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Research Article

Performance Comparison of Various Digital Filters for Elimination of Power Line Interference from ECG Signal

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Abstract

Heart problems are increasing day by day and Electrocardiogram (ECG) is a vital signal monitoring measurement of the cardiac activity. One of the main problems in biomedical signals like electrocardiogram is the separation of the desired signal from noises caused by power line interference, muscle artifacts, baseline wandering and electrode artifacts. Different types of digital filters are used to separate signal components from unwanted frequency ranges. Present paper deals with design and simulation of digital techniques like FIR filter, IIR filter and Kaiser Window which demonstrates the removal of power line interference (PLI) noise. Complete design is performed with the help of FDA tool in the Mat lab. The result shows before filtering and after filtering results which clearly indicates the removal of the power line interference in the ECG signal.

Keywords: *FIR filter, IIR filter, ECG signal, PLI*

1. Introduction

ECG signal, detected by the sensor with electrode pattern, is the cardiac electric activity behaving in human body surface, and belongs to weak signal areas. In the process of detecting signals, various interferences and noises inevitably mix into signals. Power interference and base line drift both have serious influences on ECG signal processing, diagnosing and analyzing. The former mainly affects the reliability of signal processing and the latter the accuracy. So power interference and base line drift are the key research problems in extracting ECG signals. The goal of ECG signal enhancement is to separate the valid signal components from the undesired artifacts, so as to present an ECG that facilitates easy and accurate interpretation (Min Li, Jiyin Zhao *et al*, 2001). ECG composed of P wave, QRS complex and T wave records the electrical activity of heart. Since ventricles form the major pumps of the heart, acquisition, processing and analysis of QRS complex that represents the activity of ventricles is a major area of current research. Any deviations from the normal morphology as well as electrical patterns indicate cardiac disorders. The normal amplitude of the QRS complex is up to 1.6 mg and duration is approximately 0.09 seconds (Sreelekshmi T. N *et al*, 2013). The basic ECG has the frequency range from 5Hz to 100Hz. A suitable digital filter can be used to suppress the high-frequency embedded noise.

2. Related Work

Many researchers are working on noise reduction in the ECG signal. Mitov shows a method for reduction of power line interference (PLI) in electrocardiograms with sampling rate integer multiple of the nominal power line frequency is developed and tested using simulated signals and records from the databases (Dotsinsky I *et al*, 2013). Cramer E., McManus C. D. and Neubert D. has suggested two different filters. One is based on a least-squares error fit, the other uses a special summation method. Both methods are compared with a local predictive filter by applying each filter to artificial signals and to real ECGs (Kunzmann U *et al*, 2002). Ferdjallah M., Barr R.E. Has given Frequency-domain digital filtering techniques for the removal of powerline noise (P.P.Vaidyanathan *et al* 1987). A method for line interference reduction to be used in signal averaged electrocardiography performance is analyzed by Ider YZ, Saki MC, Gcer HA (Ider YZ *et al*, 1995). Batchvarov V, Hnatkova K, Malik M. has done an assessment study on the Electrocardiogram (Kunzmann U *et al*, 2002). Christov II, Daskalov IK has worked on filtering of the electromyogram from the electrocardiogram (Kunzmann U *et al*, 2002). Von Wagner G, Kunzmann U, Schochlin J, Bolz A has described Simulation methods for the online extraction of ECG parameters under Matlab/Simulink (Kunzmann U *et al*, 2002). Some of the researchers have worked on the design and implementation of digital FIR filters (P.P.Vaidyanathan *et al*, 1987). Alireza K Ziarani, Adaibert Konrad (Alireza K Ziarani *et al*, 2010) has proposed Nonlinear Adaptive method of elimination of power line interference in ECG signals. . Mahawar1, A. Datar2, A. Potnis3 (N. Mahawar1 2013) has used the

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windowing methods to remove power line frequency. Santpal Singh Dhillon and Saswat Chakrabarti (Santpal Singh Dhillon *et al*, 2001) have used a simplified lattice based adaptive IIR Notch filter to remove power line interference. Mahesh S. Chavan, R.A. Aggarwala, M.D.Uplane (Mahesh S.Chavan *et al*, 2008) has used Digital FIR Filters based on Rectangular window for the power line noise reduction. P.E.Tikkane (Mahesh S.Chavan *et al*, 1999) has applied nonlinear wavelet and wavelet packet for denoising of electrocardiogram signal.

