Power line interference noise removal in ECG-A Comparative study

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Abstract:

The electrocardiogram has the considerable diagnostic significance, and applications of ECG monitoring are diverse and in wide use. ECG signal after acquisition contains noises such as power line interference, instrumentation noise, external electromagnetic field interference, noise due to random body movements and respiration movements. These noises can be classified according to their frequency content. It is essential to reduce these disturbances in ECG signal to improve accuracy and reliability. The bandwidth of the noise overlaps that of wanted signals, so that simple filtering cannot sufficiently enhance the signal to noise ratio. The present paper introduces the digital notch filtering to cope with the 50 Hz power line noise interference in the ECG signal. Modern biomedical amplifiers have a very high common mode rejection ratio. Nevertheless, recordings are often contaminated by residual power-line interference. Traditional analogue and digital filters are known to suppress ECG components near to the power-line frequency. FIR filter is used to remove 50 Hz power line noise interference from ECG signals(mixed with 50 Hz power line noise interference) , since it does not introduces phase distortion. A ECG signal (without noise) was mixed with constant 0.5mVp-p noise at different values of PLI frequencies 48,48.5,49,49.5,50,50.5 and 51 Hz, and processed by Band reject filters of stop band bandwidth of 48–52Hz. The order of filter are taken as 500. In this paper the proposed filters were designed using Rectangular, Blackman, Hamming, Hann, Kaiser Window method to remove PLI from ECG. Simulation results are also shown. Performance of filters are analyzed by comparing MSE(mean square error) and SNR(signal to noise ratio) of output ECG signal.

Key-Words: Rectangular, Hamming, Hann, Kaiser Window, power line noise interference(PLI)

1.Introduction:

Electrocardiogram (ECG) is the record of the electrical potentials produced by the heart. The electrical wave is generated by depolarization and re-polarization of certain cells due to movement of Na+ and k+ ions in the blood. The ECG signal is typically in the range of 2 mV and requires a recording bandwidth of 0.1 to 120 Hz [1]. The ECG is acquired by a non-invasive technique, i.e. placing electrodes at standardized locations on the skin of the patient[2]. In clinical environment during acquisition, the ECG signal encounters various types of artifacts. The ones of primary interest are power line interference, external electromagnetic field interference, noise due to random body movements and respiration movements, electrode contact noise, electromyography (EMG) noise, and instrumentation noise. These noises degrade the signal quality, frequency resolution and strongly affect the morphology of ECG signal containing important information. It is essential to reduce disturbances in ECG signal and improve the accuracy and reliability for better diagnosis. Many methods have been implemented to remove the noise from noisy ECG signal[3],[9]-[17]. The basic method is to pass the signal through low pass, high pass, and notch filters. During past few years, various contributions have been made in literature regarding noise removal, beat detection and classification of ECG signal. Most of them use either time or frequency domain representation of the ECG waveforms[19]-[27]. Many methods were proposed in the past for the removal of power line interference in the ECG[4]-[7]. They can be categorized into two: non-adaptive and adaptive filtering. The non-adaptive filtering approach employs a sharp notch filter either in analog or digital form and has advantages of easy implementation and low cost. However its performance depends on the stability of the frequency of power line. Adaptive filtering on the other hand is able to remove the time-varying power line signal effectively[18]. But it requires considerable computational power which is not suitable for the portable ECG devices. One of the ways to lower the power consumption is to utilize non-adaptive filters[8].

2.a Desirable feature:

The amplifier should faithfully reproduce signals in its frequency range. A peak amplitude of an ECG signal is in the range of 1mv , so an ECG amplifier should typically have a gain of about 1000 in order to bring the peak signal into a range of 1v . CMRR of the order of 80 dB. to 120 dB.

2. b ECG signal and its acquisition:

The ECG signal and heart rate reflects the cardiac health of human heart. :

[a] The magnitude of the P wave never exceeds 2.5mV.

[b] The PR interval is approximately between 0.12 and 0.2 Seconds.

[c] The QRS wave lasts for 0.06-0.1 Seconds.

[d]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.

[e] The T wave's magnitude is usually 1/3-2/3 of the R wave's, and the T wave's interval is longer than that of the QRS's.

