Performance Evaluation of Various Window Techniques for Noise Cancellation from ECG Signal

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ABSTRACT
Removal of noise from ECG Signals leads to the accurate analysis of potential diseases. ECG Signals are low frequency signals. In this paper, FIR low pass filter have been designed with the help of window techniques at cut off frequency 60 Hz to remove noise from corrupted signal. Additive white Gaussian noise (AWGN) is added artificially to the ECG samples recorded from MIT-BIH database. Comparison of ECG Signal before and after filtering is done on the basis of two parameters i.e. signal to noise ratio and average power. The results are calculated using Gaussian, Bartlett and Hann window based FIR filter.

Keywords
FIR digital filter, Signal to noise ratio (SNR), Average Power, Window Technique.

1. INTRODUCTION
The ECG signals are examined widely for the diagnosis of many cardiac diseases. The signals are traced using non invasive electrodes which are placed on the chest and limbs. The heart muscle cells which are located in atria and ventricles contract generating electric pulses which are then traced by the ECG. The ECG signals of a normal heart beat consist of three parts: P wave, QRS complex and T wave. The P wave represents the atrial contractions. QRS complex denote ventricle contractions. [1] The third wave in an ECG is the T wave. This is produced when the ventricles are repolarising. These waves show ample range of deformities in the ECG signal.

The ECG recordings that are obtained by placing electrodes are generally contaminated by several types of noises. These include Power Line interference (PLI), Base line wander, muscle contraction and motion artifacts. PLI constitute the main part of the distortions at 50-60 Hz. Motion artifacts are the transient baseline changes caused by mismatching of impedance between the electrodes and the skin. [2] Baseline wander is the continuous drifting of the ECG Signal from the baseline. It is mainly caused by respiration and increased body movements. [3]The distortions are also created by the noise from the recorder, electronic devices and electrostatic potentials. [4] The interference within the ECG signal affects the analysis and the detection of QRS complex. Hence, for the correct diagnosis of the cardiac disease the ECG signal should be clean and noise free. The main requirements for noise removal of ECG Signal are: 1. ECG denoising method should preserve the ECG characteristic waves and it should not disturb the sharp ECG peaks. 2. ECG denoising improves SNR. [5]

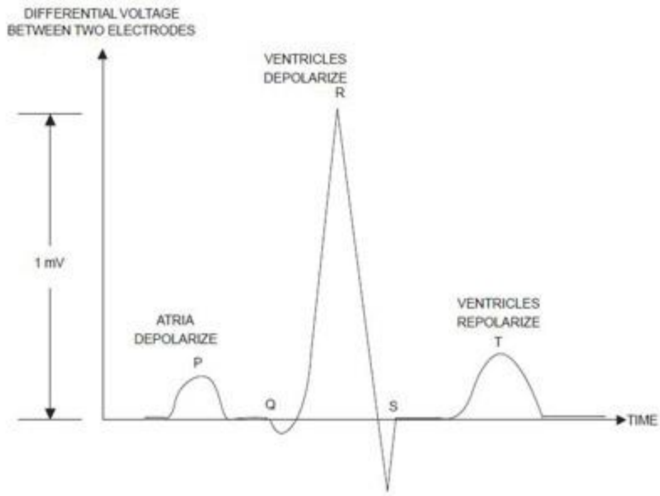

Figure 1: Typical ECG Signal [6]

ECG noise removal involves multiple filters with various techniques. Digital filters are preferred because of its high stability, frequency deviation range; computer based design, low cost implementation and increased reliability. Digital filters are generally classified into two: FIR and IIR filters. The low pass filter helps limiting the artifact for routine cardiac rhythm monitoring. It helps in the reduction of PLI. As the cardiac signals are low frequency signals, a FIR filter is the right choice to remove the noise.

2. LITERATURE SURVEY
Bhumika Chandrakar et. al. [7] proposed a survey on the noise removal techniques for the ECG Signals and it has been shown that the digital FIR filter with Kaiser Window removes the artifacts from ECG with less modification in the waveform. K.D. Chinchkhede et. al. [8] compared various window techniques for the noise removal of ECG signals and concluded that Kaiser Window works best when to Gaussian, Blackman and Blackman-Harris window techniques of FIR Filter. Geeta Kadam et. al. [9] compared all the FIR filter design techniques used for ECG signal noise removal including equi-ripple and least square algorithm. Equi-ripple and least square algorithm are more complex to design than window techniques but are more efficient in noise removal. C.B. Mbachu et. al. [10] compared adaptive notch filter and FIR notch filter designed with hamming window for removal of power line noise from ECG signals. Mahesh S. Chavan et. al. [11] compared various techniques of FIR filter design. FIR filter with equiripple have been designed and implemented.

