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Performance Comparison of Windowing Techniques for ECG Signal Enhancement

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Abstract-Electrocardiogram (ECG) signal is generally corrupted by various artifacts like baseline wander, power line interference (50/60 Hz) and electromyography noise and these must be removed before diagnosis. The task propounded in this article is removal of low frequency interference i.e. baseline wandering and high frequency noise i.e. electromyography in ECG signal and digital filters are implemented to delete it. The digital filters accomplished are FIR with various windowing methods as of Rectangular, Hann, Blackman, Hamming, and Kaiser. The results received are at order of 300,450,600.The signal taken of the MIT-BIH database which contains the normal and abnormal waveforms. The work has been in MATLAB where filters are implemented in FDA Tool. The result received for entire FIR filters with various windows 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 Kaiser Window.

Keywords: **ECG,FIR filter, windowing methods, MATLAB**

1. INTRODUCTION

The ECG is a diagnostic tool that measure and records the electrical activity of the heart. The heart's electrical activity produces currents that radiate through the surrounding tissue to the skin. The currents are then transformed into waveforms that represent hearts depolarization, repolarization cycle. An ECG complex represents the electrical events occurring in one cardiac cycle. A complex consists of five waveforms label with the letters P,Q,R,S and T . The middle three letters Q, R and S are referred to as unit, In the QRS complex "P" represents atrial depolarization –conduction of an electrical impulse through the atrial. If the P wave proceeds each QRS complex that this electrical impulse originated in the sinoatrial node (SA).The PR interval tracks the atrial impulse from the atrial through AV node, bundle his, right and left bundle branches. The QRS complex follows the P wave and represents the depolarization of the ventricles, that contraction ejects blood from the ventricles and pumps it through arteries creating a pulse. The ST segment represents the end of the ventricular conduction or depolarization and the beginning of ventricular recovery or repolarization. The T wave represents ventricular recovery or repolarization, the QT interval measures ventricular depolarization and repolarization. The length of the QT interval varies according to heart. The U wave represents the recovery period of the purkinje fibers.
The electrocardiogram (ECG) signal is one of the recognizing approaches to find heart disease. ECG analysis can be utilized to exploit important characteristic parameters. ECG signal is a graphical indicates of cardiac activity and useful to determine the different cardiac diseases and abnormalities available in heart. This signal may corrupted due to different types of the artifacts [6].ECG signal are generally corrupt by unwanted interference like motion artifacts, muscle noise, electrode artifacts, base line drift line 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 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 demonstrate the performance of digital FIR filters with different windowing techniques. In the results are indicating to comparatively in frequency spectrums 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 [7] website[8].

2. THEORY

2.1. Digital FIR filter:

FIR filters are digital filters with finite impulse response. They are also known as non-recursive digital filters as they do not have the feedback, even though recursive algorithms can be used for FIR filter realization.FIR filter is characterized by following equations:

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

2.2. Window method:

In this method, we start with the desired frequency response specification $Hd(\omega)$ and the corresponding unit sample response $hd(n)$ is determined using inverse Fourier transform. The relation between $Hd(\omega)$ and $hd(n)$ is as follows :

$$Hd\,(\omega) = \sum hd\,(n)\, e^{-j\omega n}. \quad (2)$$

Where

$$hd\,(n) = \int H\,d\,(\omega)\, e^{\,jwn}\, d\omega \quad (3)$$

Thus, the impulse response of the FIR filter becomes

$$h(n) = hd\,(n)\, w(n) \quad (4)$$

Now, the multiplication of the window function $w(n)$ with

$hd(n)$ is equivalent to convolution of $Hd(\omega)$ with $W(\omega)$, where $W(\omega)$ is the frequency domain representation (Fourier transform) of the window function. By using appropriate window functions method which is time function we can reduce Gibbs oscillations.