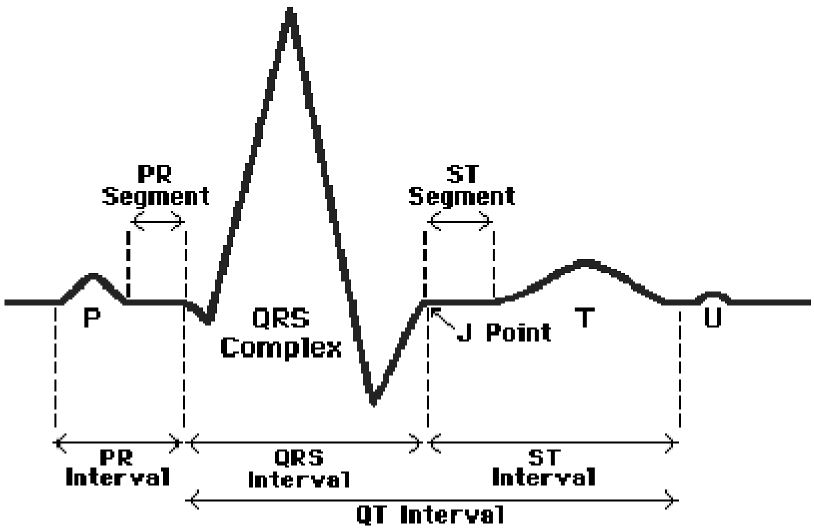

Fig. 1: ECG waveform

Any disorder in heart rate or rhythm or change in the morphological pattern of ECG signal is an indication of cardiac arrhythmia. It is detected and diagnosed by analysis of the recorded ECG waveform. The amplitude and duration of the P-QRS-T-U wave contains useful information about the nature of disease related to heart.

- ECG signal is acquired from the surface of the body using disc type floating electrodes. For ECG data acquisition a quad-op amp consisting of four high speed BIFET op amp can be used.
- The gain of instrumentation amplifier should be such as to give output of 1volt. The output of instrumentation amplifier is connected to band pass filter for frequency band of 0.05 Hz to 106 Hz. The noise signal produced due to patient movement is by passed to ground through right leg before amplification through instrumentation amplifier.

2.c Input ECG:

ECG signal is taken from a hospital ECG database[28] with sampling frequency of 500 Hz as shown below in Figure 2. A ECG signal (without noise) was mixed with constant 0.5 mVp-p 50 Hz interference shown in Figure 3.

