Filtering Techniques for Reduction of Power Line Interference in Electrocardiogram Signals

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Abstract

ECG is the graphical recording of the electrical activity of the heart and this biological signal used for clinical diagnosis. The ECG signal is very sensitive in nature, and even if small noise mixed with original signal the various characteristics of the signal changes. The frequency components of a human's ECG signal fall into the range of 0.05 Hz to 100 Hz and as far as the noise are concerned. Hence filtering remains an important issue, as data corrupted with noise must either filter or discarded. This paper discusses overview of different filtering techniques used in ECG signal in recent research work.

In this paper we survey on all type of filter which is used in to achieve noise free signal. Many types of filter have been suggested by the researchers. The results have clearly indicated that there is reduction in the power line noise in the ECG signal.

Keywords: *ECG signal, power line interference, adaptive volterra filters, nyquist filter, FIR & IIR filter.*

"1. Introduction"

Before going to how to removed noise from ECG firstly we moved towards to ECG.

Electrocardiogram (ECG) is a diagnosis tool that reported the electrical activity of heart recorded by skin electrode. The morphology and heart rate reflects the cardiac health of human heart beat. It is a non invasive technique that means this signal is measured on the surface of human body, which is used in identification of the heart diseases. Any disorder of heart rate or rhythm, or change in the morphological pattern, is an indication of cardiac arrhythmia, which could be detected by analysis of the recorded ECG waveform. The ECG signal provides the following information of a human heart,

- heart position and its relative chamber size
- impulse origin and propagation
- heart rhythm and conduction disturbances
- extent and location of myocardial ischemia
- changes in electrolyte concentrations
- drug effects on the heart

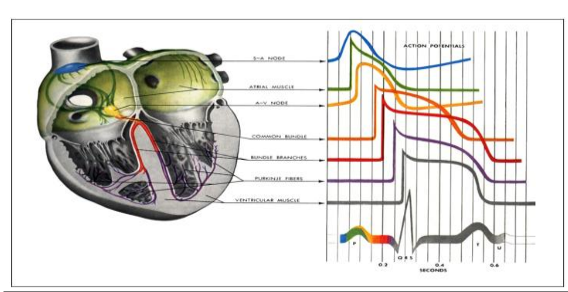
ECG does not afford data on cardiac contraction or pumping function.

1.1 The heart anatomy

Heart contains four chambers that is right atrium, left atrium, right ventricle, left ventricle and several atrio ventricular and sino atrial node are present. The two upper chambers are called the left and right atria, while the lower two chambers are called the left and right ventricles.

The atria are attached to the ventricles by fibrous, non-conductive tissue that keeps the ventricles electrically isolated from the atria. The right atrium and the right ventricle together form a pump to the circulate blood to the lungs. Oxygen-poor blood is received through large veins called the superior and inferior vena cava and flows into the right atrium. The right atrium contracts and forces blood into the right ventricle, stretching the ventricle and maximizing its pumping (contraction) efficiency. The right ventricle then pumps the blood to the lungs where the blood is oxygenated. Similarly, the left atrium and the left ventricle together form a pump to circulate oxygen-enriched blood received from the lungs (via the pulmonary veins) to the rest of the body.

1.2 ECG signal generation



"Fig.1 Generation of signal from heart"

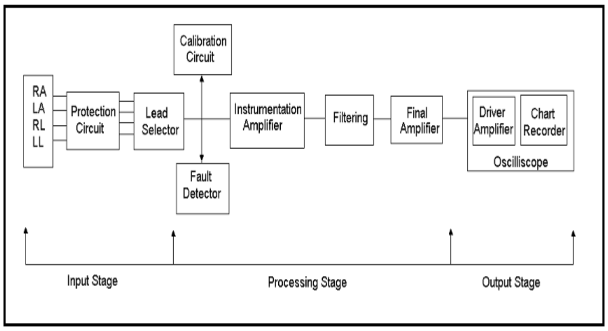
P wave: signal spread from SA node to make the atria contract.

P-Q Segment: signal arrives AV node stay for a instant to allow the ventricle to be filled with blood.

