Power Line Interference Removal from ECG Signal Using Different IIR Filters

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Abstract – *Electrocardiogram (ECG) signal is widely and primarily used for diagnosis purpose of various cardiac diseases by the physicians. An ECG records the electrical impulses generated by the myocardium and describes the condition of the heart. A good quality ECG signal is always desirable for accurate diagnosis of a life-threatening patient. However, in real circumstances, these signals are corrupted by prominent noises, artifacts and interference like power line interference (PLI), electrode movement noise, white noise, muscle artifacts, etc., and these must be removed before diagnosis. From the above mentioned artifacts PLI is conspicuously prominent. Different IIR (Butterworth, Notch, and Chebyshev) filters are designed to remove PLI from ECG signal. Through the consecutive employment of these filters, ECG signal will become free from artifacts in a remarkable amount. After exploring the simulation results of both the output waveforms and the values of SNR, it is notified that the Notch filter is the best suited for the removal of PLI. In this paper, a comparative approach is presented for removing PLI from ECG signal using various digital filters.*

Keywords: *ECG, IIR filter, power line interference, SNR.*

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I. Introduction

ECG stands for electrocardiography. The technique of recording the electrical activity of the heart according to over a period of time is known as Electrocardiography [1]. It works as the electrodes placed on the skin by detecting tiny electrical signal that comes from the heart muscles. It is generally used to detect any cardiac problems. The heart is excited by an electrical energy. This energy occurs in a group of cells at the top of the heart which is known as the sinoatrial (SA) node. The sinoatrial node is called the pacemaker of the heart. Each and every heart-beat can be observed as a series of deflections away from the baseline on the ECG. ECG is a single cycle, which relates to one's heart rate, historically labeled with its points pointing to P, Q, R, S and T waves [2]. The P wave on the Electrocardiogram denotes the electrical signal moving through the atria. The P wave represents the atrial depolarization and it is spread of the electrical impulse through both atria [2]. The QRS complex is the sharp deflection of the ECG signal and it is the largest waveforms of the ECG signal. The process of pumping blood to the lungs and rest of the body by the ventricles is denoted as the QRS waves on the ECG signal [3]. The QRS is the most prominent than the P wave. The QRS Complex is the combined of three waves Q, R and S. If the R wave is taller than the S wave the QRS complex is positive but if not, then the QRS complex is negative [4]. When the ventricles go back to their normal state, this process is denoted as T wave which is the last wave of the ECG and corresponds to the left ventricular repolarization phase of the heartbeat [5]. From experienced physicians, the ECG offers a lot of information about the heart structure and function of the ECG [6]. In particular, it is possible to measure the frequency and rhythm of the ECG, the size, and position of the cardiac rhythm, the damage to the muscle cells or the heart rate of the ECG. The function of the conduction system described the impact of heart medication and the implanted pacemaker [7]. The captured ECG signal is usually contaminated by noise [8]. Therefore, it is important to filter these noises and interferences to prevent any mistakes in further analysis of the signal. Among those noises and artifacts, the 50Hz power line interference (PLI) critically affects the ECG signal [9]. So, in order to obtain a reliable ECG signal for diagnosis purpose, it has become very essential to remove the PLI from the ECG signal. This problem is solved by using

FIR and IIR filters [10]-[12]. Between those two filters, we choose IIR filter for several reasons. First of all is due to its non-linear characteristics. Then, its system response is infinite, it is better for lower-order monitoring, it has limit cycles and above all these types of filters are recursive and can be used as an alternative [13]. For real-time digital filter calculation channels, IIR filters can be set up where FIR filter is available only in software [14]-[17]. Butterworth, Notch, Chebyshev type I, Chebyshev type II and Elliptic filters are some of the categories of IIR filter. This paper is organized as follows. In section (II) a brief literature review is given related to this work. Materials and methods for completing this research are presented in section (III). Section (IV) represents all the simulation results and their corresponding discussions. The conclusion of this research work follows in section (V).