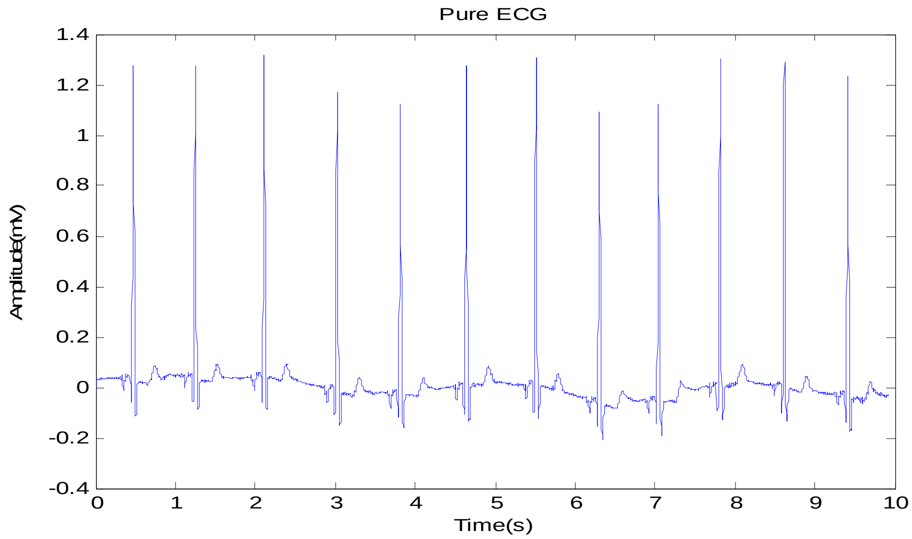

Fig. 2: Input ECG signal with sampling frequency of 500 Hz

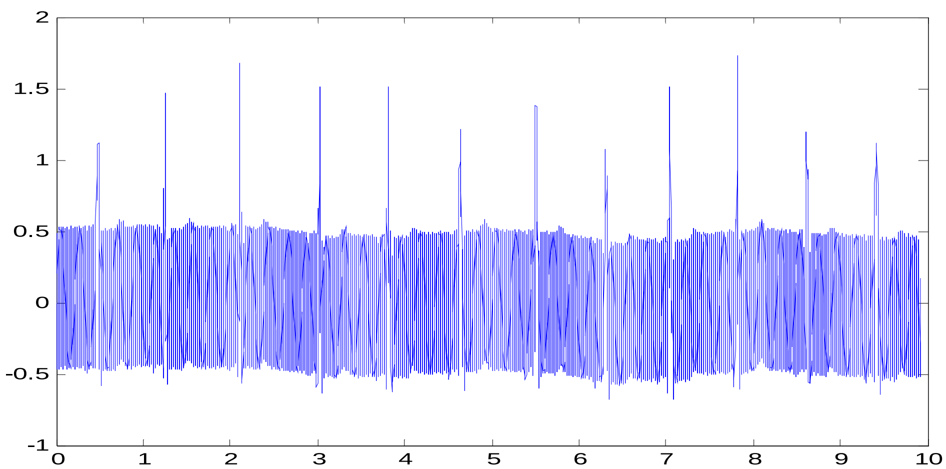

Fig.3: Noisy ECG

3.Window method of ECG de-noising:

In our work, we have used the window method of FIR filter design for noise reduction. The window method of filter design is discussed below; The Window Based FIR Filter Design In this method, we start with the desired frequency response specification $H_d(\omega)$ and the corresponding unit sample response $h_d(n)$ is determined using inverse Fourier transform. The relation between $H_d(\omega)$ and $h_d(n)$ is as follows :

$$H_d(w)=\sum_i^{\infty} h_d(n)e^{-jwn}$$

$$H_d(n)=\int_{-\pi}^{\pi} H_d(w)e^{jwn}dw$$

The impulse response $h_d(n)$ obtained from the above eqn. is of infinite duration. So, it is truncated at some point , say n = M - 1 to yield an FIR filter of length M (i.e. 0 to M-1). This truncation of $h_d(n)$ to length M - 1 is done by multiplying $h_d(n)$ with an window . Here the design is explained by considering the "rectangular window", defined as

$W_R(n)$=1 for mode of N=M-1/2

=0,Otherwise

Thus, the impulse response of the FIR filter becomes

$$h(n)=h_d(n)*W_R(n)$$

Now, the multiplication of the window function $W_R(n)$ with $h_d(n)$ is equivalent to convolution of $H_d(\omega)$ with $W(\omega)$, where $W(\omega)$ is the frequency domain representation (Fourier transform) of the window function i.e.

$$W(w)= \sum_i^{\infty} W_R(n)e^{-jwn}$$

Rectangular window :- the weighting function of rectangular window is given by

$W_R(n)=1$ for mode of $N=M-1/2$

$=0$,Otherwise

Kaiser window:- An FIR filter with side lobe attenuation of β dB, Kaiser window parameter α that affects the side lobe attenuation is given by

$\alpha= 0$; $\beta \leq 21$

$\alpha= 0.5842(\beta-21)^{0.4} + 0.07886(\beta-21)$; $21<\beta \leq 50$

$\alpha= 0.1102(\beta-8.7)$; $\beta >50$

where $\beta= 20\log_{10}\delta_s$

Hamming window:- The causal Hamming window function is expressed by

$W_H(n)= 0.54-0.46\cos(2\pi n/M-1) \quad 0 \leq n \leq M-1$

$= 0$,otherwise

Hanning window:- The causal Hanning window function is expressed by

$W_{Hann}(n)= 0.5-0.5\cos(2\pi n/M-1) \quad 0 \leq n \leq M-1$

$= 0$,otherwise

Blackman window:- The causal Blackman window function is expressed by

$W_B(n)= 0.42-0.5\cos(2\pi n/M-1) \quad 0 \leq n \leq M-1$

$= 0$,otherwise

4.Result:

For performance measures SNR and mean square error MSE are considered.

$MSE=\sum_0^N(x^\wedge[n]-x[n])^2/(N)$ $\qquad$ $SNR_o=10\log(So/No)$

$x^\wedge[n]$ is estimated ECG and $x[n]$ is original ECG

N is number of Samples

S_o and N_o are mean square power of estimated ECG and residual noise.

