PROCESSING ECG SIGNAL WITH KAISER WINDOW- BASED FIR DIGITAL FILTERS

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Abstract
Heart attacks mostly occur in people who suffer from heart or heart-relate diseases if these diseases are not detected early enough and treated. There is therefore the need for a reliable means of detecting these diseases to save the patients from these attacks which are increasing in proportion all over the world. Electrocardiography (ECG), which is the electrical activity of the heart, generates a signal referred to as ECG signal or simply ECG and the shape of this signal tells much about the condition of the heart of a patient. Naturally the ECG signal gets distorted by different artifacts which must be removed otherwise it will convey an incorrect information regarding the patients heart condition. The work in this paper is the design of FIR digital filters with Kaiser Window to remove the interferences or the artifacts. Three filters are considered: low pass, high pass and notch filters. Each filter is used to filter the raw noisy ECG signal after which the three filters are used in cascade. Results are observed and recorded in each case, using FDA tool.

Key words: Kaiser Window, Matlab, corrupting signals.

Introduction
Digital FIR filters are successfully employed in processing electrocardiographic signals for measurement. ECG which is a biomedical signal is naturally corrupt by various interferences such as 50/60Hz power line interferences (PLI) and some other biomedical signals like baseline wander, electromyogram (EMG) and electroencephalogram (EEG). ECG signal frequency is approximately between 0.5Hz and 100Hz. Baseline Wander frequency is below 1 Hz while that of EEG is above 100Hz. But EMG frequency can be below or overlap with ECG frequency depending on body muscle movement. These interferences have to be removed from ECG signal in order to obtain correct clinical information of the heart. Since the frequency of electromyogram depends on the muscle movement rate and pressure it can be reduced to the barest minimum during ECG measurement by the patient staying still and quiet so that the muscles are fully relaxed.

Different researchers have worked on interference removal or reduction in ECG. In [1] Mahesh S. Chavan et al suggested that Kaiser window can be used to design FIR digital low pass, high pass and notch filters for processing ECG signal. Nobert Henzel in [2] presented a new method of designing linear phase FIR filters for ECG noise reduction. The new method does not only use the constraints on the designed filter’s frequency response but takes also into account the constraints on the output, time domain, signal. This approach exploits the error-insensitive loss function that plays recently an important role in a vast range of intelligent processing systems. Ch. Renumadhavi et al [3] worked on the evaluation of signal to noise ratio (SNR) of ECG signals, using a new approach of Noise power equal to mean square difference between actual and expected signal, and implementation of the approach. Sachin Singh and K. L. Yadav in [4] considered least means square (LMS) and recursive least square (RLS) algorithms in evaluating the performance of different adaptive filters for ECG signal processing. In [5] Mahesh S. Chavan et al designed and carried out software implementation of digital FIR equiripple notch filter for the removal of powerline interference in ECG, using FDA tool in the Matlab. Similarly, in [6] Mahesh S. Chavan employed FDAtool in the Matlab to design a FIR digital notch filter with a view to removing 50Hz powerline interference in ECG. The authors also simulated the filter with the tool, using ECG signal with 50Hz noise superimposed on it. In [5] the researchers carried out a comparative analysis of the filtration abilities and effects of filters on ECG signal, when designed with different windows. In [7] N. V. Thakor and Y. S. Zhu worked on how to use adaptive filters to do ECG analysis. In [8] Pranab Kumar Dhar et al designed and implemented FIR digital filters for audio signal processing, and this can be adapted to ECG signal processing. Mitov I. P. [9] worked on a method of reduction of powerline interference in ECG. In [10] Guohuo Lu et al worked on removing ECG noise from surface EMG signals using adaptive filters. Fig1a shows a normal ECG signal devoid of noise.

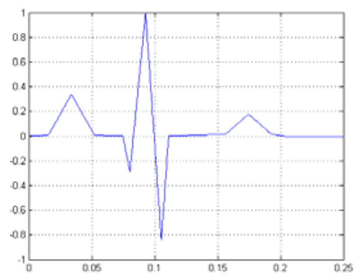


Fig. 1a: Normal ECG waveform

Kaiser Window Function

Kaiser window has very desirable characteristics both in time domain and frequency domain [11]. A good window should be a time limited function with a Fourier transform that is band limited and Kaiser Window possesses such characteristics closely. Kaiser window is defined by the expression

$$\omega_k(\beta,n)=\left\{\begin{array}{ll}\dfrac{J_o\left[\beta\left[1-\left(\dfrac{2n}{N-1}\right)^2\right]^{\frac{1}{2}}\right]}{J_o\beta}, & \text{for } \dfrac{(N-1)}{2}\le n\le\dfrac{(N-1)}{2} \\ =0, & \text{otherwise}\end{array}\right. \quad \ldots \quad (1)$$

where N is the order of the filter and $J_o(x)$ is the modified Bessel function of the first kind of order zero, and is given by

$$J_o(P)=1+\sum_{k=0}^{\infty}\left[(p/2)^k/k!\right]^2 \quad \ldots \quad (2)$$

From (2), for k = 0

$J_0(P) = 1 + \ldots$..