A) Rectangular window:

The rectangular window is rarely used for its low stop band attenuation. Rectangular window coefficients as all coefficients between 0 and N-1 (N-filter order) are equal to 1, which can be expressed in the following way:

$$W[n] = 1;\ 0 \le n \le N-1 \qquad (5)$$

B) Hanning window:

The Hann window is used to higher stop band attenuation than the rectangular window function and ability to relatively fast increase the stop band attenuation. The Hann window coefficients can be expressed as:

$$w[n] = \frac{1}{2}\left[1 - \cos\left(\frac{2\pi n}{N-1}\right)\right];\ 0 \le n \le N-1 \qquad (6)$$

C) Hamming Window:

The Hamming window is one of the most popular and most commonly used windows. A filter designed with the Hamming window has minimum stop band attenuation. The transition region is somewhat wider than that of the Hann window, whereas the stop band attenuation is considerably higher. The Hamming window coefficients are expressed as:

$$w[n] = 0.54 - 0.46\left(1 - \cos\left(\frac{2\pi n}{N-1}\right)\right);\ 0 \le n \le N-1 \qquad (7)$$

D) Blackman Window:

The Blackman window has high attenuation makes this window very convenient for almost all applications. The Blackman window coefficients are expressed as:

$$w[n] = 0.42 - 0.5\cos\left(\frac{2\pi n}{N-1}\right) + 0.08\cos\left(\frac{4\pi n}{N-1}\right);\ 0 \le n \le N-1 \qquad (8)$$

E)Kaiser Window:

An optimal window is a function that has a maximum attenuation according to the given width of the main lobe. The optimal window is also known as Kaiser Window. Its coefficients are expressed as:

$$w[n] = \frac{I_o\left(\beta \cdot \sqrt{1 - \left(\frac{n-\alpha}{\alpha}\right)^2}\right)}{I_o(\beta)};\ 0 \le n \le N-1 \qquad (9)$$

$$\alpha = \frac{N-1}{2}$$

$$N = \frac{a_a - 8}{4.57 \cdot \Delta\omega} + 1$$

Where a_a is the minimum stop band attenuation, and $\Delta\,\omega$ is the width of (normalized) transition region.

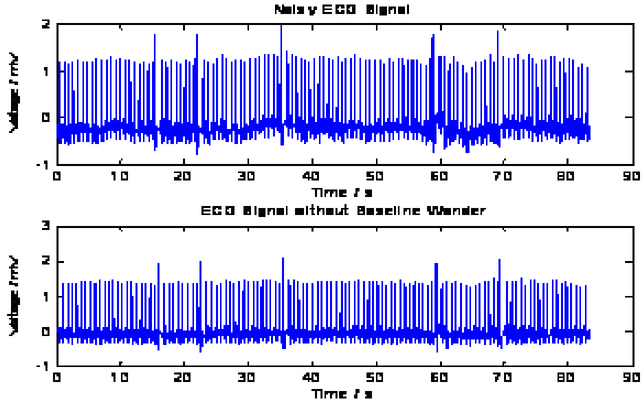

Fig.1.ECG before & after filtering of Baseline Wander

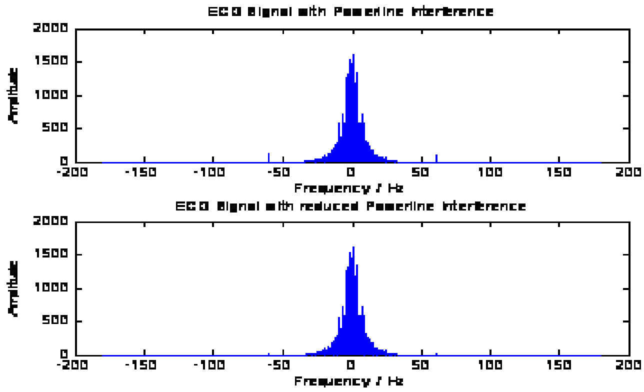

Fig.2.ECG before & after filtering of Power line Interference

3. METHODOLOGY

The FIR filter design procedure with window functions method can be classified to different stage:

- Defining filter characteristic
- Determining a window function according to the filter characteristics
- Calculating the filter order required for a given set of characteristics
- Computing the window function coefficients
- Calculating the ideal filter coefficients according to the filter order
- Computing FIR filter coefficients according to the gain window function and ideal filter coefficients
- If the resulting filter has too wide or too narrow transition area, it is required to change the filter order by increasing or decreasing it according to denoising of ECG signal.

In this paper following the above stages we worked as follow: 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 FIR with high pass filter cut off frequency 0.5 Hz based on window to deleting baseline wander noise from noisy ECG signal, in second step removing power line interference (50/60 Hz) by band stop with cut off

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frequency (59.5Hz-60.5 Hz) , in third step we deleting 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,108,109(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.