Type of filter	**Filter order**	**MSE**	**SNR of output ECG**
Rectangular	500	0.000806	-0.2383 dB
Blackman	500	0.0000386	13.163 dB
Hann	500	0.000005999	19.827 dB
Hamming	500	0.000006094	21.632 dB
Kaiser	500	0.0000015277	27.847 dB

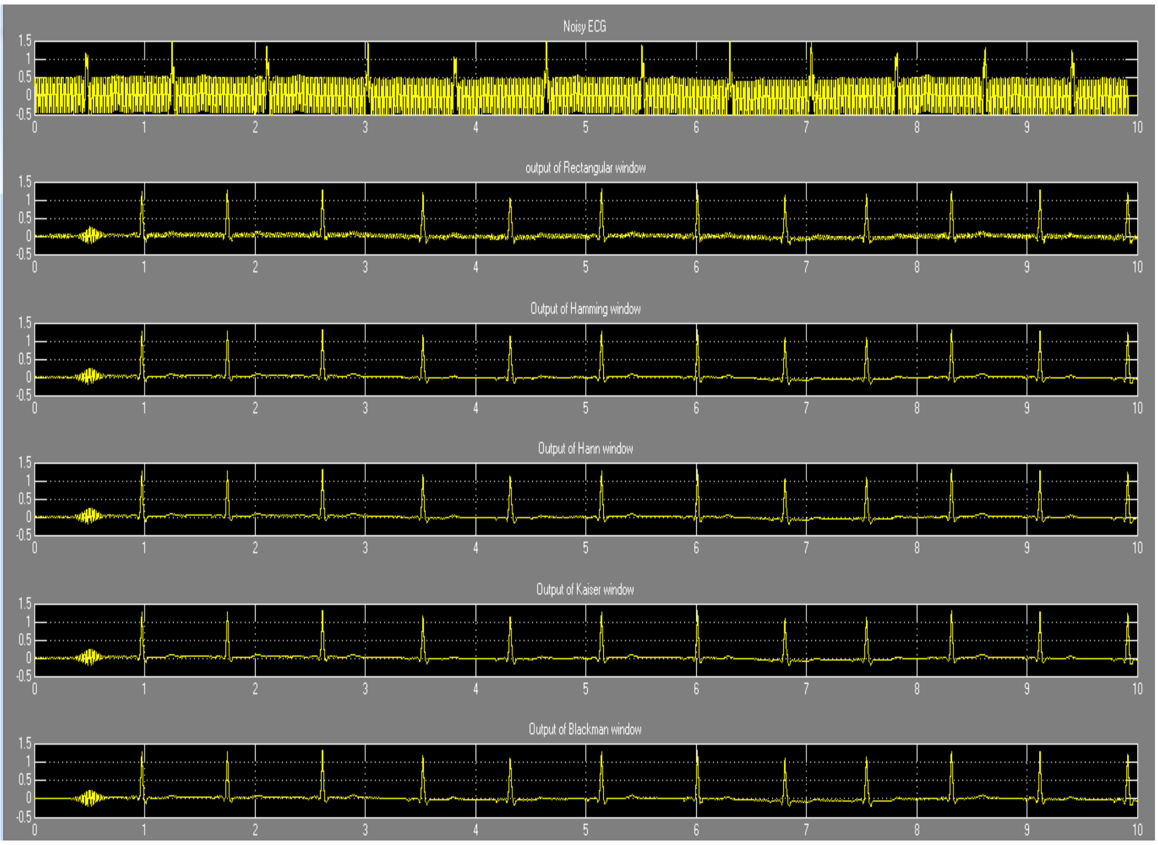

Fig.4-Simulation result in Matlab12

5.Conclusion:

The filtering algorithms used in this study are window based FIR filtering. The algorithm is the window based FIR filters, which are designed using Rectangular window, Hamming window, Hann window, Kaiser window and Blackman window. The designed filters are of order 500. The Band reject filters of stop band bandwidth of 48–52Hz was used. The performance of Rectangular window is lowest due to Gibb's phenomena. The performance of Kaiser window based filter is better than the rest of window based filters as MSE is lowest and SNR is highest.

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