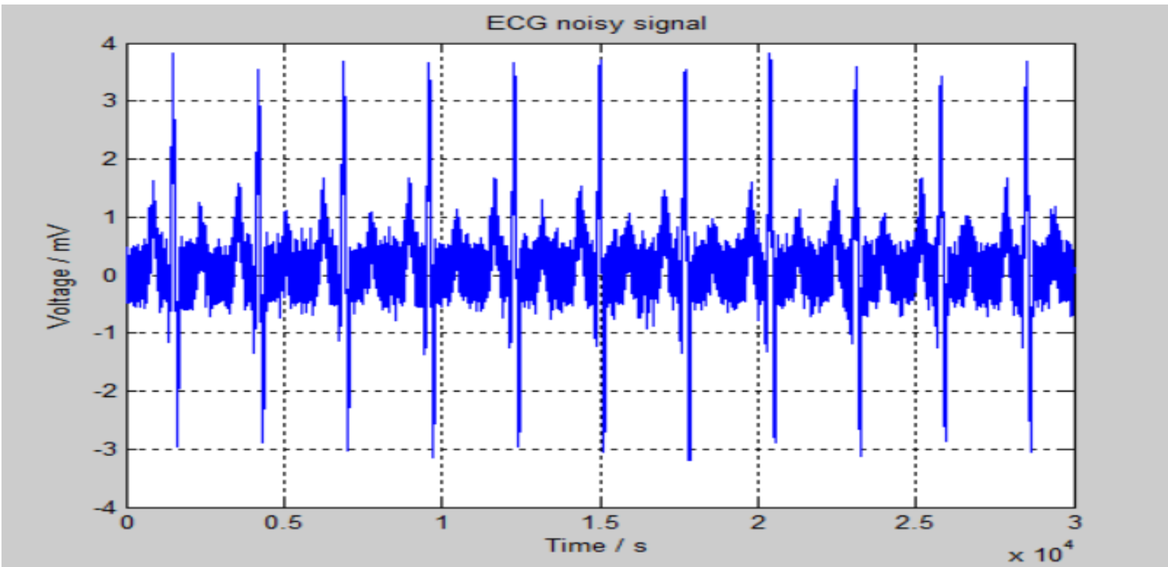

Figure 5.21: ECG noisy signal

Noise removal using Chebyshev filter low pass

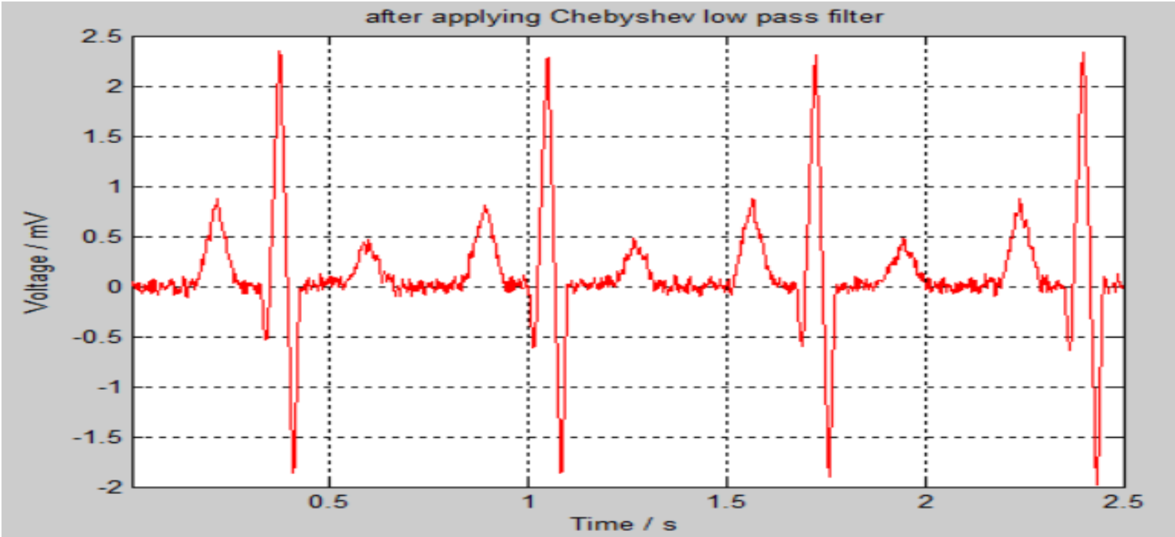

Figure 5.22: After chebyshev low pass filter

Magnitude and Phase response of Chevyshev filter

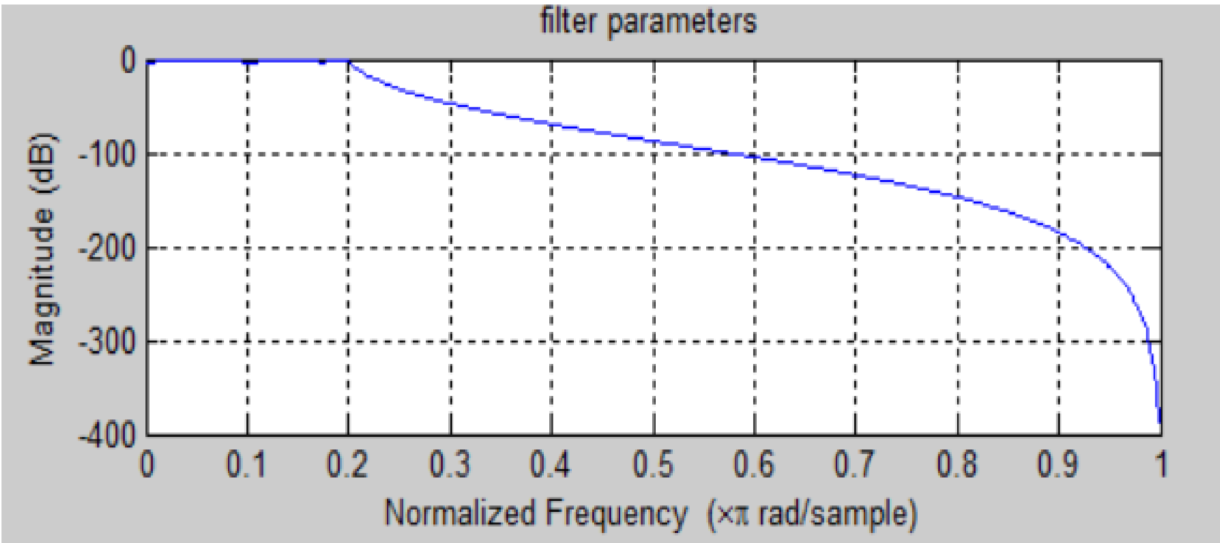

Figure 5.23: chebyshev filter parameters

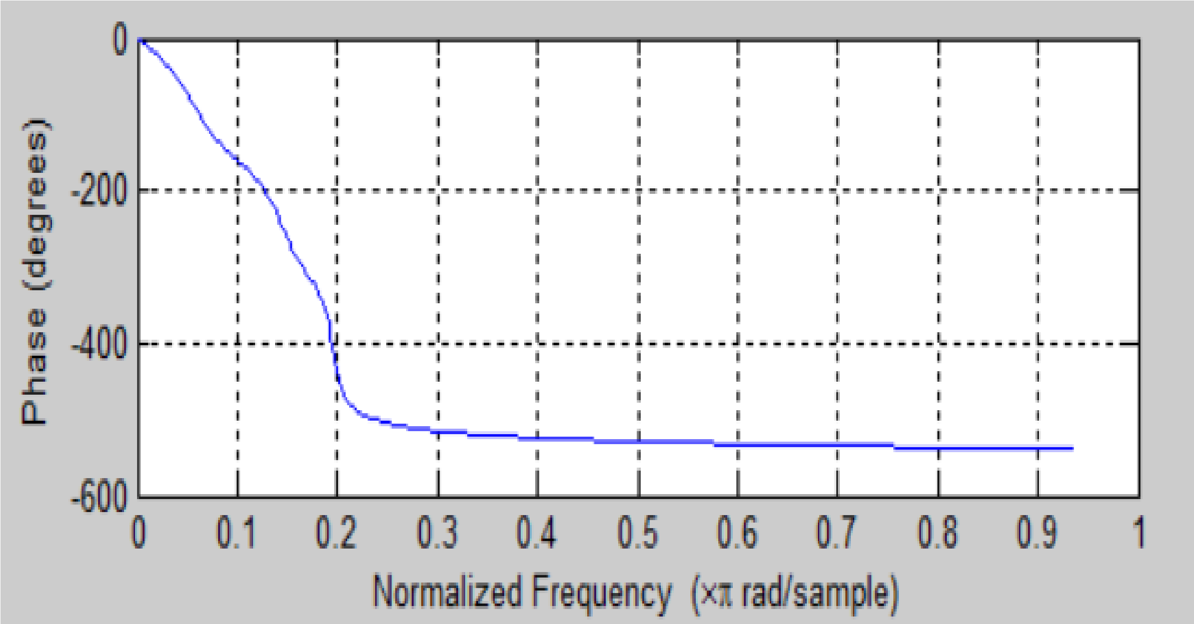

Figure 5.24: Normalized frequency

Table 5.1: Parameters for Chevyshev Filter

Sr.No.	Parameters	Before Filtering	After Filtering
1.	SNR	37.0809	41.1978
2.	MSE	0.0499	0.0192

5.6 Adaptive Filter:

In this Figure 5.25 shows the output of original signal ECG original signal. In adaptive filter the value of SNR before filtering is decreased and after filtering the value is increased. In case of MSE before filtering the value is decreased and after filtering the value is increased.

