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ECG Denoising Using MATLAB

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Abstract- At present many of the ECG recording instruments are based on analog recording circuitry. Due to this, noises from various sources are inherently added to the signal. Sometimes power of noise becomes even larger than the signal. In this study various sources of noise that usually corrupt the ECG signal are identified and attempt is made to get rid of such noises. Various filtration techniques such as low pass filter, high pass filter, band pass filter and notch filter are used to filter the signal from noises. One more filter called as moving averaging filter is also implemented which has shown very good efficiency in smoothing out the waveform and suppressing 50 Hz Power line noise.

Key words- Band pass filter, Electrocardiogram, Fast Fourier Transform, High pass filter, MATLAB, Kaiser window, Low pass filter, Moving average filter, Notch filter, Peak detection algorithm, Power Spectral Density, Windowing.

1 INTRODUCTION

It should be noticed that even though the ECG signals from different patients have the similar forms, the ECG of each individual patient is different. Also electrocardiographic (ECG) signals are often contaminated by noise from diverse sources and forms.Some of them are: 50Hz power line interference, motion artifact from the electrode–skin interface, muscle activities etc. Therefore, signal conditioning for baseline correction and noise suppression is typically the first step in the analysis of ECG signals. Hence keeping this aim in our mind we in our project has attempted to filter out the noise components in ECG waveform using digital filtration with the help MATLAB.

2 ELECTROCARDIOGRAM (ECG)

An ECG is a series of waves and deflections, recording the heart's electrical activity from a certain "view". Many views, each called a pair of leads are placed in different positions on the body[1]. A normal ECG signal is shown in figure:

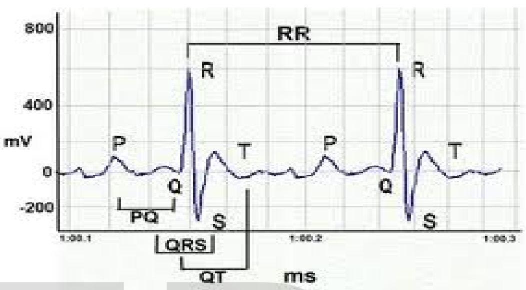

Fig.1.1. Normal ECG Signal

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

3 LITERATURE REVIEW

Researchers have worked on the removal of the power line interference in the ECG signals. Many methods have been suggested or proposed. Alireza K Ziarani, Adaibert Konrad [3] has proposed Non linear Adaptive method of elimination of power line interference in ECG signals. S.Pooranchandra, N.kumarave [4] has used the wavelet coefficient threshold based hyper shrinkage function to remove power line frequency. Santpal Singh Dhillon and Saswat Chakrabarti [5] have used a simplified lattice based adaptive IIR Notch filter to remove power line interference. Mahesh S. Chavan, R.A. Aggarwala, M.D.Uplane [6] has used Digital FIR Filters based on Rectangular window for the power line noise reduction. P.E.Tikkane [7] has applied Non linear wavelet and wavelet packet for denoising of electrocardiogram signal.

4 THE WINDOWING TECHNIQUE

The windowing method has its roots in signal processing, where the windowing operation allows the spectral analysis of non-periodic signals. It is

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very simple to understand conceptually and simple to apply. Various types of predefined windows such as Kaiser, Rectangular, Bartlett, Hanning, Hamming, Blackman windows are available. Kaiser window is used in this thesis. In Kaiser Window it is possible to control the length of filter and the transition width of main lobe by adding additional parameter β.

Kaiser window function is given by,

$$w_k\,(n,\beta) = \frac{I_0\left[\beta - \sqrt{1-[\frac{2n}{N-1}]^2}\right]}{I_0(\beta)} \quad for\ |n| \leq \frac{N-1}{2}$$

$$= 0 \qquad Otherwise$$

Where β is the adjustable parameter and I_0 (x) is the modified zero th order Bessel functions of the first kind [16].

5 RESULTS

In this study low pass filter, high pass filter, band pass filter, notch filter and moving averaging filter are implemented. Following figure shows ECG signal contaminated by the various noise sources.