II. Literature Review

In recent years numerous designs have been evolved for removing different types of noises and artifacts from the ECG signal. For the removal of artifacts and noises from ECG signal a comparative investigation was made between FIR and IIR filters is done by Seema et. al. [17]. Signals average power and spectral densities are regarded as two important parameters for the elimination of these types of noises. In their paper, they demonstrated that IIR filters are more efficient than FIR filters in terms of power dissipation, a complication of estimation and memory specifications. A comparison between notch filter (both general and equiripple), and comb notch filter was done by Ying -Wen Bai et. al. [18]. Mean square error was the key parameter for measuring the performance of these filters. In their study, they showed that the practical significance of the ECG signal is maintained by using the notch filter with equiripple. While the general features of the ECG signal were reduced by the use of general notch and comb filters. In order to make ECG signal free from PLI Mahesh Chavan et. al. [11] worked out with an equiripple notch filter. Though this filter successfully reduces the PLI, it requires a higher order of filtering. As a result, computational which is regarded as the major limiting parameter complexity is increased. FIR filter algorithms based on window method is proposed by Bai et. al. in [18]. The de-noising technique is performed by measuring the SNR values of the processed ECG signal and filtered signal. Kaiser, Gaussian, Blackman, and Blackman-Harris are some of the types of window methods. Among these, Keiser window performs significantly in removing PLI. Also, a comparative study of some digital filters (Butterworth, Chebyshev Type-I and Chebyshev Type-II) is performed in [19].

III. Materials and Methods

Power line interference presents a momentous challenge in the analysis of ECG signal data. So, it is necessary that efficient strategies must be made to prevent that PLI. In order to remove the PLI and reconstruct the ECG signal from the corrupted signal, here some IIR filters named, Butterworth filter, Notch filter, and Chebyshev type II filter are used. A basic block diagram is given in Fig. 1.

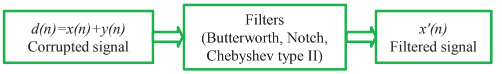

Fig. 1. Basic block diagram of filtering

Butterworth filters have maximally flat passbands in the same order. Another name of this filter is a magnitude filter which has a maximum flat response. This is a type of signal processing filter designed to have as flat a frequency response as possible in the passband [15]. The transfer function of general IIR filters is given below.

$$h(z)=\frac{\sum_{k=0}^{N} b_k z^{-1}}{1+\sum_{k=0}^{N} a_k z^{-1}} \quad (1)$$

In frequency response characteristics a Notch filter usually contains one or more deep notches, or perfect nulls [9]. In these types of filters, a specific frequency from the noisy signal is eliminated while other components of that signal remain unchanged. The frequency response of a Notch filter is given in [20].

$$H(e^{j\omega})=\begin{cases}0, & \omega_0\\ 1, & \text{Otherwise}\end{cases} \quad (2)$$

Here, ω_0 represents the center frequency of the Notch filter [21].

Also, another IIR filter named Chebyshev type II filter is chosen for having the characteristics of equiripple in the stopband. One important feature of this filter is the minimization of errors between the characteristics of actual and idealized filters. The magnitude response of the Chebyshev type II filter is given in equation (3),

$$|H(j\omega)|=\frac{1}{1+\varepsilon^2\left|\frac{C_N^2(\frac{\omega_s}{\omega_p})}{C_N^2(\frac{\omega_s}{\omega})}\right|} \quad (3)$$

Here, ε = a constant and controls the amount of passband ripple. ω_p and ω_s = edge frequencies of the passband and stopband respectively. N = filter order, and $C_N(\omega)$ = Chebyshev polynomial [22].

Also the equation for the first kind of N^{th} order polynomial is obtained from [20], which is given in equation (4),

$$C_N(\omega) = \begin{cases} \cos(N\cos^{-1}\omega), & \text{for } |\omega| \le 1 \\ \cos(N\cosh^{-1}\omega), & \text{for } |\omega| \ge 1 \end{cases} \quad (4)$$

Signal to noise ratio (SNR) is a measurement ratio, which is measured by comparing the level of a desired signal to the background noise level. If the values of SNR is greater than 1, it reveals that there remains more data signal comparing with the noise signal. Besides at the time when both the signal and noise powers are same then it shows a zero output value and results in the signal borders on an unreadable state. SNR measurement equation is given here.

$$SNR_{dB} = 10\log_{10}\frac{Signal\,power}{Noise\,power} \quad (5)$$

Several properties of SNR are described in [23]. These are:

a) A signal is clearly readable when a standard difference exists between the signal and noise power.
b) A signal is called marginal when the signal is much weaker but not lower than noise power.
c) A notable situation is observed at the time when noise power becomes greater than signal power. In such conditions, SNR will give a negative value. In these situations, it is quite inconceivable to provide reliable communication.