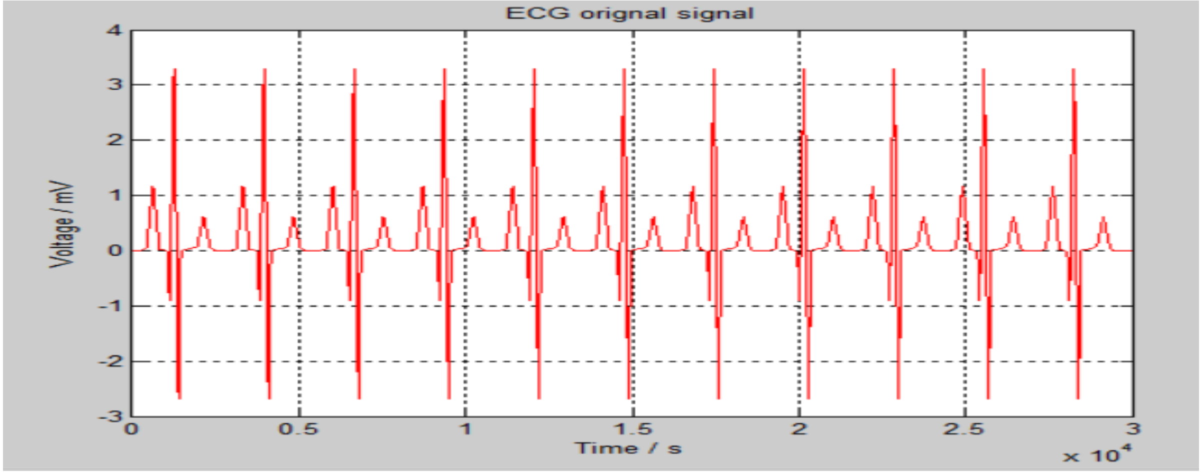

Figure 5.25: ECG original signal

Figure 5.26 shows the output of generated ECG signal

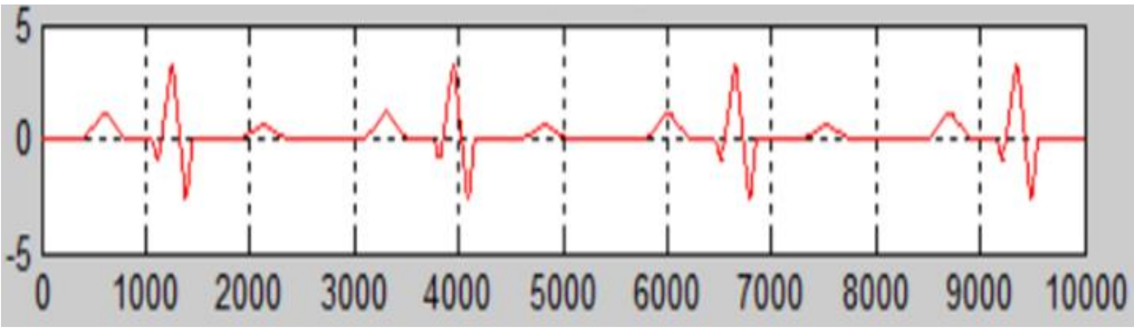

Figure 5.26: Generated ECG original signal

White noisy signal

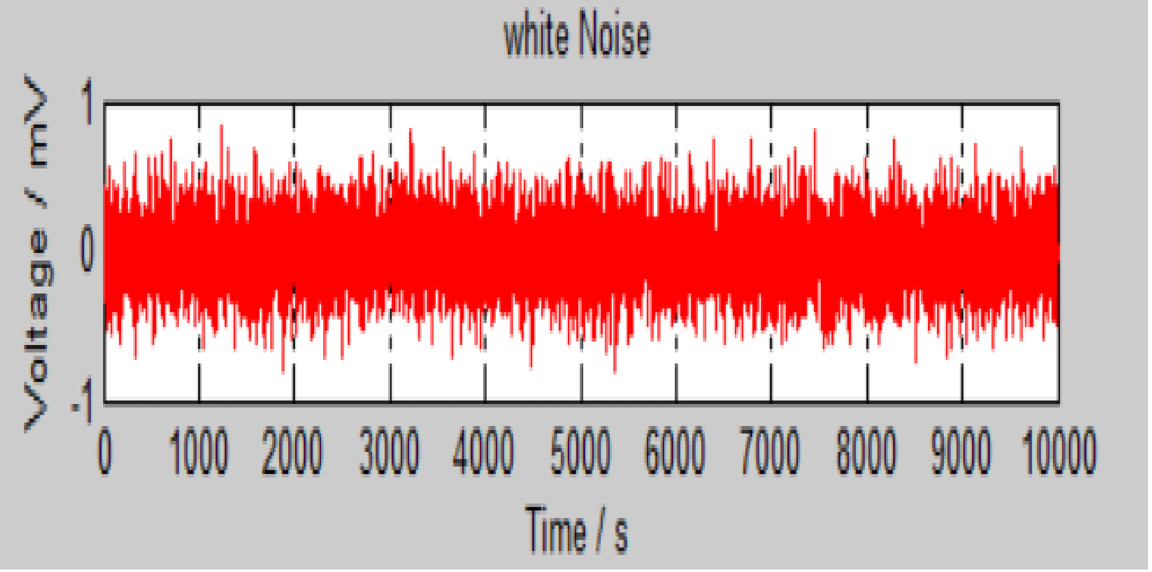

Figure 5.27: White noise

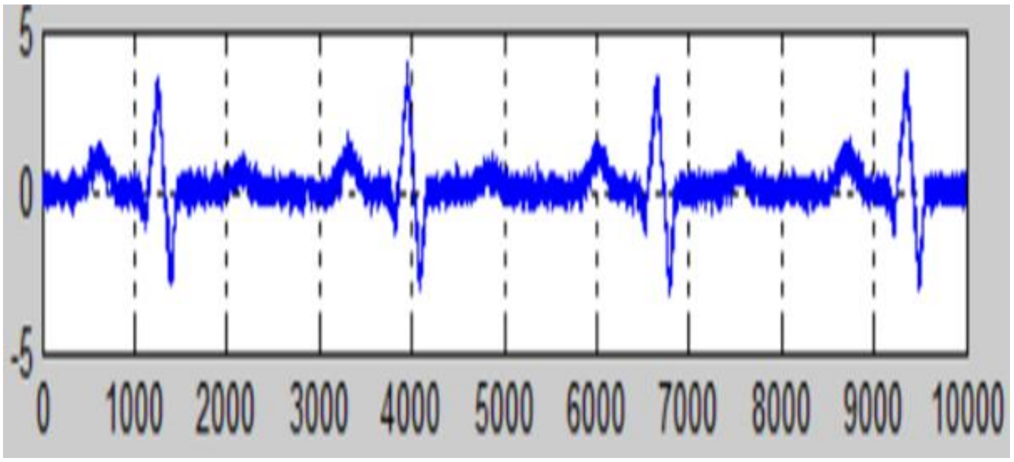