Q wave: After the Buddle of His the signal is divided into two branches and run through the septum.

R,S wave: Left and right ventricle contraction are marked by the R,S wave.
T wave: ventricle relaxing.

1.3 ECG block diagram



"Fig.2 Block diagram of ECG"

Protection Circuit: It protects the system from high level voltages or DC shock used to resuscitate heart attack patients.
Lead Selector Design: Connect the patient leads to non inverting amplifier terminal (+) & inverting terminal(-).
Calibration Circuit: It is a circuit consisting of resistive network connected to a voltage source that gives at its output 1mV. It is used to check the amplifying factor of the system before using ECG machine.
Fault detector: It can be detected manually or automatically, depending on operating modes and how quickly the system needs to be restored.
Oscilloscope: The oscilloscope is basically a graph-displaying device - it draws a graph of an electrical signal.

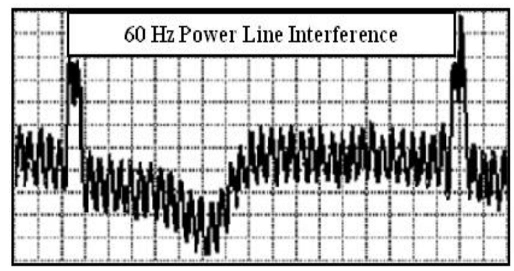
1.4 Types of noise in ECG signal

The objectives of acquisition of ECG signal and signal processing system is to acquire the noise free signal [4].

The major sources of noise are,
1. Power line interference
2. Baseline drift
3. Motion artifacts
4. Muscle contraction
5. Electrode contact noise
6. Noise generated by electronic devices
7. Electrical interference

Generally the recorded ECG signal is often contain by different types of noises and artifacts that can be within the frequency band of ECG signal, which may change the characteristics of ECG signal. Hence it is difficult to extract useful information of the signal.

Power line interferences contains 60 Hz pickup (in U.S.) or 50 Hz pickup (in India) because of improper grounding. It is indicated as an impulse or spike at 60 Hz/50 Hz harmonics, and will appear as additional spikes at integral multiples of the fundamental frequency. Its frequency content is 60 Hz/50 Hz and its harmonics, amplitude is up to 50 percent of peak-to-peak ECG signal amplitude. A 60 Hz notch filter can be used remove the power line interference.



"Fig.3 Power line interferences"

"2. Literature survey"

Many researchers have proposed methods for cancelling a periodic interference namely the power line interference from the ECG recordings. Santpal Singh Dhillon and Dr. Saswat Chakrabarti et al (2001) [21] have power line interference removal from electrocardiogram using a simplified lattice based adaptive IIR notch filter. Chavdar Levkov, Georgy Mihov, Ratcho Ivanov, Ivan K. Daskalov Ivaylo Christov, Ivan Dotsinsky et al (2004) [20] have used Subtraction method for powerline interference removing from ecg. Suzanna M. M. Martens, Massimo Mischi, S. Guid Oei, and Jan W. M. Bergmans et al (2006) [19] have described a method based on improved adaptive power line interference canceller. Rafael Ramos, Antoni Mànuel-Làzaro, Joaquín Del Río, and Gerard Olivar, et al (2007) [18] have presented FPGA-Based Implementation of an Adaptive Canceller for 50/60-Hz Interference in Electrocardiography. Mahesh s. Chavan, R.A.agarwala, M.D. Uplane et al (2007) [17] have used a simple Digital FIR Filters based on rectangular window. Manpreet Kaur, Birmohan Singh et al (2009) [15] have proposed an Combination of MA Method and IIR Notch for the reduction of the fundamental power line interference component and harmonics. The signal to power line interference ratio obtained using this method is 30 dB higher than that produced by a notch filter. Different filter structures have been proposed by L D Avenda no-Valencia, L E Avenda˜no2, JM Ferrero, G Castellanos-Dom´ınguez et al (2009) [13] an Extended

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Kalman Filter. Jacek Piskorowski (2010) [11] has investigated a technique for suppressing the t Digital Q-Varying Notch IIR Filter C. kezi selva vijila, P.kanagasabapathy, Ebbie selva kumar et al (2011) [7] have mentioned some aspects of A survey of interference cancellation in biosignals International Journal of Reviews in Computing sing dynamic neural networks in predictive-type ECG filtering in comparison with adaptive linear filters. Li Tan, Jean Jiang and Liangmo Wang et al (2012) [1] have proposed Pole-Radius-Varying IIR Notch Filter with transient suppression.