3. ECG Statistics

The ECG is a nearly periodic signal that reflects the activity of the heart. A lot of information on the normal and pathological physiology of heart can be obtained from ECG.

The ECG signal is represented as PQRST waveform as seen in Fig.1. The first phase of cardiac muscle activation is the stimulation of the right and left atria by an electrical signal generated from the SA node. The depolarization of atria appears as the P-wave on the ECG waveform. The ECG records the electrical signal of the heart and its properties are mentioned in Fig.1.The following is the description and significance of each deflection in the ECG:

P- Wave indicates atria depolarization (contraction).

PR- Interval measures time during which a depolarization wave travels from the atria to the ventricles.

QRS- Interval includes three deflections following P wave which indicates ventricular depolarization (and contraction). Q wave is the first negative deflection while the R wave is the first positive deflection. S wave indicates the first negative deflection after R wave.

ST- Segment measures the time between ventricular depolarization and beginning of depolarization.

T- Wave represents ventricular depolarization.

QT- Interval represents total ventricular activity.

Table 1, table 2 and 3 gives the properties of ECG signal and the normal values of ECG for duration and amplitude. (Indu Udai *et al*, 2012)

Table 1 ECG Properties

Mechanical actions	Associated wave	Wave frequency (Hz)
Auricular depolarization	P wave	10
Depolarization of the ventricle	QRS complex	20 – 50
Repolarisation of the ventricles	T wave	5
Repolarisation of the auricles		Hidden wave

Table 2 Normal values of ECG for amplitude

P wave	0.25 mV
R wave	1.60 mV
Q wave	25% of R wave
T wave	0.1 to 0.5 mV

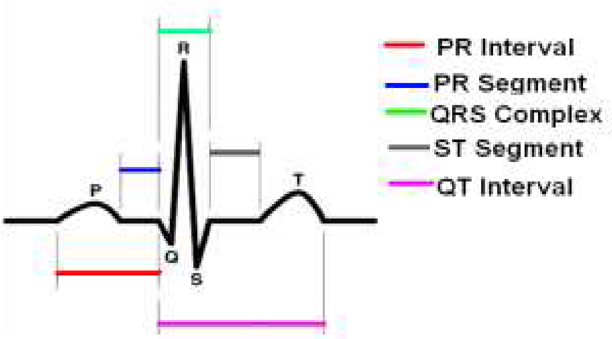

Fig. 1: ECG Waveform

4. Filter Design

The two major types of digital filters are finite impulse response digital filters (FIR filters) and infinite impulse response digital filters (IIR). The basic characteristics of Finite Impulse Response (FIR) filters are given below. They show a linear phase characteristic. They have a high filter order (more complex circuits), and gives stability. The basic characteristics of Infinite Impulse Response (IIR) are: IIR filters have non-linear phase characteristic. They give low filter orders (less complex circuits) and resulting digital filter has the potential to become unstable.

4.1 FIR Filter

The basic equation for a single-channel FIR filter is shown in equation

$$y(n) = \sum_{k=0}^{N-1} h\,(k)\; x\,(n-k) \qquad (1)$$

The terms in the equation can be described as input samples, output samples, and coefficients. Imagine x(n) as a continuous stream of input samples and y(n) as a resulting stream (i.e., a filtered stream) of output samples (Min Li 2001), n and k in the equation correspond to a particular instant in time, so to compute the output sample ,y(n) at time n, a group of input samples at N different points in time, or x(n), x(n-1), x(n-2), ... x(n-N+ 1) is required. The group of N input samples is multiplied by N coefficients and summed together to form the final result y(n).Fig. 2 shows the logical structure of an FIR Filter (Santpal Singh Dhillon *et al*, 2002)

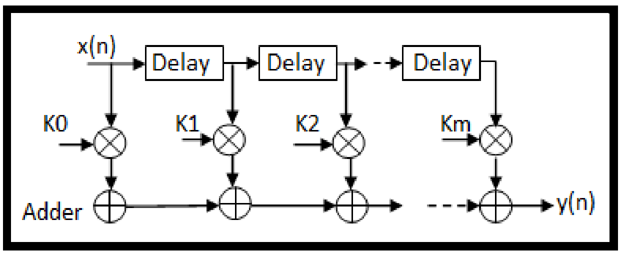

Fig. 2: Logical Structure of an FIR filter

Notch Filters are Optical Filters that selectively reject a portion of the spectrum, while transmitting all other wavelengths. A notch filter actually can also be perceived as a band stop filter with a high Q factor i.e. it often wants to filter out the undesired signal in the specific frequency (e.g. noise) only. However, the conventional band stop filter usually has a relatively wide stop band.

