Design and Comparison of Digital IIR Filters for Reduction of artifacts from Electrocardiogram Waveform

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Abstract-Electrocardiogram (ECG) signal has been broadly used in cardiac pathology to find heart disease. ECG signal is commonly corrupted by disparate artifacts as baseline wander, power line interference (50/60 Hz) and electromyography noise and these should be eliminated before diagnosis. The function proposed in this paper is removal of low frequency interference i.e. baseline wandering and high frequency noise i.e. electromyography in ECG signal and digital filters are performed to eliminate it. A digital infinite-impulse response (IIR) filter design in this article. The digital filters accomplished are IIR with different approximation methods as of Butterworth, ChebyshevI, Chebyshev II and Eliptic. The results obtained are at order of 1, 2 and 3. The signals taken from the MIT-BIH database which contains the normal and abnormal waveforms. The task has been in MATLAB where filters are implemented in FDA Tool. The result received for whole IIR filters with different methods are evaluated the waveforms, power spectrums density, signal to noise ratio (SNR) and means square error (MSE) of the noisy and filtered ECG signals. The filter which shows the excellent outcomes is the Butterworth.

Keywords: ECG, IIR filter, SNR, MSE, MATLAB, Butterworth, Chebyshev I, Chebyshev II, Eliptic.

INTRODUCTION

The electrocardiogram (ECG) is a time-varying signal causing the ionic current flow which reasons the cardiac fibers to compress and subsequently relax. The ECG is obtained by recording the potential difference among two electrodes placed on the surface of the skin. A single normal period of the ECG indicates the consecutive atrial depolarization/repolarization and ventricular depolarization/repolarization which happens with each heartbeat. These may be almost associated with the peaks and troughs of the ECG waveform labelled P, Q, R, S, and T as shown in Fig. 1.

Extracting helpful clinical data from the noisy ECG needs reliable signal processing methods [1]. These contain R-peak detection [2], [3], QT-interval detection [4], and the derivation of heart rate and respiration rate from the ECG [5], [6]. The RR-interval is the time among consecutive R-peaks, the reverse of this time interval gives the instantaneous heart rate. A series of RR-intervals is called as a RR tachogram and variability of these RR-intervals shows significant data about the physiological condition of the subject [7]. Now days, new biomedical signal processing algorithms are generally evaluated by using them to ECGs in a wide database like the Physionet database [8][10].

This signal may corrupt due to different types of the artifacts [9]. ECG signal are generally corrupt by unwanted interference like motion artifacts, muscle noise, electrode artifacts, base line drift noise and respiration. So for correct and significant clinical data of heart these artifacts have to be removed or filtered out for which analog and digital filters are employed, but digital filters are at present capable of exciting performed offering more benefits compare the analog one. Digital filters are more accurate due to absence of instrumentation.

The typical digital signal processing (DSP) includes z transform, correlation, Fourier transform, convolution, and filtering, etc. The benefits of DSP are programmable; it has excellent reliance, high accuracy, strong anti-interference, simple to maintain, and simple to design for gaining linear phase, etc. IIR methods have an impulse response function that is non zero over an infinite duration of time. IIR Filter can be accomplished as either analog or digital filter. In digital filter, the output feedback is rapidly apparent in the equation describing the output.

The process of removing noise has been success when applying filtering method such as linear filter and moving average filter. Complete filter design is accomplished with FDA tool in the MATLAB. In this paper display the performance of digital IIR filters with different methods. In the results are indicating to comparatively in frequency spectrum density , signal to noise ratio (SNR) and mean square error (MSE).The designed filters are tested with the samples from MIT-BIH database through the physionet website.

