

Comparative Study of Different Filters with Several Window Techniques Using Wavelet for Removing Noise from ECG Signal

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Abstract— This paper presents removal of noise from the ECG signal by using Digital filters designed with FIR and IIR technique. Results are obtained for the given order of the filter using windowing technique for the FIR filter. The wavelet transform is used to reduce the effect of noise to get refined signal. The power spectral density and average power, before and after filteration using different window techniques and wavelet utilization at 4 and 6 dB are compared. Order of the filter is also different. Filter with the Kaiser window shows the best result

Index— ECG, FIR Filter, Windowing Technique, Wavelet Transform, power spectral density and average power.

I. INTRODUCTION

Interference occurs in ECG signal is very common and serious problems. Digital filter are designed to remove this limitation. FIR with different windowing method is used. The results are obtained at low order . The input signals are taken from ECG database which includes the normal and abnormal waveforms. FDA tool is used in MATLAB to design these filters [1]. Many times when ECG signal is recorded from surface electrode that are connected to the chest of patient, the surface electrode are not tightly in contact with the skin as the patient breath the chest expand and contract producing a relative motion between skin and electrode. This results in shifting of baseline which is also known as low frequency baseline wander. The fundamental frequency of baseline wander is same as that of respiration frequency. It is required that baseline wander is removed from the ECG before extraction of any

analyze ECG, especially in the detection of ST-segment deviations.

II. FILTER DESIGN

A. FIR-Filter

The design parameters and the block diagram of the filter is shown in figure 2.

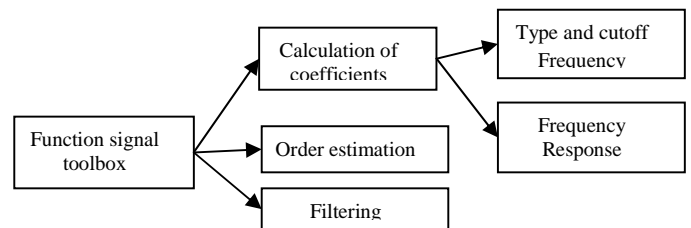


Fig. 2 Block diagram of design process of filter

Steps for designing the filter are given explained as follows:

Step 1: Selection of standard ECG data and extraction of ECG signal.

Step 2: Design and implementation of FIR and IIR filters for the removal of Baseline noise from ECG signal.

Step 3: Implementation of Wavelet for overall denoising.[5]

Step 4: Design and implementation of adaptive filters for the removal of Powerline noise from ECG signal.

This paper cover, all the steps that preceded project

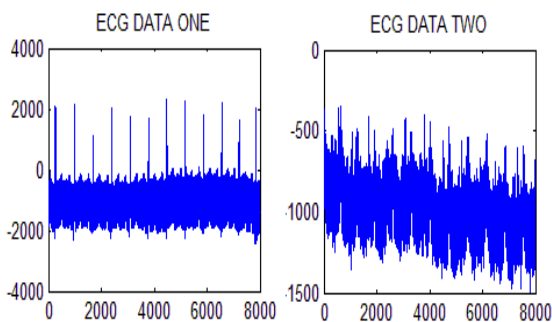


Fig. 1 ECG data with 8000 sampled on the conference website.

meaningful feature. Baseline wander makes it difficult to

implementation. A major element of this stage was the extraction of ECG signals the standard database that chosen for the work. After extraction, the signals are subject to processing, using several tools available in the MATLAB[6].

B. Window Use In Designing

FIR filters can also be designed using the windowing method. The ideal filter have infinite number of samples in time domain given in equation 3. Windows are performed in order to have finite number of samples in time domain for realiable filter design.

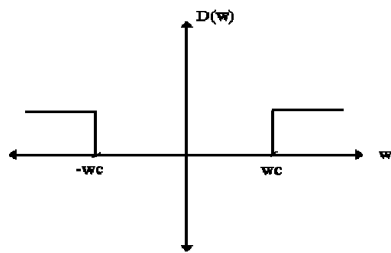


Fig. 3 Magnitude response of an ideal filter.