"3. Proposed system"

A filter is a device when a signal is given; it changes to some desired form by changing its shape, amplitude, frequency or phase frequency. They are usually employed to remove the noise, extract information signals and separate two or more combined signals.

There are two main classes of filter, analog and digital filters. These filters are used for different applications; the selection for the filter depends upon the required output of the application. Digital filters are extremely used in noise cancellation, echo cancellation and also in the field of biomedical engineering to remove unwanted noise from ECG, EMG and EEG.

The filtering techniques are primarily used for pre-processing of the signal and have been implemented in a wide variety of systems for ECG analysis. Filtering of the ECG is contextual and should be performed only when the desired information remains ambiguous. Many researchers have worked towards reduction of noise in ECG signal. Most types of interference that affect ECG signals may be removed by band pass filters; but the limitation with band pass filter is discouraging, as they do not give best result. At the same time, the filtering method depends on the type of noises in ECG signal. In some signals the noise level is very high and it is not possible to recognize it by single recording, it is important to gain a good understanding of the noise processes involved before one attempt to filter or pre-process a signal. The ECG signal is very sensitive in nature, and even if small noise mixed with original signal the characteristics of the signal changes. Data corrupted with noise must either filtered or discarded, filtering is important issue for design consideration of real time heart monitoring systems.

Now we will see different filtering techniques for reduction of power line interference in ECG signal using,

3.1 Adaptive volterra filter

When harmonics are neglected, the power line interference signal may be represented as[14],

$$i[n] = A[n] \cos(\omega_i n) \qquad \text{.........(1)}$$

Where, $A[n]$ = power line amplitude and

$\omega_i =$ power line frequency

The first harmonic of this interference is

$$i_1[n] = A_1[n] \cos(2\omega_i n) \qquad \text{.........(2)}$$

We know that $\cos 2\theta = 2\cos^2\theta - 1$. Hence

$$i_1[n]=A_1[n]\left(2\frac{i^2}{A^2[n]}-1\right) = 2\frac{A_1\ n}{A^2\ n}\, i^2 - A_1[n]$$

Proceeding in a similar way, the second harmonic $i^2[n] = A^2[n] \cos(3\omega^i n)$ can be written as

$$i_2[n]= 4\frac{A_2\ n}{A^3\ n}\, i^3[n] - 3\frac{A_2\ n}{A\ n}\, i^2$$

If we take phase for the power line interference also into account,

$$\text{i.e. } i[n] = A[n] \cos(\omega^i n + \phi i) \qquad \text{...........(3)}$$

Therefore minor changes occur in the expressions for the harmonics We again observe that $i''[n]$ is a phase-shifted version of $i[n]$.

The truncated volterra series expansion for the output y[n] resulting from a nonlinear system when the input is x[n] is given by[14]

$$y[n] = \sum_{r1=0}^{M-1} h1[r1]x[n-r1] + \sum_{r1=0}^{M-1}\sum_{r2=0}^{M-1} h2[r1,r2]x[n-r2] + ...$$