The effect of filtration of QRS complex with equiripple and least square method is also shown. In comparison with the window techniques, the reduction of noise is more in equiripple and least square technique, with more computational time being the disadvantage.

3. FIR FILTER

FIR filters are used to realize frequency-selective operations. These filters are less complex, have powerful design algorithms. The FIR computation can be ended by looping an individual instruction hence they are easy to implement. They require fewer calculations when suited to multi rate applications, and hence have more computational efficiency. To have an ideal frequency-selective filter having a noncausal, infinite-duration impulse response, and window methods should be preferred. The impulse response of such a filter is truncated to obtain a linear phase and casual FIR filter. Hence it is necessary to select an appropriate window function. The window techniques compared here are being described below:

3.1 Window Techniques Used in Design

3.1.1 Bartlet Window

The rectangular window undergoes sudden transitions from 0 to 1 (or 1 to 0), which results gibbs phenomenon. Bartlett window offers a more steady transition in the form of a triangular window, which is given by

For N even, Bartlett window can be defined as:

$$w(n) = \begin{cases} \frac{2n}{N-1} & 0 \le n \le \frac{N}{2} - 1 \\ 2 - \frac{2n}{N-1} & \frac{N}{2} \le n \le N-1 \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

For N odd, Bartlett window can be defined as:

$$w(n) = \begin{cases} \frac{2n}{N-1} & 0 \le n \le (N-1)/2 \\ 2 - \frac{2n}{N-1} & \frac{(N-1)}{2+1} \le n \le N-1 \end{cases} \ldots\ldots\ldots (2)$$

The N defines the order of the window function.

3.1.2 Gaussian Window

Gaussian window function is calculated by the following equation:

$$w(n) = e^{-1/2\left(\alpha\frac{n}{N/2}\right)^2} \ldots\ldots (3)$$

where, – (N-1)/2≤ n ≤ (N-1)/2. The value of α defaults to 2.5.The relation between α and σ is denoted by σ = N/2α. As the σ increases, the truncation gets severe and the Gaussian window gets wider. The higher the standard deviation the better the frequency response approximates the ideal one. [12]

3.1.3 Hann Window

Hann window is a raised cosine window function which is given by-

$$w(n) = 0.5\left(1 - cos\left(2\pi\frac{n}{N}\right)\right), \quad 0 \le n \le N \ldots\ldots\ldots (4)$$

where, N defines the order of the filter.[13]

The window is also known as Cosine bell. It is a tapering function i.e. it smoothens the discontinuities. The spectral leakage behaviour can be improved by choosing a tapered window i.e. reducing the level of sidelobes. The Hann window has the fastest sidelobe decay.

The fig.2 shows time domain and frequency domain representation of the windows described above. (1-Gaussian window, 2-Bartlett window, 3-Hann window)

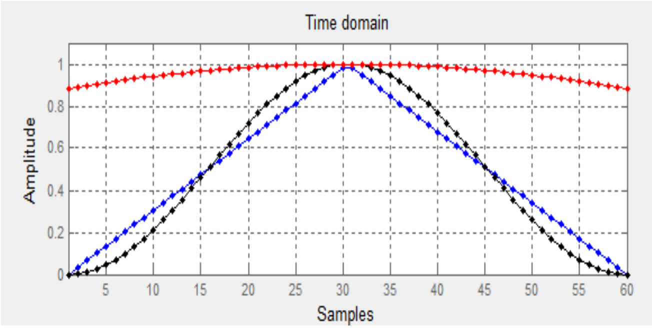

Figure 1: Time domain spectrum of window techniques.

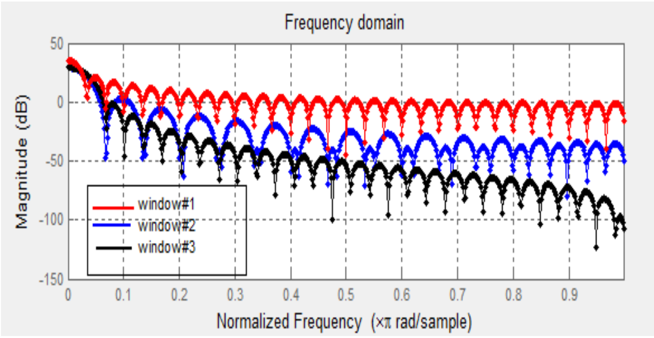

Figure 3: Frequency domain spectrum of window techniques.