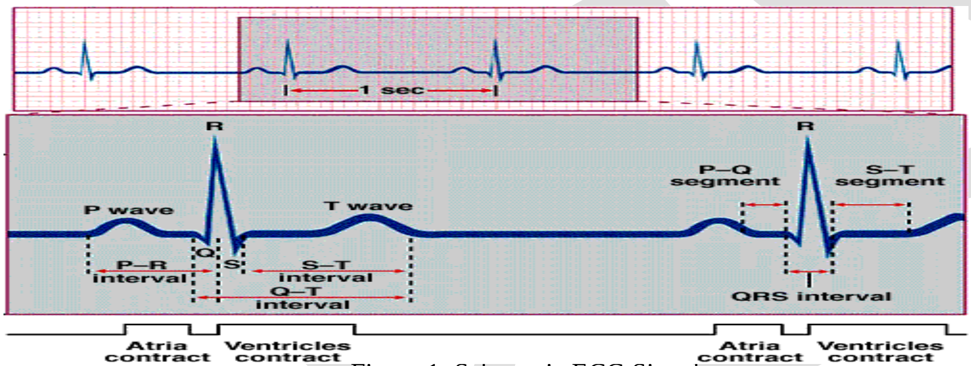

Figure 1: Schematic ECG Signal

Digital IIR filter

Digital Filters are designed by using the values of both the past outputs and the present input, an action brought about by convolution. If such a filter is subjected to an impulse then its output not requirement essentially become zero. The impulse response of such a filter may be infinite in period. Such a filter is known as an Infinite Impulse Response filter or IIR filter. The infinite impulse response of such a filter implies the capability of the filter to have an infinite impulse response. This represents that the system is prone to feedback and inconstancy.

The paper indicates various types of IIR filters containing the Butterworth Filter, Chebyshev I & II Filters and Elliptic of Low pass, High pass and Band stop filters. IIR filters are designed fundamentally by the Impulse immutability or the Bilinear Transformation method. IIR filter is determined by below equations:

$$y(m)=\sum_{k=1}^{N} a_k y(m-k)+\sum_{k=0}^{M} b_k x(m-k) \qquad (1)$$

A) Butterworth Filters

The Butterworth filter is a kind of signal processing filter designed to have as flat a frequency response as possible in the passband. It is also mentioned to as a maximally flat magnitude filter. Butterworth filters are normal in character and of different orders, the lowest order showing the excellent in the time domain, and the higher orders showing better in the frequency domain. Butterworth or maximally flat filters have a uniform amplitude frequency response which is maximally flat at zero frequency response and the amplitude frequency response reductions logarithmically with increasing frequency. The Butterworth filter has minimal phase shift over the filter's band pass when evaluate to other conventional filters

$$\overline{B(\omega)}B(\omega) = \frac{1}{1+\left(\frac{\omega}{\omega_0}\right)^{2n}} \quad (2)$$

B) Chebyshev Filters:

Chebyshev filters have the feature that they minimize the error between the idealized and the real filter characteristic over the range of the filter, but with ripples in the passband. Because of the passband ripple intrinsic in Chebyshev filters, the ones that have a smoother response in the passband but a more irregular response in the stopband are preferred for some applications. Chebyshev filters are of two types: Chebyshev I filters are all pole filters which are equi-ripple in the passband and are montonic in the stopband. Chebyshev II filters contain both poles and zeros presenting montonic behaviour in passband and equi-ripple in the stopband. The frequency response of the filter is given by

$$|H(\Omega)|^2 = (1+\epsilon^2 T_N^2(\Omega/\Omega_p))^{-1} \quad (3)$$

Where ϵ is a parameter related to the ripple present in the pass band

$$T_N = \begin{cases} \cos(N\cos^{-1}x) & |x| \le 1 \\ \cos(N\cosh^{-1}x) & |x| \ge 1 \end{cases} \quad (4)$$

C) Elliptic Filters:

Elliptic filters are determined by equi-ripples in both passband and stop bands. The amount of ripple in each band is independently adjustable, and no other filter of equal order can have a faster transition in gain between the passband and the stopband, for the given values of ripple (whether the ripple is equalized or not). Alternatively, one may give up the ability to independently adjust the passband and stopband ripple, and instead design a filter which is maximally insensitive to component variations. They prepare a realization with the lowest order for a specific set of conditions.

$$|H(j\Omega)| = 10^{-Rp/20} \quad \Omega = 1 \quad (5)$$

As the ripple in the stop band approaches zero, the filter becomes a type I Chebyshev filter. As the ripple in the passband approaches zero, the filter becomes a type II Chebyshev filter and finally, as both ripple values approach zero, the filter becomes a Butterworth filter.