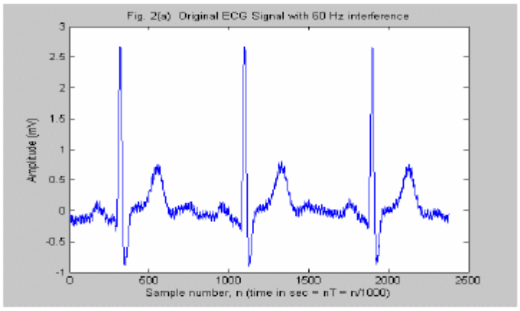
The update equations for the second order volterra filter are

$$h_1[r_1 : n+1] = h_1[r_1 : n] + \mu_1 e[n]\ x[n-r_1]$$

$$h_2[r_1, r_2 : n+1] = h_2[r_1, r_2 : n] + \mu_2 e[n]\ x[n-r_1]x[n-r_2]$$

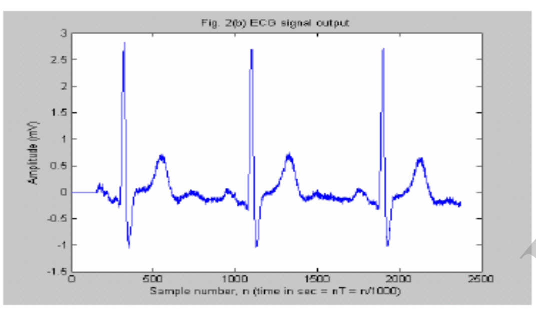
Here e[n] is the error signal i.e. $e[n] = d[n] - y[n]$, where d[n] is the desired signal. μ_1 and μ_2 are small positive constants that control the speed of convergence of the adaptive filter.

The proposed scheme is implemented using the well-known model for adaptive noise cancellation, while use of a linear filter is more common, the adaptive filter in our case is a volterra filter that consists of a linear as well as a nonlinear part.



"Graph.1 shows an ECG signal with power line interference contained" [14]

Graph 1 shows an ECG signal with power line interference contained in it. Graph 2 shows the signal obtained as the difference between this signal and the volterra filter output. It is the desired ECG signal, free from power line interference. It is observed that the power line interference is substantially less in the system output.



"Graph.2 shows the signal obtained as the difference between this signal" [14]

3.2 Nyquist filter

The typical operation of an FIR digital filtering is defined as [5],

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

Where, h(k), k = 0, 1, ..., N are the coefficients of the filter, and are, respectively, the input and output of the filter.

The transfer function is very useful in evaluating the frequency response of digital filter and is given as,

$$H(z) = \sum_{k=0}^{N} h(k)z^{-k}$$

The relation between the frequency response and the transfer function of digital filters is given [5],

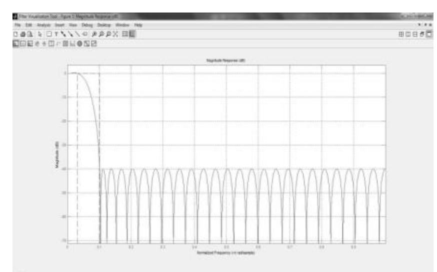
$$H(e^{jw}) = H(z) \text{ at } z = e^{jw}$$

Here we have designed the linear phase nyquist filter for cancellation of noise. To evaluate the performance of the filter we need to construct an ECG signal model simulation. Here we show how we construct the standard ECG signal model which we need to simulate the noise reduction.

We use the electrocardiogram reference to create the standard ECG signal, which including the following features:

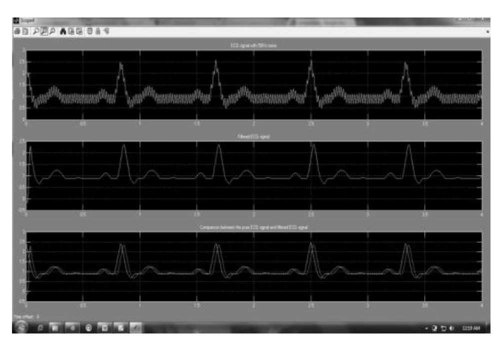
1. The magnitude of the P wave never exceeds 2.5mV.
2. The PR interval is approximately between 0.12 and 0.2 Seconds.
3. The QRS wave lasts for 0.06-0.1 Seconds.
4. The QT interval is about 40% of the R wave to the next R wave when the body is not in the state of exercise.