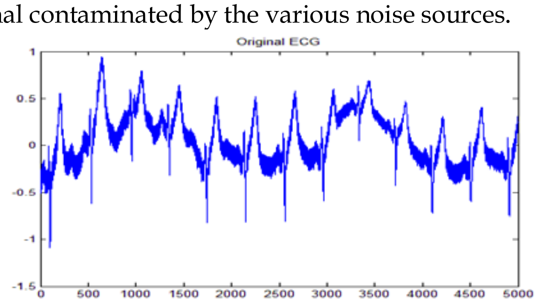

Fig.5.1. ECG Contaminated by Noise

The FFT (Fast Fourier Transform) and PSD(Power Spectral Density) of the original recorded signal are as shown below:

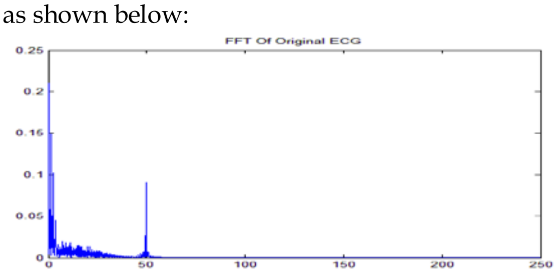

Fig.5.2. FFT of Original ECG

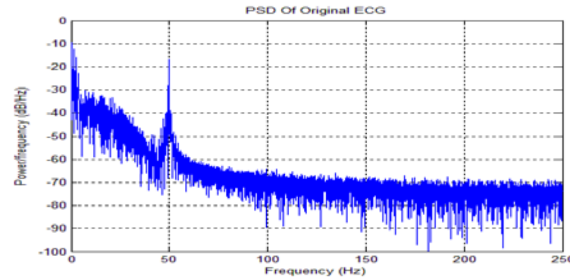

Fig.5.3. PSD of Original ECG

This signal is passed through a low pass filter designed using Kaiser window with a cut off frequency of 100 Hz, pass band ripple of 1dB and minimum stop band attenuation of 80dB. The order is set to 10. The filtered ECG signal is shown below:

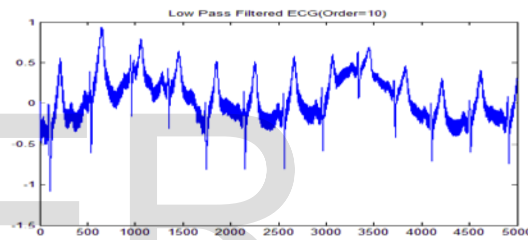

Fig.5.4. Low Pass Filtered ECG

The FFT and PSD of the Low pass filtered signal are as shown below:

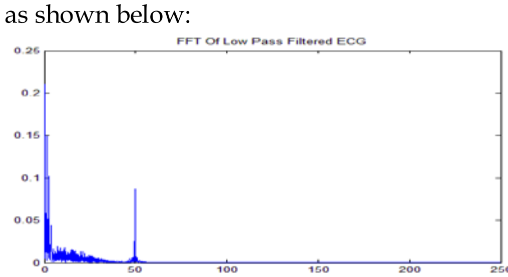

Fig.5.5.FFT of Low Pass Filtered ECG

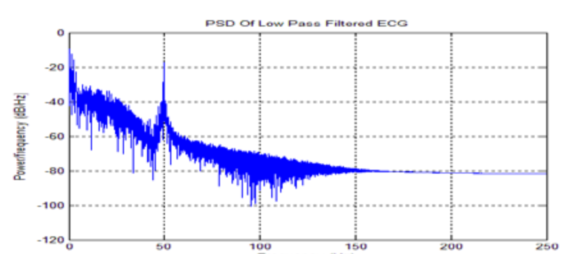

Fig.5.5.PSD of Low Pass Filtered ECG

Another filter described in the report is the high pass filter using Kaiser Window with a cut off frequency of 10 Hz, pass band ripple of 1dB and minimum stop band attenuation of 80dB. The order is set to 10.The output of the filter is shown below:

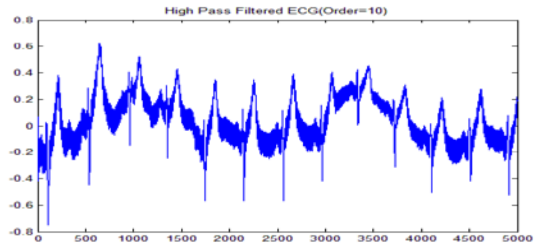

Fig.5.6High Pass Filtered ECG

The FFT and PSD of the High pass filtered signal are as shown below:

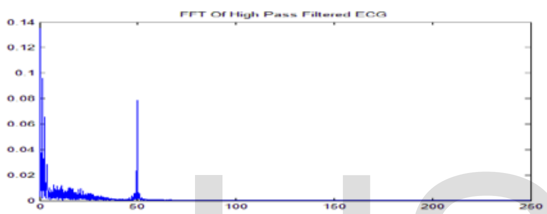

Fig.5.7.FFT of High Pass Filtered ECG

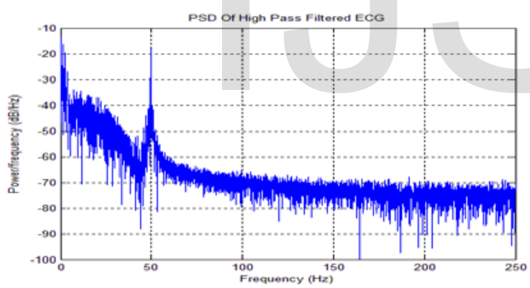

Fig.5.8.PSD of High Pass Filtered ECG

As it is clear from FFT and PSD of original signal, ECG is corrupted with large amount of 50 Hz Power Line noise, some technique is required to suppress the power line interference. The signal is filtered using a 50 Hz Notch Filter. The filtered ECG signal is shown below:

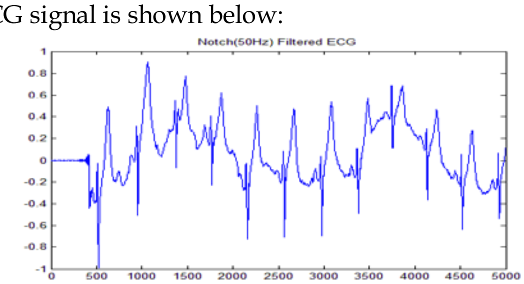

Fig.5.9.Notch Filtered ECG

The FFT and PSD of the Notch filtered signal are as shown below:

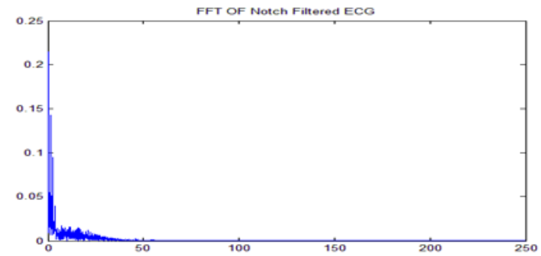

Fig.5.10.FFT of Notch Filtered ECG

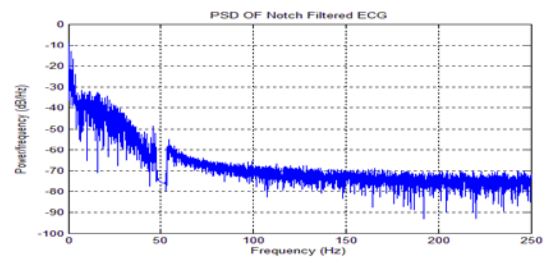

Fig.5.11.PSD of Notch Filtered ECG

It is clear from the above FFT and PSD of Notch filter the 50 Hz frequency component is suppressed. The plot of original signal shows that it has large baseline interference. To clear out the base line wandering and combine the effects of high pass and low pass filters, band pass filter with pass band of 5 Hz to 110 Hz is implemented using Kaiser Window. The maximum pass band ripple is set to 1dB and minimum stop band attenuation is 80 dB. The output of the filter is as shown below:

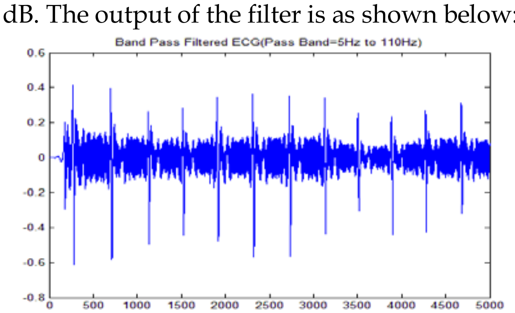

Fig.5.12.Band Pass Filtered ECG

The FFT and PSD of the Band pass filtered signal are as shown below:

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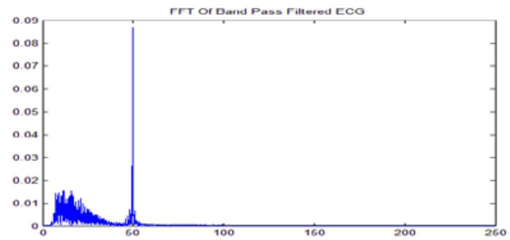

Fig.5.13.FFT of Band Pass Filtered ECG

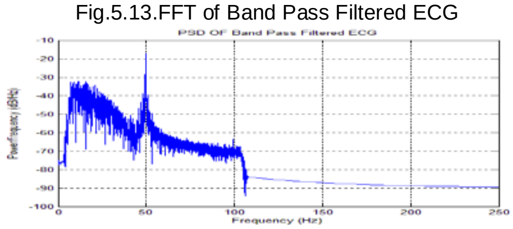

Fig.5.14.PSD of Band Pass Filtered ECG

The signal is also corrupted with high frequencies vibrations to a great extent. To smooth out the vibrations moving averaging filter with variable number of averaging points is implemented. For the above test signal, 20 point averaging was found to be optimum. The result of application of moving averaging filter is shown below:

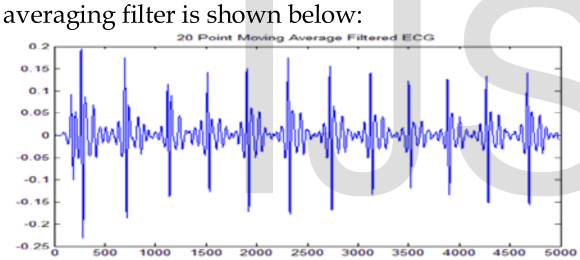

Fig.5.15.Moving Averaging Filtered ECG

The FFT and PSD of the Moving averaging filtered signal are as shown below:

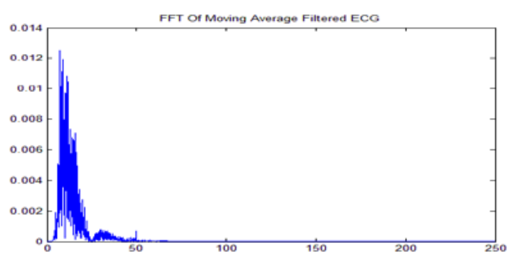

Fig.5.16.FFT of Moving Averaging Filtered ECG

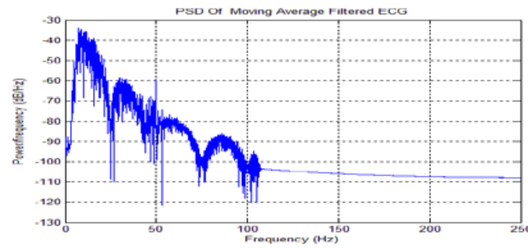

Fig.5.17. PSD of Moving Averaging Filtered ECG

Followed by application of moving averaging filter a peak detector algorithm, developed during project was used to detect the R-peaks of the smoothened ECG waveform which is free from baseline wandering. The detected peaks are used to calculate the heart rate of the subject under study. The peak detector algorithm and the calculation of heart rate from it, is done to demonstrate a simple practical application of the work done during the thesis. The result of application of peak detector algorithm for test signal is shown below:

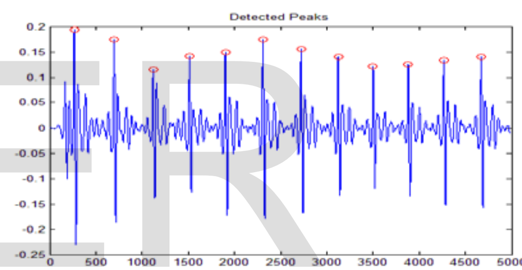

Fig.5.18.Peak Detection Using Peak Detector Algorithm

6 DISCUSSIONS

During this study various filtration techniques were tested. Many windowing techniques were tested including Rectangular Window, Blackman Window, Hamming Window, Hanning Window, etc. Apart from windowing techniques, Pan Tompkins algorithm was also tested. The techniques which showed optimum results for large number of samples were selected and implemented in the study.

7 CONCLUSIONS

The design of the filters indicates that there are some ripples in the filters but the responses are stable. The phase is also linear which indicates that even if a multiple frequency signal is applied to it there will be no differential phase shift and hence no distortion. The results of the implementation show that each filter removed the noise specifically meant for it to filter. The notch filter showed great results in suppression of power line interferences. This is clear from FFT and PSD of the filtered signal shown in the results. However one of the major drawback is that there may be 50 Hz component in the ECG signal itself and application of notch filter may result in loss of this 50Hz component. But usually this 50Hz component is not that significant for diagnosis purpose and so it may be compromised for the extent to which power line interference is cleared from the signal.

The high pass and low pass filters were initially implemented separately. Then the effects of both filters are combined to implement a band pass filter. The band pass filter efficiently cleared off the baseline wander and also some of the high frequency noise.

Though moving average filter was efficient in smoothing the signal it couldn't clear the baseline wandering. So, to overcome this moving averaging filter was applied to band pass filtered EGC which was already free from baseline wander. The combination of band pass filter and moving averaging filter was highly efficient in clearing considerable noise along with baseline wander. At optimum point moving average filter was also able to suppress power line interference to a considerable amount. To speak about limitation of moving averaging filter we notice that it may result in significant amount of data loss if number of points to be averaged is not optimum. It also may sometimes enhance the high frequency vibrations if range is not selected properly.

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