METHODOLOGY

ECG signal is fundamentally containing of frequency between 0-250Hz. Research proofs that the frequency range of the ECG signal is 0-250 Hz, The sampling frequency was selected to facilitate performances of 60 Hz digital notch filter in arrhymia detectors, sampling frequency of data signal is 360 Hz and amplitude 1mv.We designed the filter for corrupted ECG signal in four steps: In first step with the help of FDA Tool in MATLAB software design IIR with high pass filter cut off frequency 0.5 Hz to eliminating baseline wander noise from noisy ECG signal, in second step removing power line interference (50/60 Hz) by band stop with cut off frequency (59.5Hz-60.5 Hz) , in third step we reducing EMG noise by applying low pass filter with cut off frequency 100Hz, finally moving average filter to smooth the ECG waveform. The task was accomplished in various orders. The efficiency analysis contained the comparison of outcomes generated by filters designed during the modelling method with replacing filter parameters so arranging them the one where outcomes obtained were best. The results were collected with performing the filters through the ECG database from MIT-BIH site. The ECG samples 100m,104m,105m,106m,108m,109m(MLII,VI) obtained from MIT have supported the own research into arrhymia database consists 48 half hours excerpts of two channel ambulatory ECG recordings are utilized to verify the results of digital filter designed as described above in methodology.

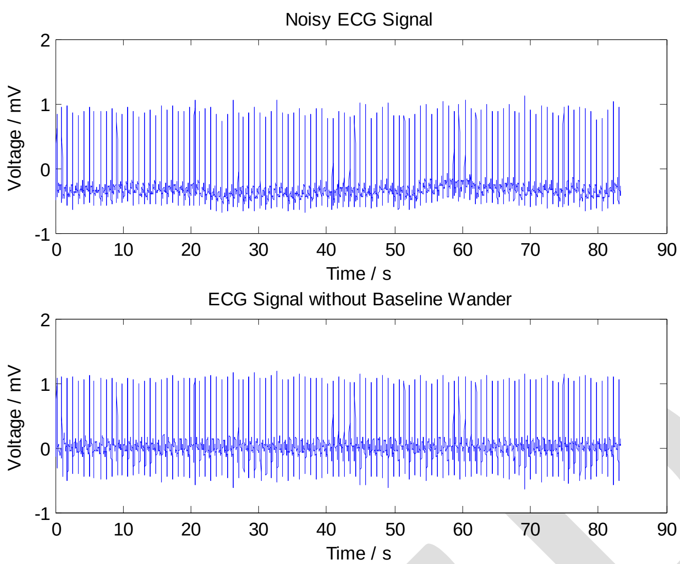

Fig.1.ECG before & after filtering of Baseline Wander

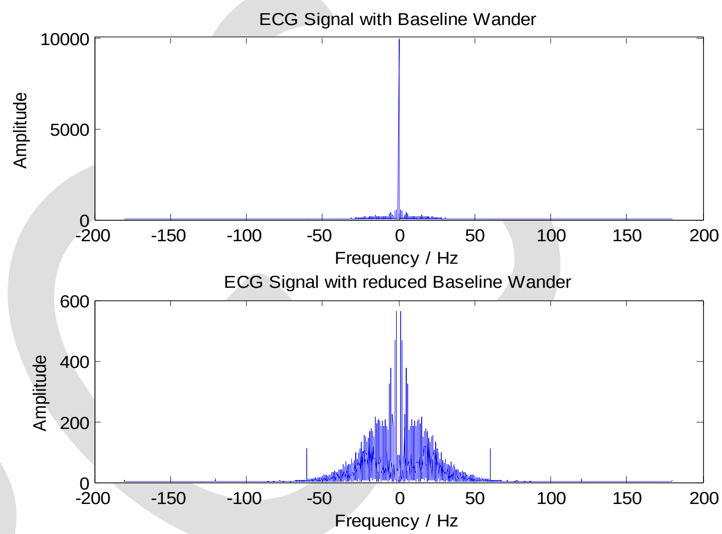

Fig.2. ECG before & after filtering of Baseline Wander (FFT)