Where the filter order is minimum, the normalized transition width is $\Delta\omega=0.04\pi$, filter structure is Direct-Form FIR, sampling frequency is 50 Hz, stop band attenuation Astop = 10 dB. Magnitude response of Nyquist filter using the Equiripple algorithm is shown in graph 3.



"Graph.3 Magnitude response of the nyquist filter designed by the Equiripple Algorithm" [5]

Simulation result using Equiripple algorithm is shown in graph 4.



"Graph.4 ECG signal using nyquist filter" [5]

The 50Hz noise filtered from ECG signal using nyquist filter designed by Equiripple Algorithm.

In this method a linear phase nyquist filter is designed for suppression of 50 Hz (India) power line

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interference from ECG signal. The nyquist filter is designed using Kaiser Window method and Equiripple algorithm. Simulation result shows that the power line interference has been removed effectively. It is observed from the simulation work that filtered signal obtained by nyquist filter using Equiripple algorithm is much better and faster than the Kaiser Window[5] method.

3.3 FIR filter

FIR filters are widely used due to the powerful design algorithms that exist for them, their inherent stability when implement in non-recursive form, the ease with which one can attain linear phase, their simple extensibility to multirate cases, and the ample hardware support that exists for them among other reasons

3.3.1 Design of Equiripple notch filter[8]

Linear-phase equiripple filters are desirable because they have the smallest maximum deviation from the ideal filter when compared to all other linear-phase FIR filters of the same order. An Equipple design technique provides an alternative to windowing by allowing the designer to achieve the desired frequency response with the fewest number of coefficients. This is achieved by an iterative process of comparing a selected coefficient set to the actual frequency response specified until the solution is obtained that requires the fewest number of coefficients. Though the efficiency of this technique is obviously very desirable, there are some concerns. For equiripple algorithms some values may converge to a false result or not converge at all. Therefore, all coefficient sets must be pre-tested off-line for every corner frequency value.

Equiripple designs are based on optimization theory and require an enormous amount of computation effort. With the availability of today's desktop computers, the computational intensity requirement is not a problem, but combined with the possibility of convergence failure.

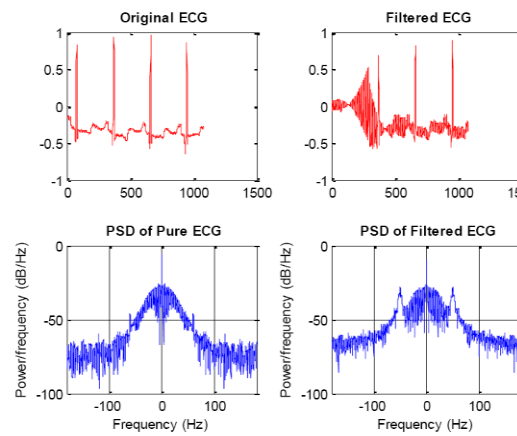
3.3.2 Performance measuresment [8]

The efficiency of FIR filter based de-noising is measured by evaluating SNR of enhanced ECG signal. SNR of denoised ECG signal is given by

$$SNR = 10\log_{10}\frac{\sum (x_{denoised})^2}{\sum (x_{org} - x_{denoised})^2}$$

In which x_{org} is raw ECG signal and $x_{denoised}$ is filtered ECG signal.

On implementation of above designed filters on ECG signals with powerline interference, the following results are obtained graph 5 shows the results for Equipripple notch filter and shows the results for least square filter.



"Graph.5 Results for Equiripple notch filter" [8]

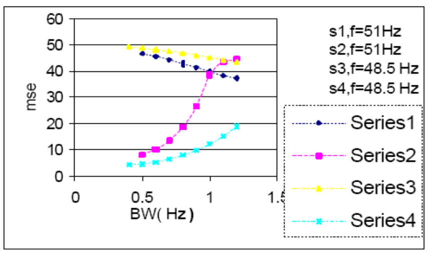
The Finite Impulse Response [FIR], filter produces the impulse response which has a limited number of terms. These types of filters are generally realized non recursively, which means that there is no feedback involved in computation of the output data. The output of the filter depends only on the present inputs. FIR filters based on equiripple design have been designed and implemented. In comparison with the window method reduction in signal power of 50 Hz is more in the Equiripple and Least squares methods [8]. In the window method the numbers of elements required are less while in equiripple method more computational elements are required therefore computational time is the major difficulty of the equiripple type digital filter implemented on the noisy ECG signal. Method is cost effective and flexible.