$$H(z) = bo(1 - e^{j\omega o}z^{-1})(1 - e^{-j\omega o}z^{-1})$$
$$= bo(1 - 2cos\omega oz^{-1}) + z^{-2} \quad (2)$$

Fig. 3 shows the logical structure of an FIR notch Filter.

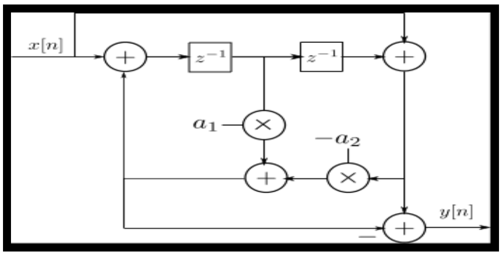

Fig. 3: FIR notch filter

Power line interference is one of the reasons of corruption of the ECG signal. Mostly it causes the 50Hz interference and their higher order harmonics such as second; seventh etc gets added to the ECG. To remove the Power line interference from ECG, the equiripple notch filter is implemented.

4.2 IIR Filter

The most important filter required to be designed for the task of removing noise from the bio signal is a notch filter because it helps in removing the specific 50 Hz power line interference. The digital IIR notch filter is obtained from its analogue counterpart by applying bilinear transformation. Figure 4 shows the magnitude characteristic of the proposed IIR notch filter. A stable single notch IIR filter of order 2 with notch frequency 50 Hz is designed for this application.

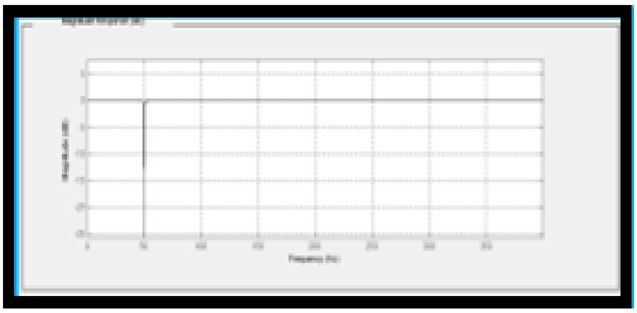

Fig.4: Magnitude characteristic of the proposed IIR notch filter

The transfer function of IIR Filter ig given by

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

Window functions are used to truncate the infinite data series to some finite limits.

4.3 Kaiser window

In design of a low pass filter using windowing technique, four parameters the pass band edge *ωp*, the stop band edge *ωs*, pass band ripple *A*ppend stop band attenuation *as*, are required. The prototype filter *h*(*n*) is designed using widely used Kaiser window. The Kaiser Window function *w(n)* is given as (Indu Udai *et al*, 2001)

$$W(n) = \begin{cases} \dfrac{Io\{\alpha\sqrt{1-\left(\frac{n^2}{N}\right)}}{Io(\alpha)} & -N \leq n \leq N \\ 0 & \text{otherwise} \end{cases}$$

Where I0 the 0th order is modified Bessel function, which can be computed as:

$$Io(x) = 1 + \sum_{k=1}^{\infty}\left(\frac{0.5x^k}{k!}\right)^2$$

The adjustable parameter α can be determined by designed as

$$\alpha = \begin{cases} 0 & \text{for As} < 50 \\ (0.5842(As - 21))^{0.4} + 0.07886(-21) & \text{for } 21 < \text{As} \leq 50 \\ 0.1120(\text{As}-807) & \text{for As} > 50 \end{cases}$$

For desired *as* and an appropriate chosen transition bandwidth Δω, the order of window *N* can be estimated as:

$$D = \begin{cases} 0.922 & \text{for As}<21 \\ \dfrac{(\text{As}- 7.95)}{14.36} & \text{for As}>2 \end{cases}$$

5. Simulink Model

The Filter Design and Analysis Tool (FDA Tool) is a powerful graphical user interface (GUI) in the Signal Processing Toolbox™ of MATLAB for designing and analyzing filters. FDA Tool enables to quickly design digital FIR or IIR filters by setting filter performance specifications. It also provides tools for analyzing filters, such as magnitude and phase response plots and pole-zero plots. The Simulink model of proposed filters is designed for their minimum orders of filter with sampling frequency of 1000Hz with notch at 50Hz frequency. Here FFT (fast Fourier Transform) block is used for analyzing the signal in the frequency domain. Simulink model of the proposed filter is shown in figure 5.