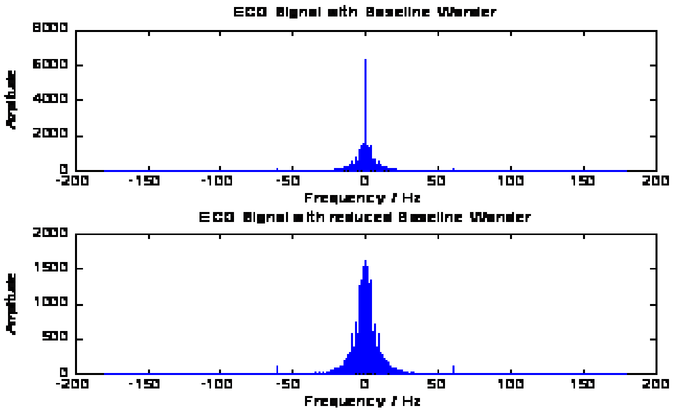

Fig.3. ECG before & after filtering of Baseline Wander (FFT)

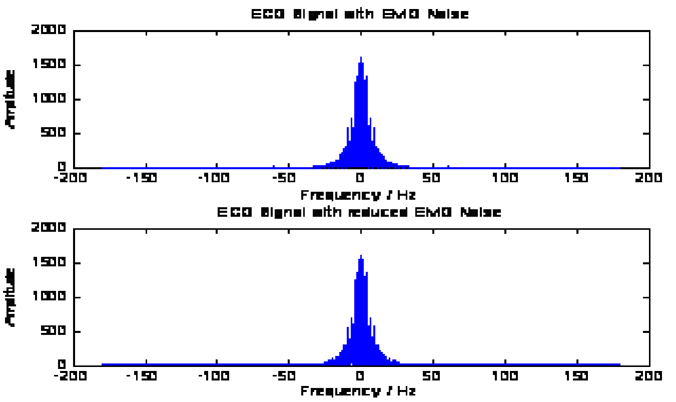

Fig.4.ECG before & after filtering of EMG noise (FFT)

4. RESULTS

The results were generated with the designed filters applying various raw MIT-BIH data for various windowing of digital FIR high pass filter and low pass filter. The filter with various windowing at order 300,450,600 shows different results. The graphs for the signal and their power spectrums density before and after filtering are shown for various windows at 300 orders. Using these windows, we designed the high pass filter of cut-off frequency 0.5 Hz for removing 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 removing EMG noise.

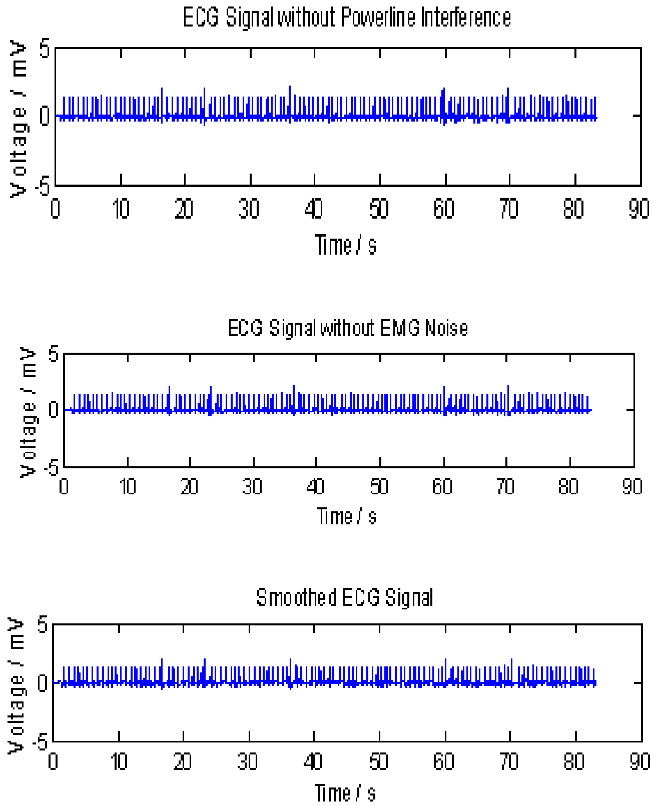

Fig.5.ECG shows signal after denoising and smoothing

The Comparison of different FIR filters by calculation of SNR (Signal to noise ratio) and MSE (mean square error) was done at 300 orders. The results are shown in tabular form:

Table 1 SNR (Signal to noise ratio) comparison of window based FIR filters

Real ECG data	SNR	Signal to noise ratio of FIR (windowing) filtered ECG signal				
		Rectangular	Hann	Hamming	Blackman	Kaiser
100m	12.2	12.331	14.14	13.977	14.144	12.42
104m	8.09	7.8216	7.520	7.581	7.7855	7.793
105m	8.30	9.2670	8.396	8.4674	8.5737	9.333
106m	10.1	10.963	12.44	12.478	12.504	13.01
108m	4.71	3.4711	5.155	4.9928	5.4241	5.516
109m	6.33	7.2382	6.258	6.3297	6.3841	7.184