RESULTS

The results were generated with the designed filters applying various raw MIT-BIH data for various methods of digital IIR high pass filter and low pass filter. The filter with various methods at order 1, 2 and 3 shows different results. The graphs for the signal and their power spectrums density before and after filtering are shown for various methods at 1 order.

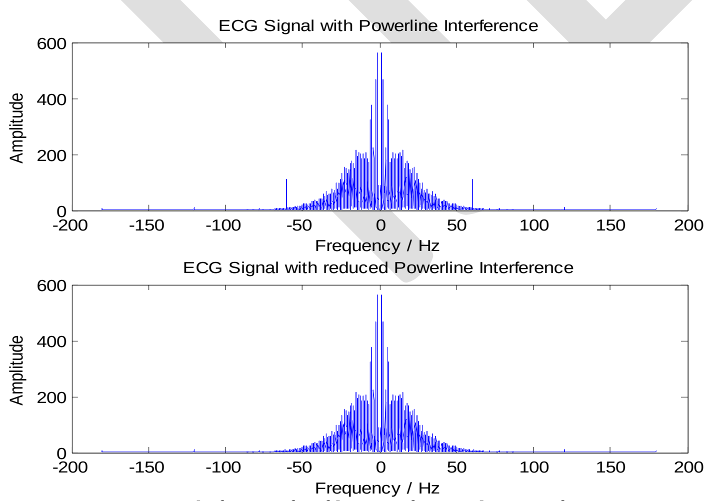

Fig.3.ECG before & after filtering of Power line Interference

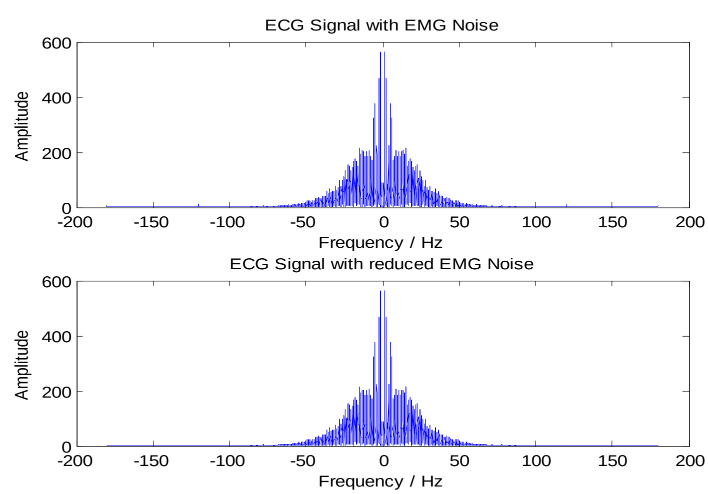

Fig.4.ECG before & after filtering of EMG noise (FFT)

In Butterworth based on IIR filter response, it was clear that the filter has sharp attenuation and pulsation in the stop band. In the pass band, the filter was found to be stable. The Chebyshev I, Chebyshev II and Eliptic do not have a sharp cut-off like the Butterworth. The above figures show the filtered ECG signal by passing through the IIR filter based on various approximation methods respectively.

Using these methods, we designed the high pass filter of cut-off frequency 0.5 Hz for eliminating baseline wandering, band stop filter of cut-off frequency 59.50Hz - 60.50 Hz for removing power line interference and the low pass filter of cut-off frequency 100Hz for reducing EMG noise.