Alternatively, $J_0(P)$ can be written as

$$J_o(P)=1+\sum_{k=1}^{\infty}\left[(p/2)^k/k!\right]^2 \quad \ldots \quad (3)$$

In most cases the upper limit of k turns out to be k = 9 or 10.

Experience shows that as the Parameter B is varied in (1) both the transition bandwidth of a filter and the peak ripple in the side lobes change. The filter designer can therefore trade off main-lobe width for side-lobe ripple amplitude. Typical values of β lies in the range of: $4 < \beta < 9$.
The value of B to be used in any design depends on such factors like the order of the filter, the type of signal to be filtered and targeted signal to noise ratio. A typical Kaiser window function is depicted as fig1b below.

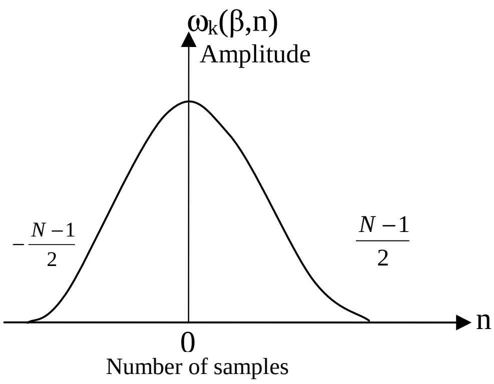


Fig. 1b: Typical Kaiser window function

2. Design of low pass filter using Kaiser Window
The low pass filter removes the corrupting high frequency noises in ECG. The cut off frequency used here is 100Hz while the sampling frequency is 1000Hz. Matlab is used for the design. The impulse response is shown in fig. 2, magnitude response in fig. 3 and phase response in fig. 4.

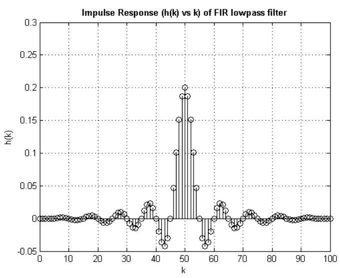


Fig. 2: Impulse response of the low pass filter.

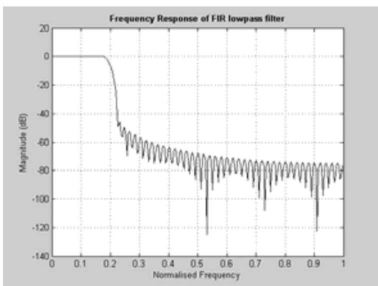


Fig. 3: Frequency response of the low pass filter

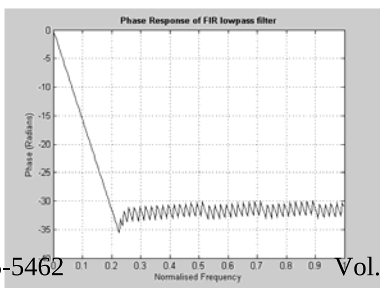


Fig. 4: Phase response of the low pass filter

3. Design of High Pass Filter Using Kaiser Window

The high pass filter removes the corrupting low frequency noises in ECG signal. The cut off frequency is 0.5Hz and the sampling frequency is 1000Hz. The order of the filter is 100. The impulse response is depicted in fig. 5, magnitude response in fig. 6 and phase response in fig. 7.

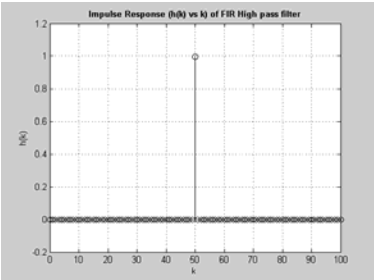
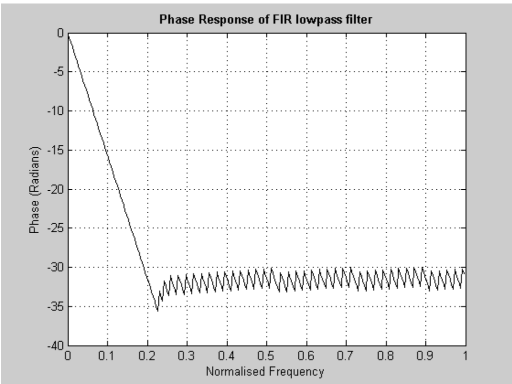