Figure 5.28: ECG generated noisy signal

ECG original signal iteration 1

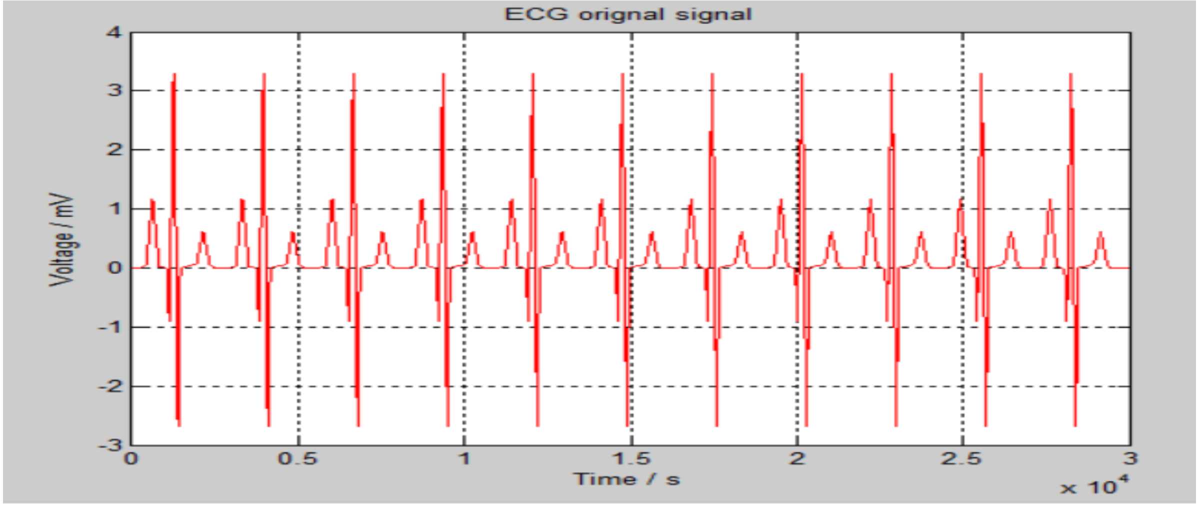

Figure 5.29: ECG original signal

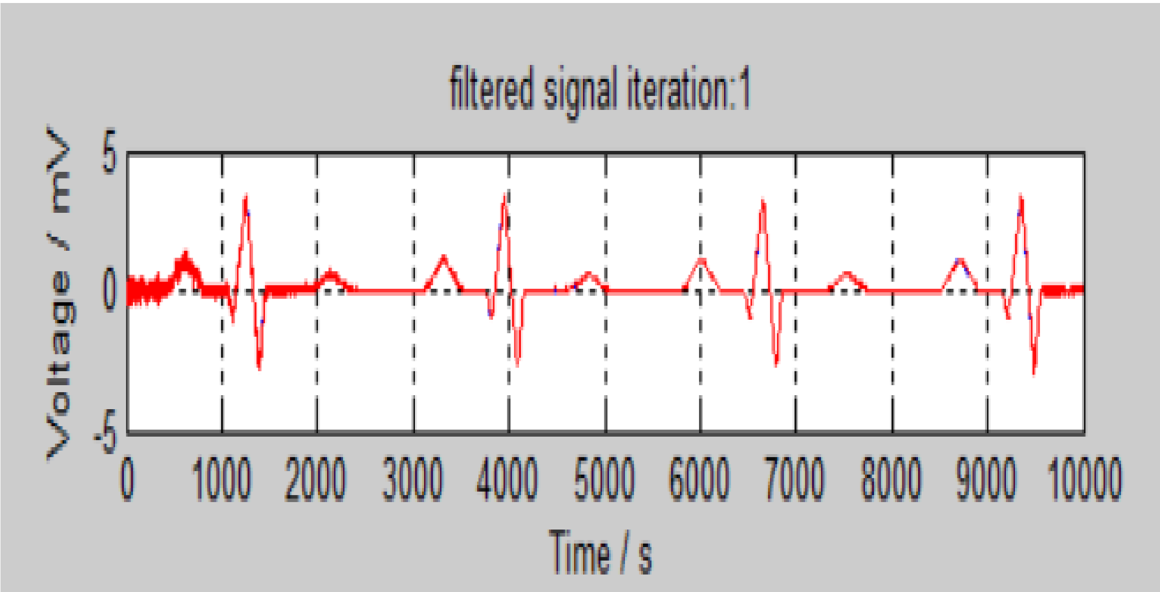

Figure 5.30: ECG filtered signal iteration 1

ECG original signal for iteration 2

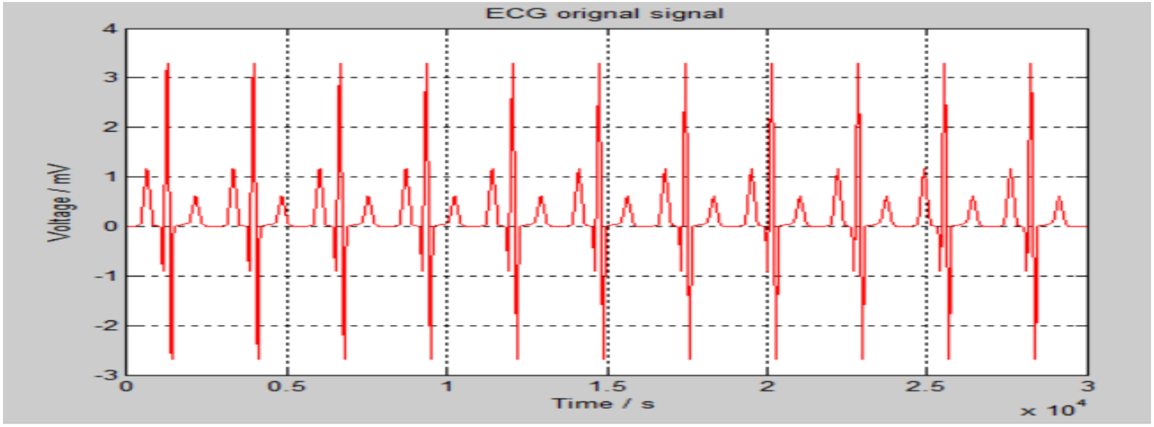

Figure 5.31: ECG original signal