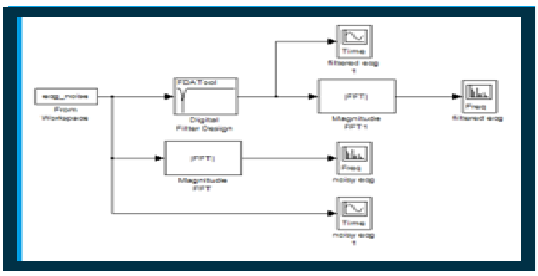

Fig 5: Simulink model

6. Simulation Results and Discussion

Figure 6 and 7 shows the ECG before application of notch filters in time domain as well as in frequency domain.

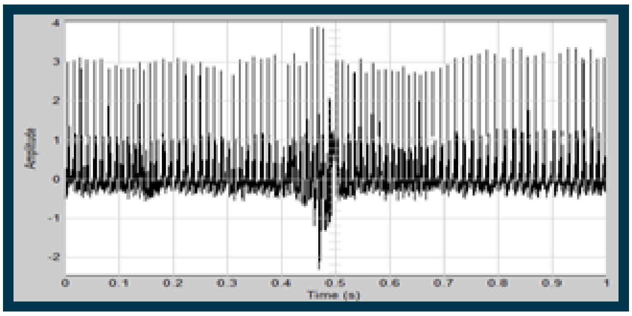

Fig.6: ECG Signal before application of notch filter (noise ECG) in time domain

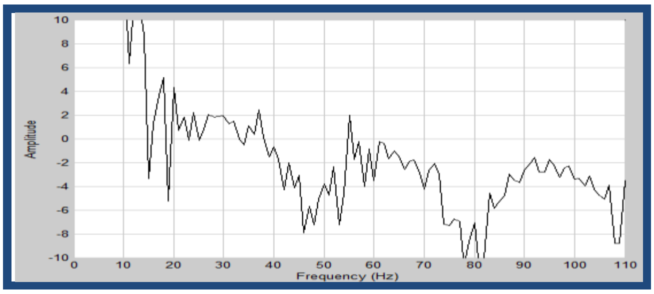

Fig.7: Frequency spectrum of the ECG before Filtration.

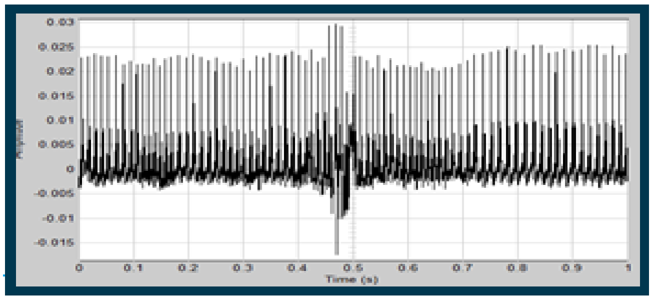

Fig.8 (a): Signal after filtration using FIR Notch Filter in time domain

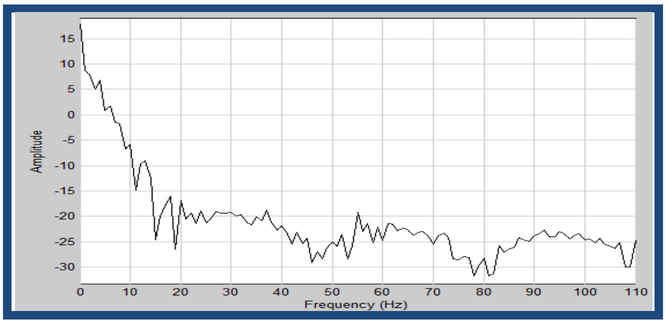

Fig.8 (b): Frequency spectrum of ECG after filtration by FIR Notch Filter.