Fig. 5: Impulse response of the high pass filter



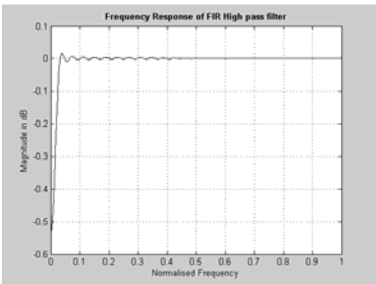


Fig. 6: Frequency response of the high pass filter

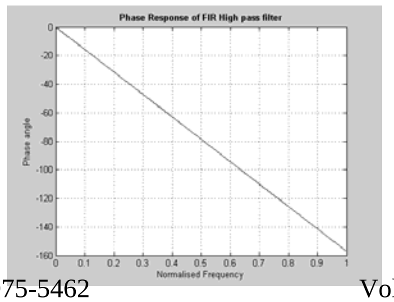


Fig. 7: Phase response of the high pass filter

4. Design of Notch Filter Using Kaiser Window

The notch filter removes the corrupting powerline frequency noise in ECG signal. The powerline frequency is 50Hz and sampling frequency is 1000Hz. The order of the filter is 100.

The impulse, magnitude and phase responses are shown in fig. 8, fig. 9 and fig. 10 respectively.

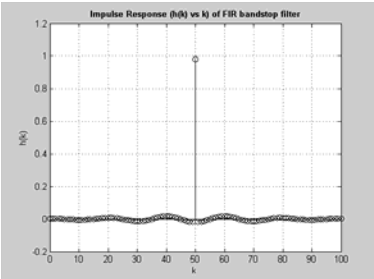


Fig. 8: Impulse response of the notch filter

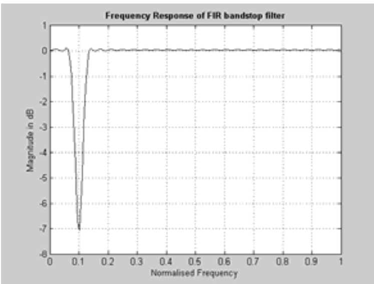


Fig. 9: Frequency response of the notch filter

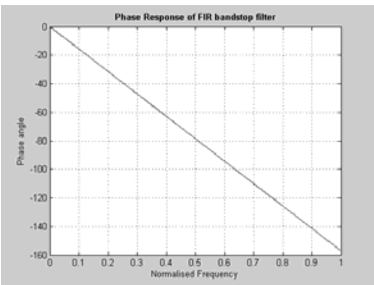


Fig. 10: Phase response of the notch filter

5. Results

There are four groups in the presentation of the implementation of the filters: the results of the low pass filter, high pass filter, notch filter and a cascade of the three filters.

5.1 Results of the Implementation of the Low Pass Filter

A raw noisy ECG signal containing corrupting high frequency, low frequency and 50 Hz powerline noises is shown in fig. 11. The frequency response is shown in fig. 12. From fig 12 the average power of the ECG signal above 100Hz is (-42.10dB)

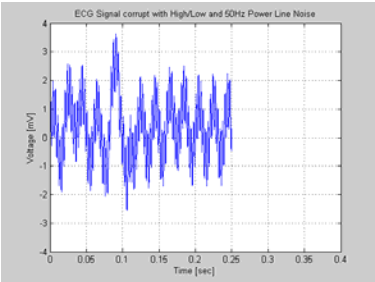


Fig. 11: ECG signal before application of low pass filter

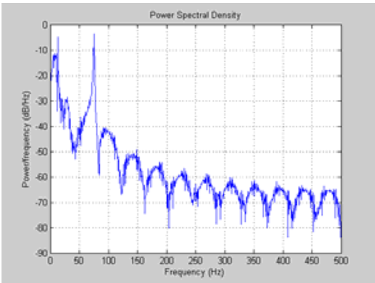


Fig. 12: Frequency response of ECG signal before application of low pass filter

The ECG signal of fig. 11 is passed through the low pass filter. The appearance after filtration is shown in fig. 13 while fig. 14 depicts the frequency response after filtration. From fig. 14, it is clear that the power of the signal above 100Hz is reduced to (-53.41dB), implying that the filter has removed high frequency noise from the raw ECG signal.