Table 2 MSE (Mean square error) comparison of window based FIR filters

Real ECG data	MSE	Mean square error of the FIR (windowing) filtered ECG signal				
		Rectangular	Hann	Hamming	Blackman	Kaiser
100m	0.1391	0.0349	0.0667	0.0631	0.0751	0.036
104m	0.1303	0.0637	0.0811	0.0792	0.0852	0.066
105m	0.1423	0.0968	0.1067	0.1054	0.1095	0.097
106m	0.1288	0.0920	0.1008	0.0997	0.1031	0.092
108m	0.0892	0.0262	0.0434	0.0414	0.0481	0.027
109m	0.2500	0.1725	0.1915	0.1891	0.1956	0.173

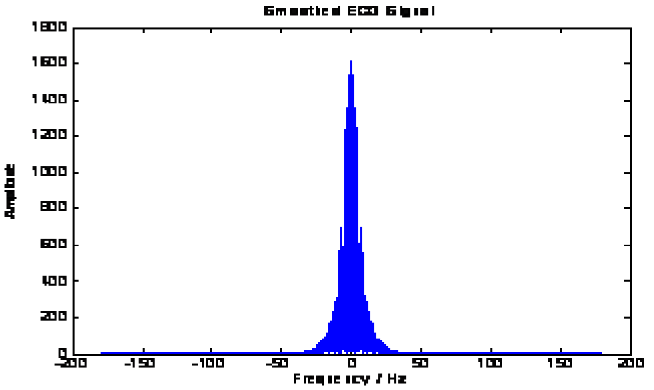

Fig.6.Smoothed ECG Signal (FFT)

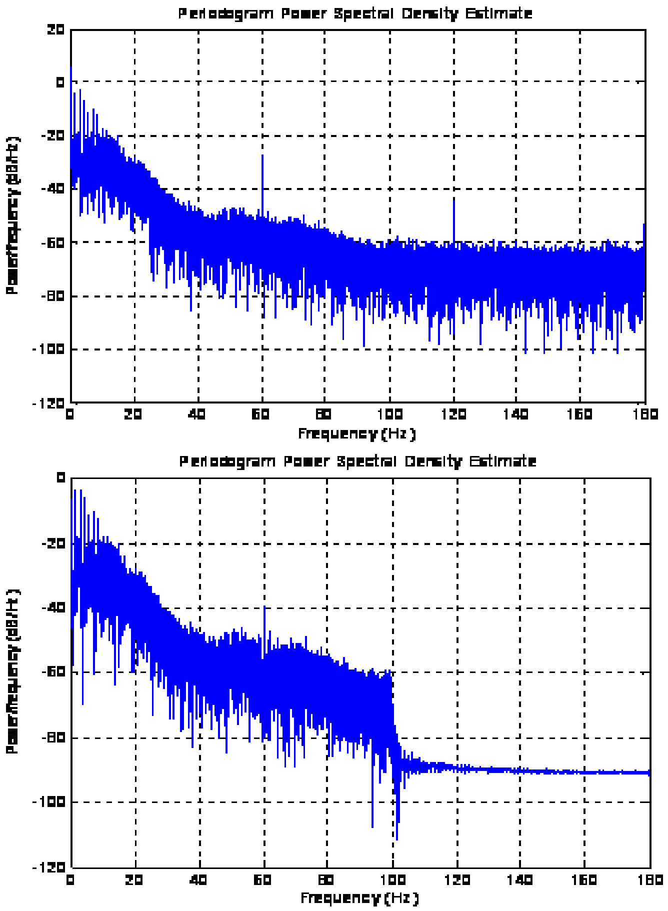

Fig.7.Shows ECG Signal before & after filtering with Power Spectrums Density (PSD)

5. CONCLUSION:

This article, introduced a method used for artifacts reduction from ECG signal which basically includes of designing of filter with different windows like Rectangular, Hann, Hamming, Blackman and Kaiser Window with different order 300,450,600 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 Kaiser Window show the best outcome. The order 300 of filters designed showing the best results comparison to order 450 and 600. Hence it can be finalized that Kaiser Windowing shows best outcomes at order 300.

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