3.2 Performance Measure: Signal to Noise Ratio (SNR)

M Signal to noise ratio evaluated the strength of a signal. It is defined as the ratio of signal power to the noise power. It is often expressed in decibels. The efficiency of FIR filter based noise removal is measured by evaluating:

$$SNR = 10log_{10}\left\{\frac{\sum X_r{}^2}{\sum(X_r - X_f)^2}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where X_r is the original ECG Signal and X_f is the ECG Signal after getting filtered by various window techniques. For evaluating the performance of the proposed window techniques SNR $_{improvement}$ measure has been used.

$$SNR_{improvement} = SNR_{out} - SNR_{in}$$

4. METHODOLOGY

The Dataset used in the study is taken from MIT-BIH Arrhythmia (mitdb) Database of record 100 from Physio bank atm. [14] Physio bank is a collection of well–characterized digital recordings of ECG signals. Many of the databases were developed at MIT and at Boston's Beth Israel Hospital. It currently contains over 40,000 recordings of annotated, digitized physiologic signals and time series, organised in over 60 databases (collection of databases). Each database consists of a set of records, identified by a record name. The samples are taken for a time limit of 10 seconds. The sampling frequency from the recorded samples comes out to be 360 Hz.

The AWGN of 10 db is added to the signal after the removal of baseline wander from the original ECG signal. For the design of FIR low pass filters, MATLAB version 7.8.0.2009a, with signal processing FDA toolbox was used. The FIR low pass filter is then designed with the sampling frequency of 360 Hz and cut off frequency of 60 Hz to remove the noise with Bartlett, Gaussian and Hann window techniques. The pole zero plots of the designed filters are indicated in figure 4 5 & 6. A comparison is made between the three window techniques on the basis of SNR and average power.

5. RESULTS

The noisy ECG Signal gets filtered with the help of FIR filter using three different window techniques. The original ECG signal is passed through FIR low pass filter with various windows. The plots of ECG before filtering and then after filtering with Bartlett window, Gaussian window and hann window are given below. Table 1 illustrates the signal to noise ratio of three different window techniques of FIR filter i.e. Bartlett window, Gaussian window and hann window. The SNR before and after filtering has been specified along with the SNR improvement.

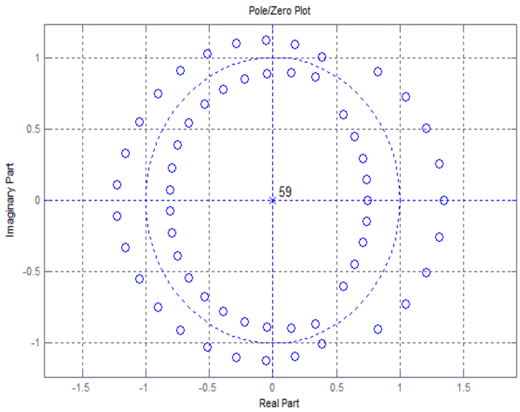

Figure 4 Pole Zero Plot of Bartlett Window.

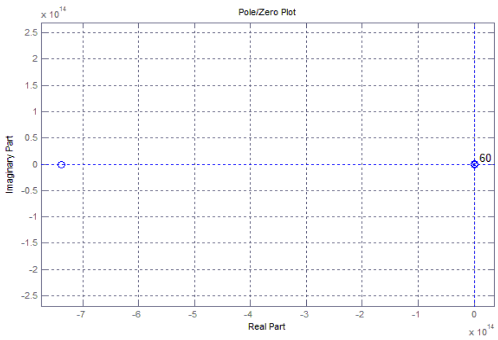

Figure 5 Pole Zero Plot of Gaussian Window.

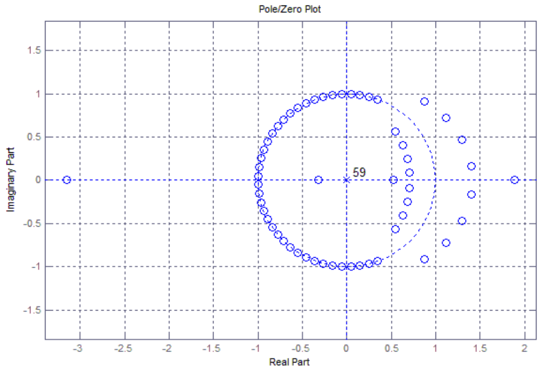

Figure 6 Pole Zero Plot of Hann Window.

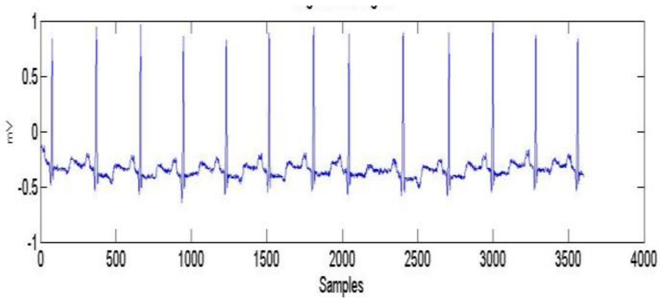

Figure 7: Original ECG Signal before adding noise.