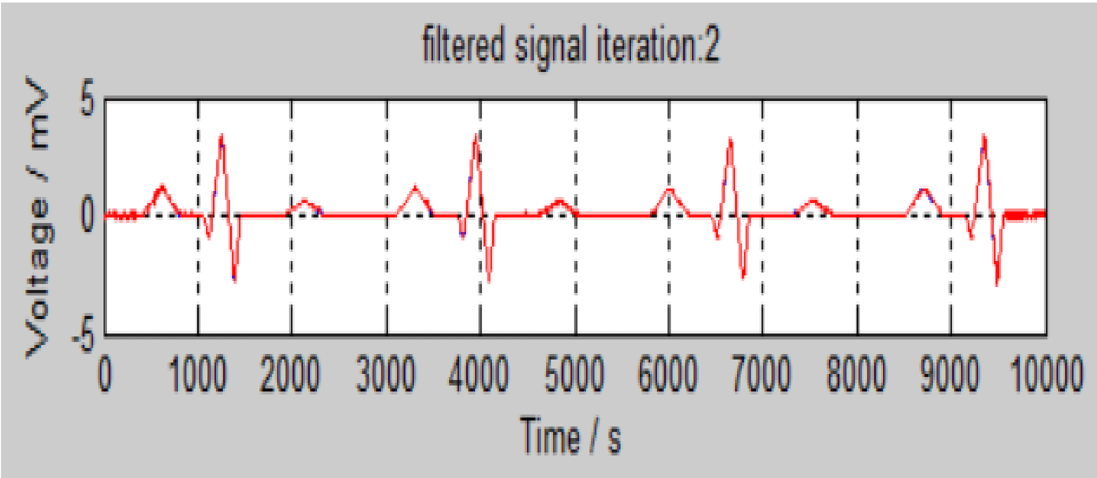

Figure 5.32: ECG filtered signal iteration 2

ECG original signal for iteration 3

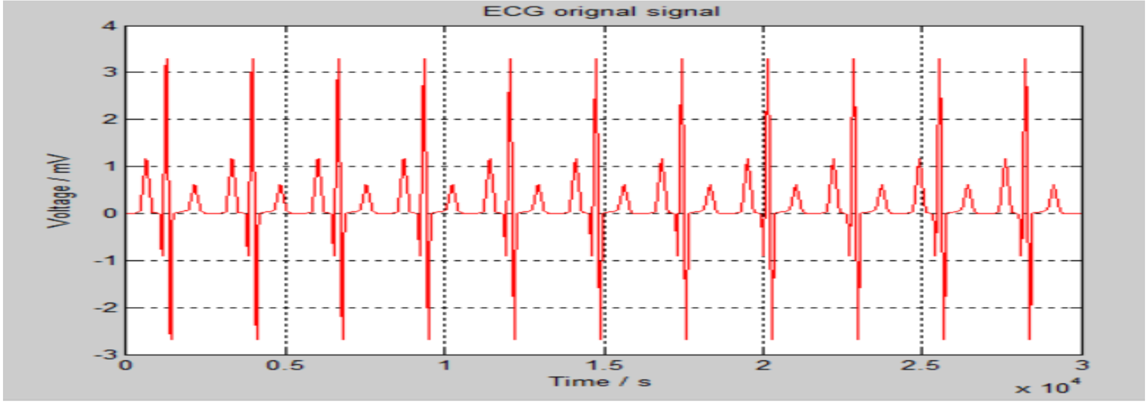

Figure 5.33: ECG original signal

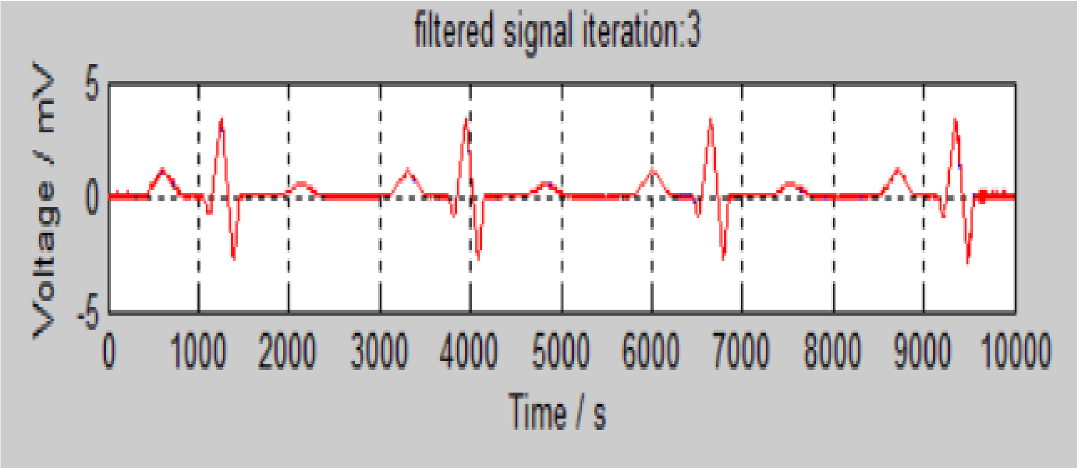

Figure 5.34: ECG filtered signal iteration 3

Table 5.2: Parameters for Adaptive Filter

Sr. No.	Parameters	Before Filtering	After Filtering
1.	SNR	37.2317	55.3697
2.	MSE	0.0482	7.4058e-04

5.7 Haar Wavelet:

In figure 5.36 shows the output of ECG original signal. In Haar wavelet the value of SNR before filtering is decreased and after filtering the value is increased. In MSE before filtering value is increased and after filtering value is decreased.