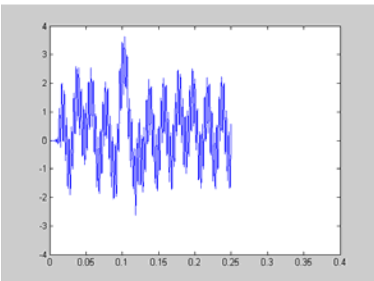


Fig. 13: ECG signal after application of low pass filter

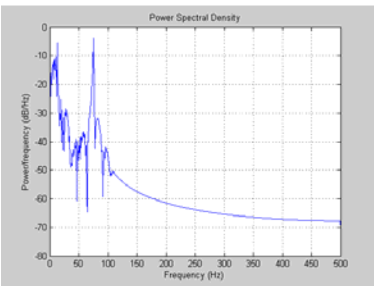


Fig. 14: Frequency response of ECG signal after application of low pass filter

5.2 Results of the Implementation of the High pass filter

From Fig. 12 the average power of the raw ECG signal below 0.5Hz is approximately (-11.98dB). The ECG signal after filtering with high pass filter is shown in fig. 15 while fig 16 provides the frequency response. Fig. 16 shows clearly that when the filter is applied the power of the signal below 0.5Hz drops to (-18.25), also implying that the high pass filter has removed the low frequency noise from the ECG signal.

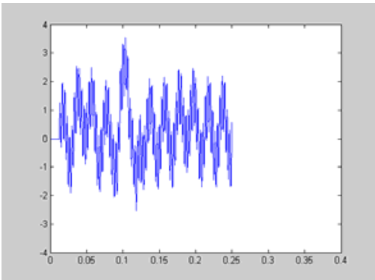


Fig. 15: ECG signal after application of high pass filter

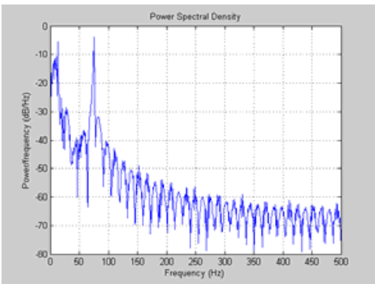


Fig. 16: Frequency response of ECG signal after application of high pass filter

5.3 Results of the Implementation of the Notch Filter

From Fig. 12 the average power of the ECG signal before filtration at 50Hz is (-37.89dB). Fig. 17 shows the ECG signal after filtering with the notch filter while Fig. 18 is a representation of the frequency response. From Fig 18, the power of the ECG signal after filtration with the notch filter is brought down to (-43dB) by the filter, which confirms that the notch filter removes power line interference in ECG.

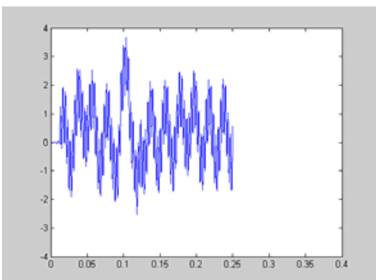


Fig. 17: ECG signal after application of notch filter

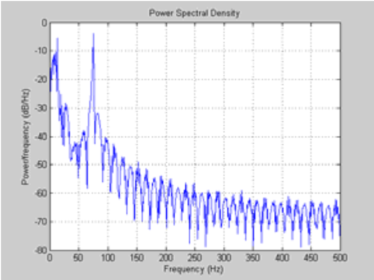


Fig. 18: Frequency response of ECG signal after application of notch filter

5.4 Results of Application of the Low pass, High pass and Notch filters in Cascade

When the raw ECG signal of fig 11 is filtered with the three filters in cascade the whole noises were removed, producing a near clean ECG signal of fig 19, almost devoid of corruption. The cascaded arrangement is how digital filters are connected in an electrocardiograph which is an instrument for checking the heart conditions of patients.

Table 1 is a summary of the implementation results of the three digital fitters.

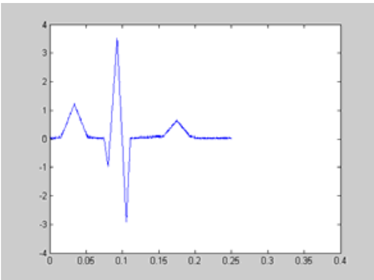


Fig. 19: ECG signal after filtration with the three filters in cascade

Table 1: Summary of the implementation results of the three digital filters designed with Kaiser Window

Type	**Signal power before filtration in dB**	**Signal power after filtration in dB**
Low pass filter, above 100 Hz	-42.10	-53.41
High pass filter, below 0.5 Hz	-11.98	-18.25
Notch filter, at 50 Hz	-37.89	-43

Conclusion

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 like ECG 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 output of the cascade of the three filters produced a near clean ECG signal almost devoid of noises and distortion which is a confirmation of the compatibility of the filters to one another and the optima of the filter orders used when Kaiser window is used to design digital filters for ECG signal processing.

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