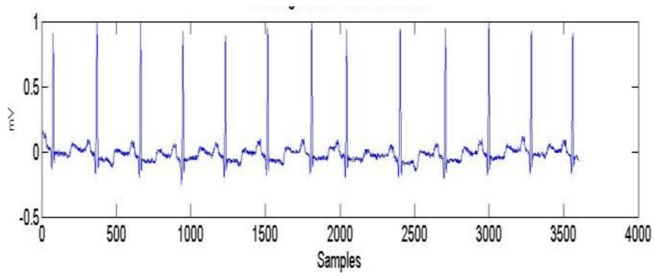

Figure 8: ECG signal after Baseline Removal.

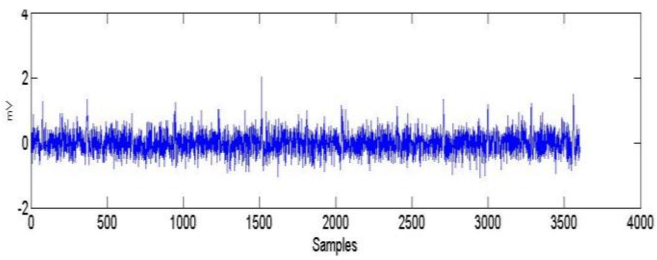

Figure 9: ECG Sign al after adding noise of snr 10 db.

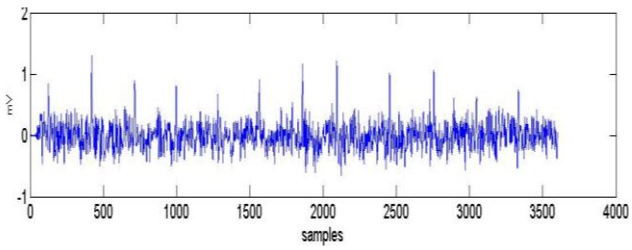

Figure 10: ECG Signal after filtering with Bartlett window.

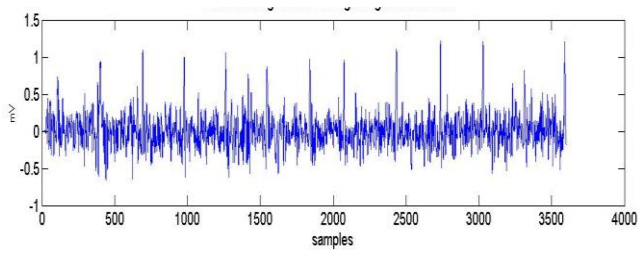

Figure 11: ECG Signal after filtering with Gaussian window.

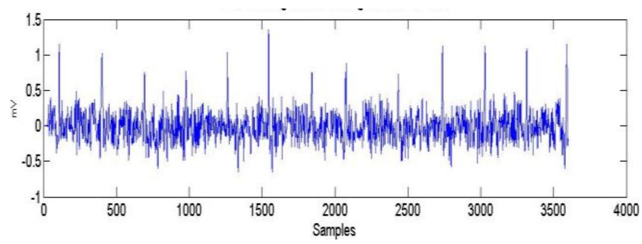

Figure 12: Plot of ECG Signal after filtering with hann window

The comparison between the window techniques will be made on the measure of SNR improvement. The best SNR improvement is of Gaussian window of all the compared window techniques. Furthermore, Hann window works better than the Bartlett for the noise removal of ECG signal. Table 2 indicates average power of ECG signal before and after filtering from the FIR filter with specified window techniques. The table clearly indicate that the average signal power of ECG signal filtered with Gaussian window is slightly higher than the other window techniques.

Hence, FIR filter with the Gaussian window works the best with other two window techniques for ECG noise removal.

Table 1. SNR for ECG signal before and after filtering for N=60

Performance measures	Bartlett Window	Gaussian Window	Hann Window
SNR Before filtering	-8.1549	-8.1549	-8.1549
SNR After filtering	-3.7648	-3.4710	-3.7082
SNR improvement	4.3901	4.6839	4.4467

Table 2. Average Power of ECG Signal

Average Power before filtering	Average Power after filtering		
	Bartlett Window	Gaussian Window	Hann Window
-17.5233	-13.1298	-12.8361	-13.0732

6. CONCLUSION

The comparison between the three windows techniques used for the design of FIR low pass filter i.e. Bartlett, Gaussian, Hann window is made. Results show that Gaussian window technique has improved SNR of the ECG signal after filtering. The average power of the ECG signal after filtering is also increased in case of FIR low pass filter with Gaussian window technique. Hence, Gaussian Window works excellent in removing PLI from the corrupted ECG signal as compared to Bartlett and hann window techniques.

7. REFERENCES

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