The Comparison of different IIR filters by calculation of SNR (Signal to noise ratio) and MSE (mean square error) was done at 1 orders. The results are shown in tabular form:

SNR OF ECG BEFORE AND AFTER FILTERING ORDER -1

MIT-BIH real ECG data	SNR of noisy ECG signal	Signal to noise ratio of IIR filtered ECG signal			
		Butterworth	*Chebyshev Type 1*	Chebyshev Type 2	Eliptic
100m	12.2022	12.6683	12.2861	2.0299	12.2861
104m	8.0892	7.6443	7.7751	2.1893	7.7751
105m	8.3009	8.2761	8.2661	3.8530	8.2661
106m	10.1212	9.9547	9.9547	0.7720	9.9547
108m	4.7045	4.1787	4.2032	0.9093	4.2032
109m	6.3300	6.2211	6.2263	1.1050	6.1828

MSE OF ECG BEFORE AND AFTER FILTERING ORDER -1

MIT-BIH real ECG data	MSE of noisy ECG signal	MSE of IIR filtered ECG signal			
		Butterworth	*Chebyshev Type 1*	Chebyshev Type 2	Eliptic
100m	0.1391	0.0284	0.0293	6.5477e-14	0.0293
104m	0.1303	0.0612	0.0654	9.9768e-14	0.0654
105m	0.1423	0.0914	0.0934	5.0927e-14	0.0937
106m	0.1288	0.0897	0.0925	5.3251e-14	0.0925
108m	0.0892	0.0208	0.0226	8.5044e-14	0.0226
109m	0.2500	0.1653	0.1698	1.3127e-14	0.1680

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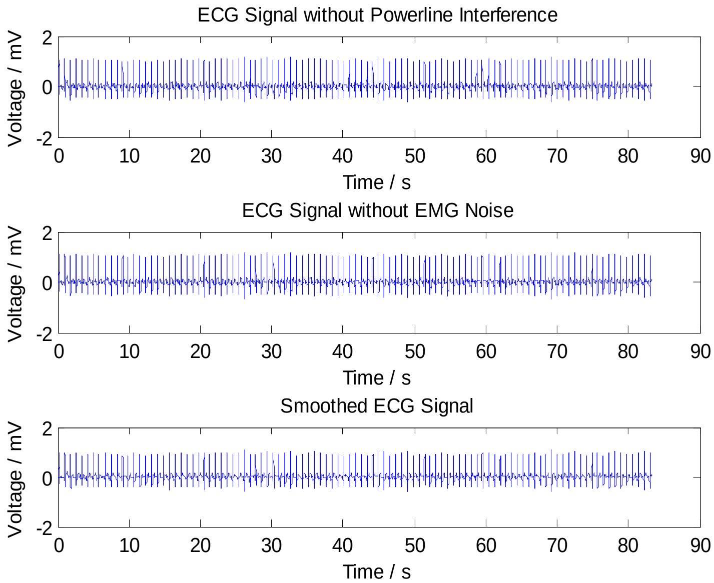

Fig.5.ECG shows signal after denoising and smoothing

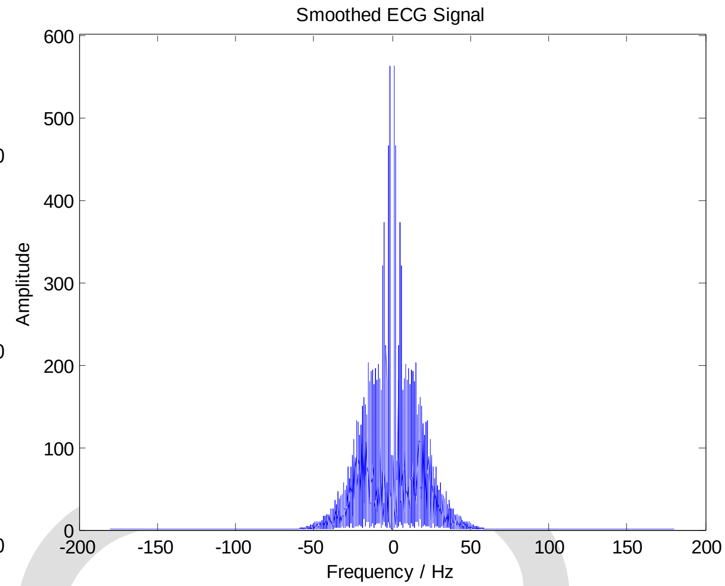

Fig.6.Smoothed ECG Signal (FFT)