The cut-off frequency is w_c . The ideal high pass filter characteristic is given in Fig. 2. The continuous frequency response and the discrete-time impulse response are related by the equation 1. The aim is giving the relation between ideal frequency domain filter and its impulse response in time domain and to show the importance of windowing method [15].

$$D(w) = \sum_{k=-\infty}^{\infty} d(k) \cdot e^{-jkw} \quad \dots(1)$$

$$d(k) = \int_{-\pi}^{\pi} \frac{D(w)}{2 \cdot \pi} e^{jwk} dw \quad \dots(2)$$

The filter's impulse response can be obtained by using the inverse Fourier transform. The filter coefficients will simply be the impulse response samples. The desired low pass filter's response is given by equation 3.

$$D(w) = \begin{cases} 1, & \text{if } |w| < w_c \\ 0, & \text{elsewhere} \end{cases} \quad \dots(3)$$

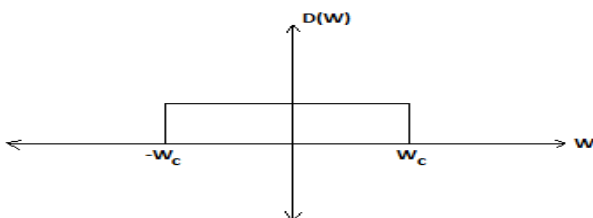


Fig 4 :Magnitude response of an ideal window.

A window function from $-w_c$ to w_c is employed to show the windowing effect[15].

There are different windowing functions. The important window functions are rectangular window, Hamming, Hanning, Blackman windows [15].

Rectangular Window

The filter is required to have finite number of values within a certain interval, from $-M$ to M . This is equivalent to multiplying $d(k)$ by a rectangular function given by

$$w(n) = \begin{cases} 1, & \text{if } |n| < M \\ 0, & \text{otherwise} \end{cases} \quad \dots(4)$$

Hamming Window

Discontinuities in the time function cause ringing in the frequency domain. The rectangular window is replaced by a window function ending smoothly at both ends which will cause reduction in ripples. The hamming window is an important window function. The hamming window is defined as:

$$w(n) = .54 - .46 \cos \left(\frac{2 \pi n}{N - 1} \right) \quad n = 1, 2, 3, 4, \dots, N - 1 \quad \dots(5)$$

Where N is the order of the filter and M is the window length. This equation defines the window samples as already shifted (indices from 0 to 'N-1'). So the impulse response of the FIR low pass filter designed using the hamming window is [15]:

$$h(n) = w(n) \cdot d(n - M) \quad h(n) = \left(.54 - .46 \cos \left(\frac{2 \pi n}{N - 1} \right) \right) \frac{\sin((n - M) \cdot w_n)}{(n - M) \cdot \pi} \quad \dots(6)$$

The ripples that occur in rectangular windowing in both the pass band and the stop band are virtually eliminated. Thus, the filtered data will have a wider transition width.

The Hamming window is defined mathematically as:

$$w(n) = .5 - .5 \cos \left(\frac{2\pi n}{N-1} \right)$$

$$n = 0, 1, 2, 3, 4, \dots, N-1 \quad \dots(7)$$

The difference of Hamming window is performed window function. This function is quite similar to the Hamming window.

- Blackman Window

The Blackman window exhibits a lower maximum stop band ripple in the resulting FIR filter than the Hamming window. It is defined mathematically as:

$$w(n) = 0.45 + 0.5 \cos \left(\frac{2\pi n}{N-1} \right) + 0.08 \cos \left(\frac{4\pi n}{N-1} \right)$$

... (8)

The width of the main lobe in the magnitude response is wider than that of the Hamming window.

- High Pass Filter Design

The amplitude response of a low pass filter is shown in Fig. 5. Low pass filter is first applied, and with simple transformations the high pass filter can then be easily performed.

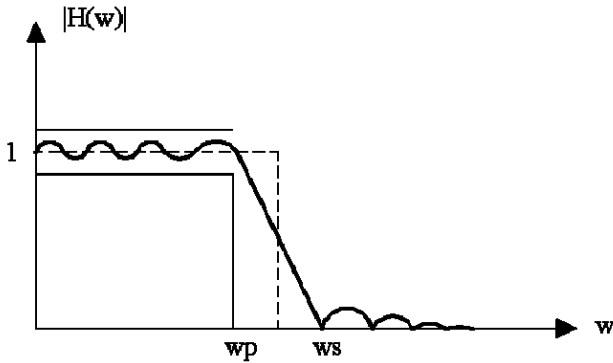


Fig. 5: Magnitude response of a low pass filter.

Pass-band and stop-band regions are illustrated with equation 9 and equation 10.