3.4 IIR notch filtering [1]

In order to compare the adaptive filtering process with the non adaptive IIR filtering process, the mean square error define was calculated by,

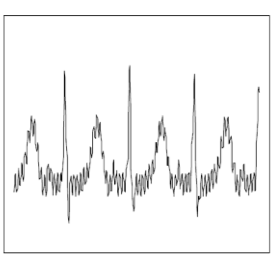
$$E = \frac{1}{N}\sum_{n=n_0+1}^{n=n_0+N} |y(n) - s(n)|^2$$

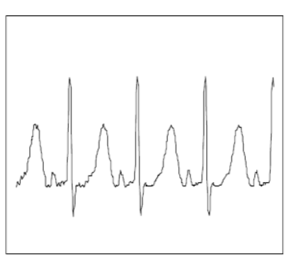
The outputs of the IIR notch filter, for the ECG signals with power line interference of varying frequency (signals 1-6), without using adaptation algorithm and with adaptation algorithm are shown in figs. 3.9. The IIR notch filter practically fails to eliminate the line interference at frequencies other than 50 Hz, whereas adaptive IIR notch filter gives a nearly noise free output. The Mean square error calculated was plotted for different bandwidths for both the second order IIR and the second order adaptive IIR filters



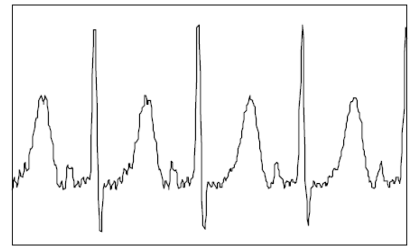
"Graph.6 Comparison of adaptive and non-adaptive IIR notch filters at frequencies of 48.5 Hz and 51 Hz."[1]

In graph 6 the series s1 and s3 indicate the mean square error for non-adaptive IIR notch filter while series s2 and s4 indicate the mean square error *(*MSE*)* for adaptive IIR notch filter at frequencies 51 Hz and 48.5 Hz resp. Thus at a frequency of 48.5 Hz and 51 Hz i.e. the upper and lower limits of line frequency variation, the response of an adaptive IIR notch filter is much better as compared to IIR filter used without adaptation [1]. Thus for power line interference removal, though an adaptive filter increases the computational load, it is to be preferred as compared to a non-adaptive filter because it can adjust to small changes in the frequency of line. In addition it can be easily implemented in hardware using a lattice structure.





"Graph.7 (a) ECG signal with 50 Hz Interference"
"Graph.7 (b) IIR Filtering without adaptation algorithm y(-1) = 0, y(-2) =0, BW =0.5 Hz"[1]



"Graph.7 (c) Adaptive IIR Filtering y(-1) = 0, y(-2) =0, BW =0.5 Hz"[1]

In this method, identifies the problem of line interference in real time ECG measuring systems where the frequency of line is not stable. A suitable remedy for the above problem in the form of second order adaptive IIR notch filter is proposed. Experimental results show that this filter gives a better performance as compared to non adaptive second order IIR notch filter when the frequency of line varies [1].

"4. Conclusion"

The ECG is the record of time varying bio – electric potential generated by electrical activity of heart. Various filters have been used to achieve noise free signal. The all of above method provides an overview of various filters. The future work primarily focuses on to designing a filter which provide noise free or accurate ECG signal.

From all above different filter method we can say that the IIR Notch filters is giving good performance for removal of power line interference is ECG signal and provides noise free signal at the output.

"5. Future enhancement"

An ECG is a recording of electrical activity on the body of surface generated by heart. The ECG detection which shows the information of heart and cardiovascular condition to enhance the patient living quality and proper treatment. The future enhancement is to design a filter which provide accurate noise free signal.

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