Whereas figure 8(a) and 8(b) shows the ECG signal after filtering due to FIR equiripple Notch filter in time domain and in frequency domain. From the frequency spectrum of unfiltered ECG it is seen that power corresponding to the 50 Hz is nearly -4.5dB. When the notch filter is used the power corresponding to the 50 Hz signal is reduced to around -27.8dB. Which shows that filter reduces the power line interference in the ECG signal. The limitation of this filter is requirement of higher order filter; which may increase the complexity of the filter.

Figure 9(a) and 9(b) shows the ECG signal in time and in frequency domain, after filtration by Kaiser Window having Notch at 50 Hz. Thus it can be seen that power corresponding to the 50 Hz signal is reduced to around -49 dB. Which shows that filter reduces the power line interference from ECG signal.

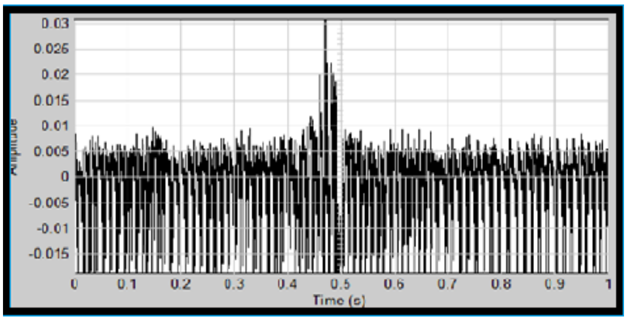

Fig.9 (a): Signal after filtration using Kaiser Window in time domain

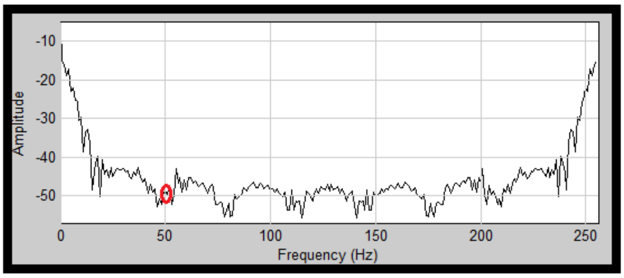

Fig.9 (b): Frequency spectrum of the ECG after filtration by Kaiser Window.

Figure 10(a) and 10(b) shows the ECG signals after filtration by IIR Notch Filter having notch at 50 Hz, in time domain and in frequency domain. After application of the IIR notch filter the power corresponding to the 50 Hz signal is reduced to around -13 dB. Which shows that filter reduces the power line interference from the ECG signal.

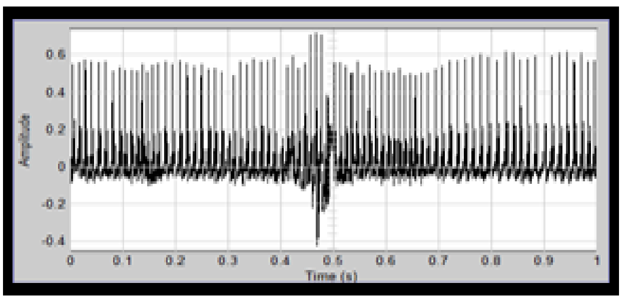

Fig.10 (a): Signal after filtration using IIR Notch Filter in time domain

Fig.10 (b): Frequency spectrum of the ECG after filtration using IIR Notch Filter.

The comparison of all designed filters is shown in table 3 on the basis of its filter order and the signal power before and after filtering.

Table 3 Comparison of designed filters

Type of Filter	Filter Order	Signal power before Filtration in dB	Signal power after Filtration in Db
Kaiser Window	102	-4.5	-49
FIR Filter	44	-4.5	-27.8
IIR Filter	2	-4.5	-13

Conclusion

As the noise present in ECG signal lead to improper diagnosis so the digital filters can be used to remove these noises. The FIR filters have the following advantage over IIR filters.

1. FIR filter are always stable as they have no recursive structure.
2. They gave the exact linear phase.
3. Efficiently realizable in hardware.
4. The filter response is of finite duration.

Thus noise removal using FIR digital filter is better option in comparison with IIR digital filter. Thus it is cleared from the results that FIR Equiripple Notch Filter is the best option as compared to Kaiser Window and IIR filter to remove the power line interference from the ECG signal due to sufficient noise reduction with minimum order. And this filtered signal has an important practical value in medical clinical diagnosis. Moreover, it is observed that there is sufficient scope for more work on complexity reduction by further reducing the order of the filter.

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