CONCLUSION

This article, introduced a method used for artifacts reduction from ECG signal which basically includes of designing of filter with various approximation methods as of Butterworth, ChebyshevI, Chebyshev II and Eliptic with different order 1, 2, 3 with proper parameters indicating the best outcomes of baseline wander noise, power line interference, and electromyography noise removal. The results for various filters are considered and evaluated by waveforms, power spectrums density (PSD), signal to noise ratio (SNR), Mean square error (MSE) where Butterworth show the best outcome. The order 1 of filters designed showing the best results comparison to order 2 and 3. Hence it can be finalized that Butterworth shows best outcomes at order 1.

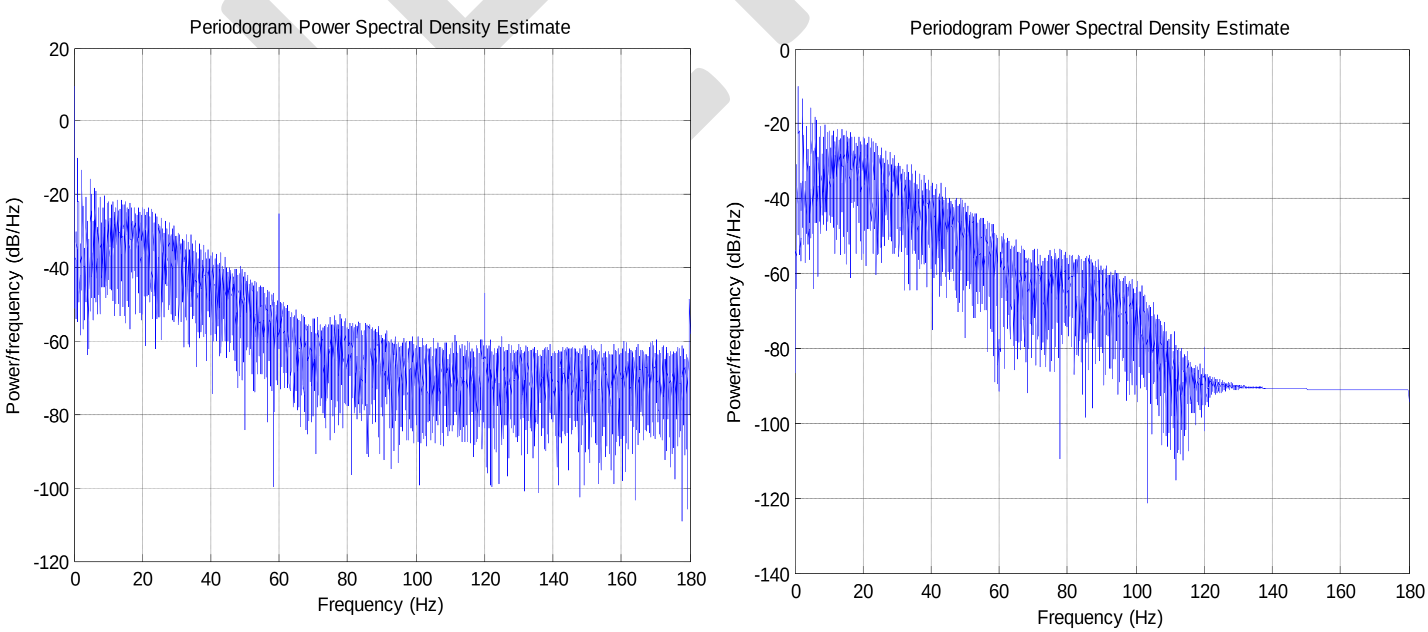

Fig.7.Shows ECG Signal before & after filtering with Power Spectrums Density (PSD)

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