The derivation of the transformation is specified with the following equations:

$$w_p = \frac{2\pi f_{pass}}{f_s}, w_s = \frac{2\pi f_{stop}}{f_s} \quad \&$$

$$w_c = \frac{2\pi f_c}{f_c} \quad \dots(9)$$

The ideal cut off frequency, f_c , is at the midpoint between the pass band and stop band edge frequencies set in equation 10:

$$f_c = \frac{f_{pass} + f_{stop}}{2} \quad \dots(10)$$

The transition width is defined as:

$$\Delta f = f_{stop} - f_{pass} \quad \dots(11)$$

Since the role of f_{pass} and f_{stop} are interchanged in order to design high pass filter. The ideal high pass impulse response is obtained from the inverse Fourier transform of the ideal high pass frequency response. It is specified by equation 12:

$$d(k) = \left(\delta(k) - \sin \left(w_c \cdot k / \pi k \right) \right) \quad \dots(12)$$

The windowed filter impulse response is:

$$h(n) = w(n) [\delta(n-M)] \frac{\sin[(n-M) \cdot w_c]}{(n-M)}$$

$$h(n) = \delta(n-M) - w(n) \frac{\sin[(n-M) \cdot w_c]}{(n-M)\pi} \quad \dots(13)$$

C. IIR Filter Design

An IIR filter is one whose impulse response theoretically continues for ever because the recursive terms feedback energy into the filter input and keep it as specified in the following equation:

$$y(n) = \left[\sum_{k=1}^N a(k) \cdot y(n-k) + \sum_{k=0}^M b(k) \cdot x(n-k) \right]$$

$$H(z) = \frac{\sum_{k=0}^M b(k) z^{-k}}{\sum_{k=0}^N a(k) z^{-k}} \quad \dots(14)$$

The theory of Butterworth function is explained here but, the order of the filter should be high and implementing a filter of that order is not easy to perform. In addition to this difficulty, solving these high order equations is not straightforward.

D. Wavelet

A wavelet[11] is a wave-like oscillation with amplitude that starts out at zero, increases, and then decreases back to zero. It can typically be visualized as a "brief oscillation" like one might see recorded by a seismograph or heart monitor. Generally, wavelets are purposefully crafted to have specific properties that make them useful for signal processing. Wavelets can be combined, using a "shift, multiply and sum" technique called convolution, with portions of an unknown signal to extract information from the unknown signal.

As wavelets are a mathematical tool they can be used to extract information from many different kinds of data, including - but certainly not limited to – audio signals and images. Sets of wavelets are generally needed to analyze data fully.

III. RESULTS AND CONCLUSION

In this paper various noise removal techniques are applied to ECG signals[10], ECG database data sample, and the performance of these approaches are studied on the basis of spectral density and average power of signal. In the first step, the most simple approach which is linear trend or a piecewise linear trend to remove baseline drift is applied after that various digital filters are applied to the noisy ECG data having Baseline noise as shown in fig 4.1 then the wavelet approach is used for overall denoising of ECG signal and finally the digital filter is applied on the sample ECG signal to remove Power line noise. All of the above steps are performed using MATLAB software

Calculation of parameters

The two important parameters to check the suppression of Baseline noises are spectral density and average power of signal[6]

Power spectral density :

Table1 and 2 shows the comparison of different filters. The trade-off between spectral density and average power is best among all the filters. But it can also visualize that the waveform got distorted to some extent in case of rectangular window. The Kaiser Window and rectangular window is also showing better results at the expense of some more computational load as the order of the filter is large. But in case of remaining windows i.e. Hanning and Blackman windows, the order of filter easily grow very much high. It increases the number of filter coefficients which increases the large memory requirement and problems in hardware implementation. So, the Kaiser Window filter can be best choice for the removal of Baseline wandering among filters[2].

Table1 Comparison of various filters for Removal of noise at ECG sample input 1.

Filter	Filter Order	Spectral Density before Filtration	Spectral Density after Filtration	Wavelet output at 4dB	Wavelet output at 6dB
Butterworth	2	61.0009	53.5685	53.5557	53.5625
Kaiser	450	61.0009	53.3143	53.3014	53.3075
Rectangular	450	61.0009	53.3131	53.3002	53.3063
Hanning	450	61.0009	55.9501	55.9431	55.9465
Blackmann	450	61.0009	56.7112	56.7053	56.7082

Spectral density of data 1 using different filters is shown as follows:

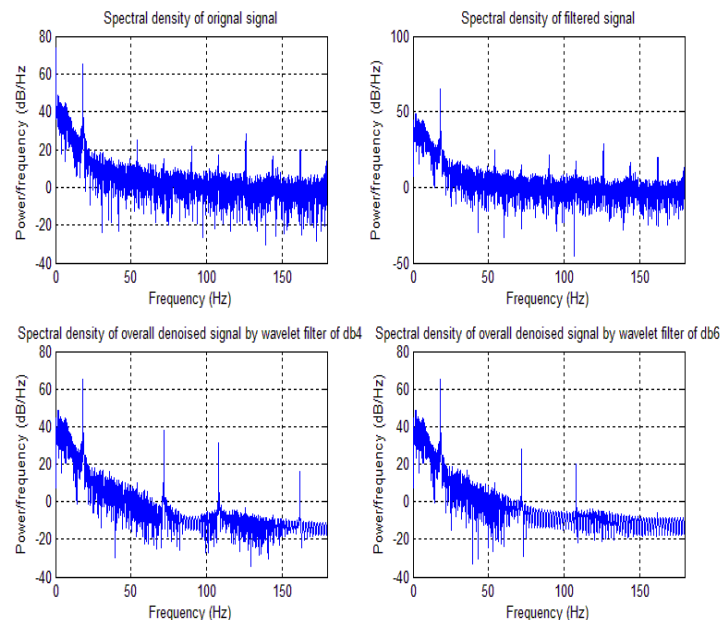


Fig.6 Spectral Density using Butterworth filter

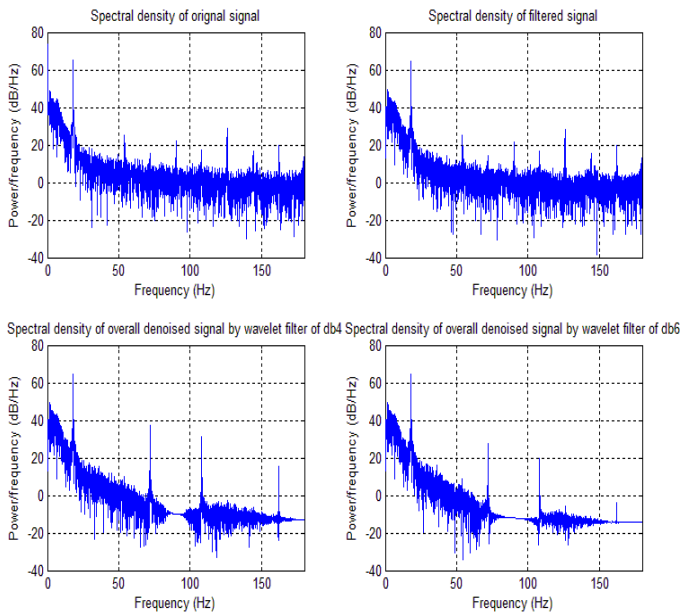


Fig.7 Spectral Density using Kaiser Filter

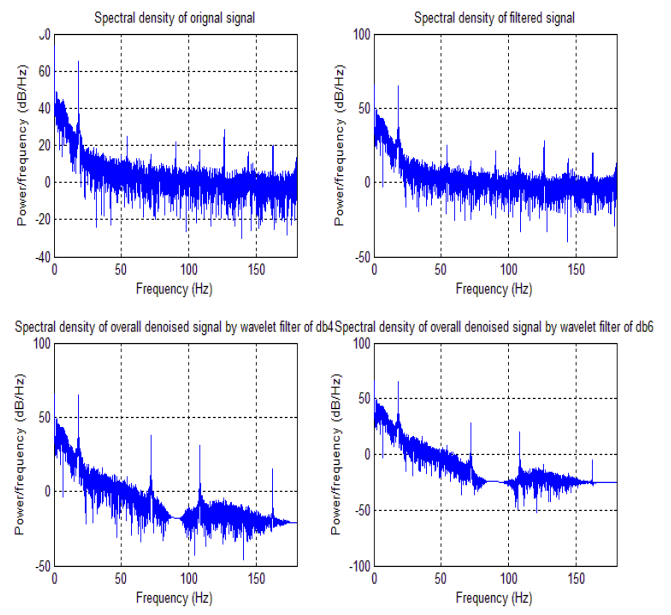


Fig.9 Spectral Density using Hanning filter

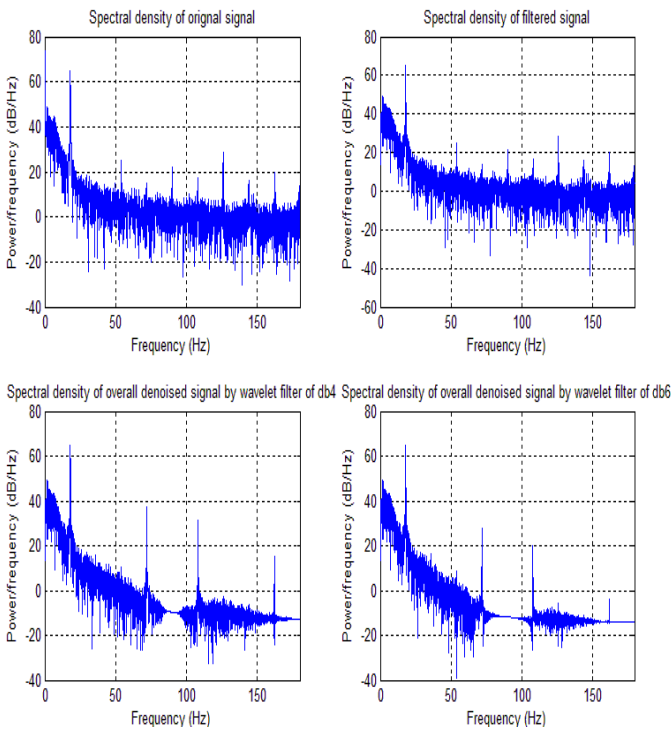


Fig.8 Spectral Density using Rectangular filter

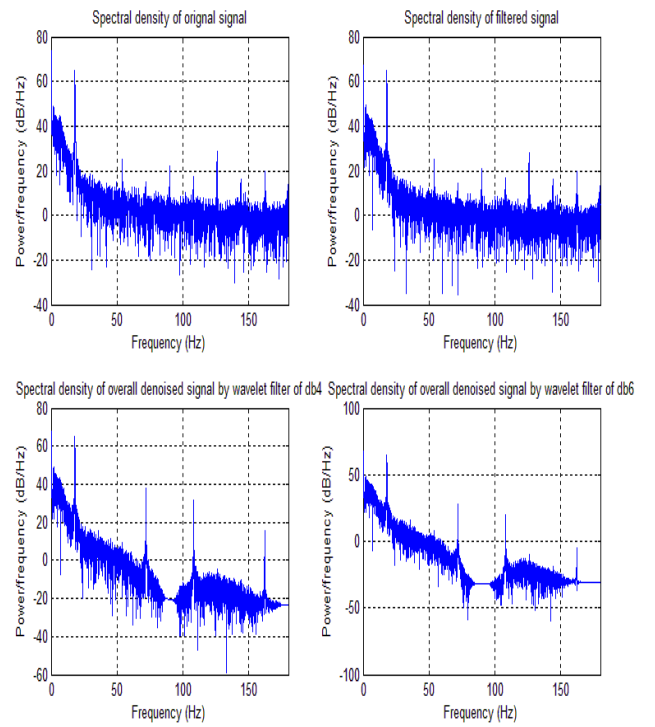


Fig.10 Spectral Density using Blackmann filter

Average power Comparison of various filters for Removal of noise at ECG sample input 1 in Table 2.

Table 2 Average power Comparison of various filters for Removal of noise at ECG sample input 1

Filter	Filter Order	Average Power before Filtration	Average power after Filtration	Wavelet output at 4dB	Wavelet output at 6dB
Butterworth	2	61.7562	56.5778	56.5649	56.5719
Kaiser	450	61.7562	56.3233	56.3104	56.3165
Rectangular	450	61.7562	56.3209	56.3080	56.3141
Hanning	450	61.7562	57.8823	57.8733	57.8776
Blackmann	450	61.7562	58.3917	58.3836	58.3875

IV CONCLUSION

This paper concludes the work in this thesis; digital FIR and IIR filter with wavelet for removal of Baseline noise were implemented in MATLAB. It is observed that the choice of the cut-off frequency is very important, a lower than required cut-off frequency does not filter the actual ECG signal component, however some of the noise successfully, but the ECG signal is distorted in the process. Cut-off frequency varies corresponding to heart rate and baseline noise spectra. Thus, constant cut-off frequency is not always appropriate for baseline noise suppression; it should be selected after a careful examination of the signal spectrum.

When FIR filter with wavelet is applied on signal it can be observe that the combination of Kaiser and wavelet yield the smallest phase delay among all the FIR filters combination. It can remove the Baseline noises without distorting the waveform. But the order of filter is 450. However, high filter orders are required to obtain this satisfactory result and this increases the computational complexity of the filter. Furthermore, there is significant delay in the filter result, thus this combination can be applied to long data window. Therefore, this combination is appropriate only for offline application, but for real time application, in which short intervals of data is filtered and fast implementation is important, FIR is not an appropriate filtering method. IIR and wavelet combination is more appropriate for real

time filtering application due to its lower computational complexity, and its better trade-off between average power and spectral density. It completely eliminates the oscillations produced at the starting of the waveform called ringing effect. For performance analysis we use different baseline noise removal methods for the purpose of comparison. The results are presented in the tabulation form. From the table it can conclude that it outperform the other method.

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