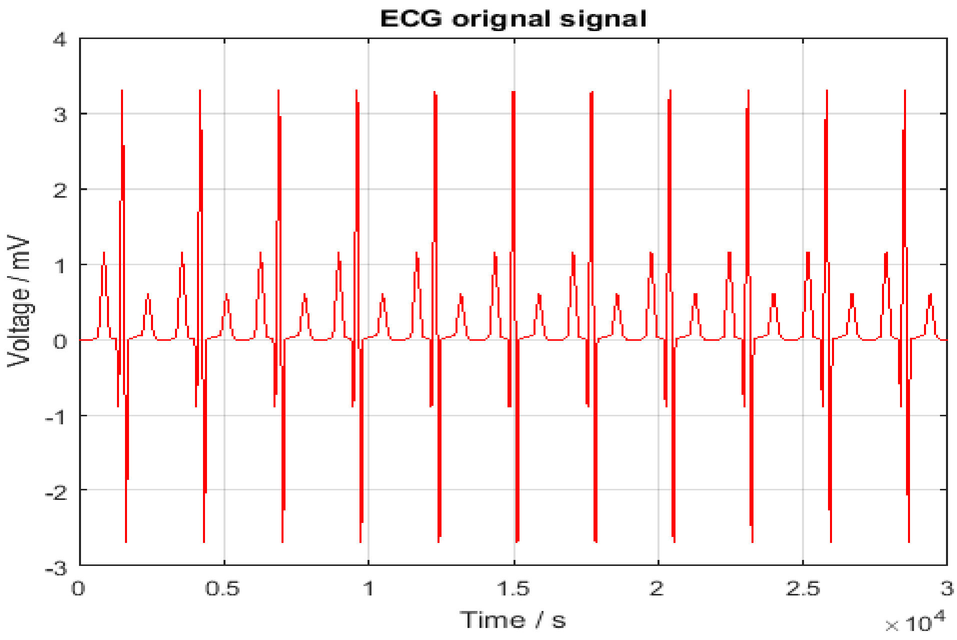

Figure 5.35: ECG Original Signal

Figure 5.36 shows the generation of ECG signal

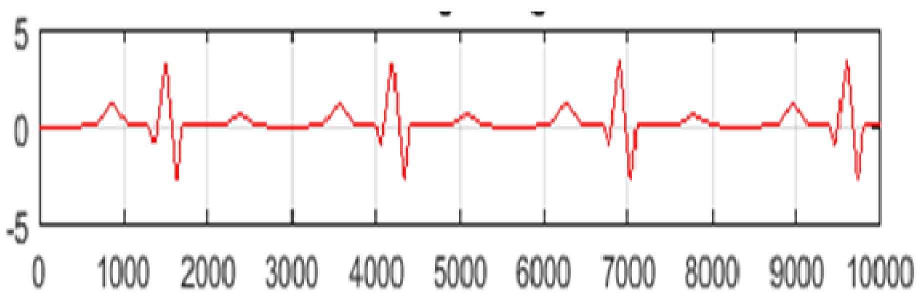

Figure 5.36: ECG Generated Signal

Figure 5.37 shows the noisy ECG signal generation

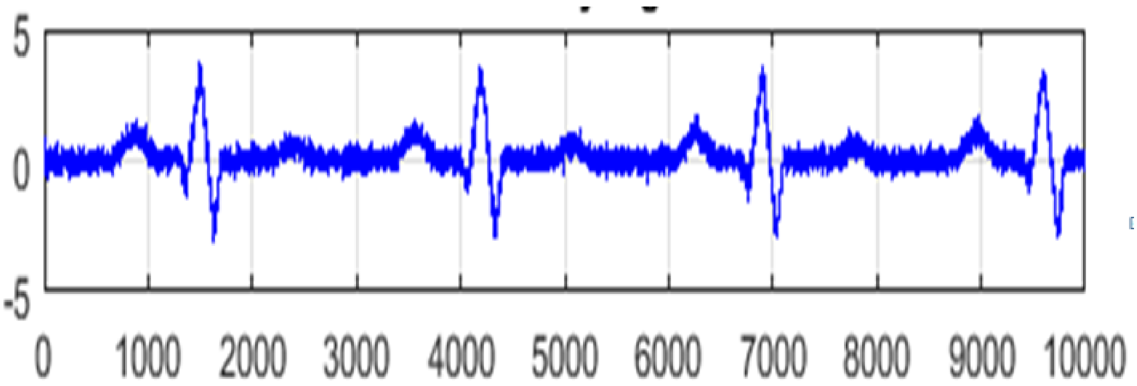

Figure 5.37: ECG Noisy Signal

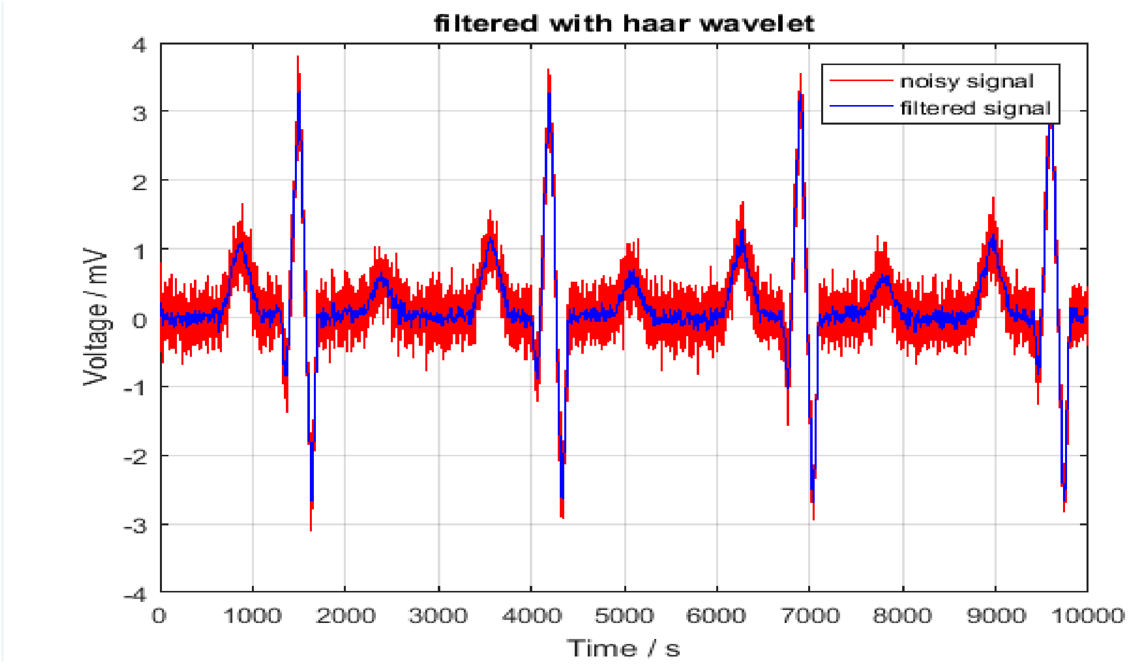

Figure 5.38: Signal Filtered With Haar Wavelet

Table 5.3 Parameters for Haar wavelet

Sr. No.	Parameters	Before Filtering	After Filtering
1.	SNR	37.2317	47.6983
2.	MSE	0.0482	0.0043

In Haar wavelet the value of SNR before filtering is decreased and after filtering the value is increased. In MSE before filtering value is increased and after filtering value is decreased.

CHAPTER – 6

CONCLUSION

ECG is a form of biomedical waveform that provides necessary information about heart and its functioning. Noise in electrocardiogram signal result in improper judgment therefore the digital filters square measure to take away these noises. FIR filter are efficiently realizable in hardware and provide the exact linear phase. Notch filter is used to achieve spike free signal and as a result of the low process value of IIR notch filter, the IIR notch filter is appropriate for real time implementation. Noise removal for FIR digital filter is best choice as compared with IIR digital filter. In this adaptive filter compares two parameters LMS and NLMS algorithm. In NLMS algorithm SNR is good as compared to LMS algorithm. LMS algorithm is mostly used for channel equalization, eco cancellation and noise cancellation. RLS algorithm is computationally complex. LMS is mostly used for filtering the signal

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PUBLICATION

Bhawna Chandel, Iresh Rastogi, Meenakshi Sood (2017). Noise Removal from ECG Signal using Filters. *Proceedings of the International Conference on Computing for Sustainable Global Development, BVICAM,* [4th: New Delhi: 1-3 March, 2017], pp.6263-6267.

Submission Info

SUBMISSION ID	806297346
SUBMISSION DATE	28-Apr-2017 10:37
SUBMISSION COUNT	1
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FILE SIZE	3.03M
CHARACTER COUNT	37842
WORD COUNT	5993
PAGE COUNT	55
ORIGINALITY	
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