The time domain analyses are done by simply designing the filter algorithms in MATLAB and the frequency domain analysis is examined by using the Fast Fourier Transform (FFT) method. Several parameters (i.e. phase margin, bandwidth, resonant peak overshoot, gain Margin, etc.) are obtained from a type of representation in the frequency domain. In this method, a signal is divided into its frequency components while it is sampled over a period of time. More information about the signal is obtained from frequency domain analysis than time domain analysis. Besides mathematical analysis is clearly computed in this frequency domain analysis. Frequency domain analysis is easier than time domain analysis.

In order to verify the usability of the designed filter, the recorded ECG signal is taken from the MIT-BIH database [18]. Noises of the ECG signals are eliminated by measuring the usable average power and the SNR values of the parameters. MATLAB is considered as the most advanced software kit for digital signal processing applications [14]. That is why, all the obtained simulation (both the graphs and the SNR values) results are extracted from MATLAB. The 50 Hz sinusoidal signal is generated by using MATLAB which is regarded as a PLI signal. The generated PLI signal is then added with the recorded raw ECG signal and then the original ECG signal is recovered by using different IIR (Butterworth, Notch, and Chebyshev) filters. All the analysis are obtained both in time and frequency domain. Besides the SNR values of the filtered signals are also evaluated. For this purpose, the signal processing toolbox of MATLAB is used. Also, it helps to verify the design and results that come from the hardware. The overall algorithm is shown in Fig. 2.

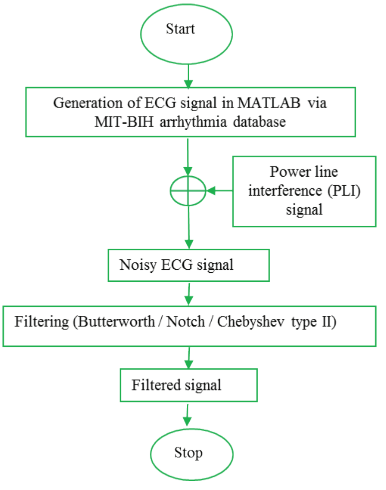

Fig. 2. Flowchart of the overall process

IV. Results and Discussion

The recorded data (record #101) is used as an original ECG signal from the benchmark MIT-BIH arrhythmia database [16]. The 6-beat real data of one patient (record #101) is selected as a reference signal from the MIT-BIH arrhythmia database. The 50 Hz PLI signal is generated matching with the original ECG signal. The noisy ECG signal is obtained by adding this PLI signal with the real ECG signal. Original, noise and noisy ECG signals are respectively plotted in the time domain, which is shown in Fig. 3(a), (b) and (c) respectively.

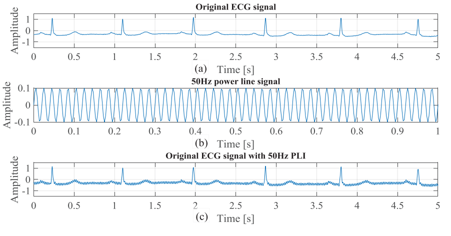

Fig. 3. (a) Original, (b) noise, and (c) noisy ECG signals in time domain

When the noisy ECG signal is passed through the Butterworth filter, then the obtained output is referred to as the Butterworth filtered ECG signal and these are respectively plotted in Fig. 4(a) and (b).

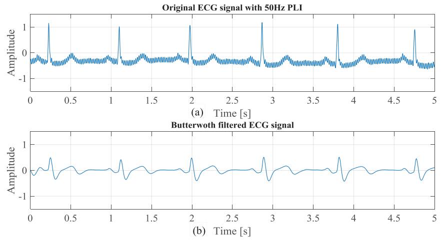

Fig. 4. (a) Noisy and (b) Butterworth filtered ECG signal in time domain

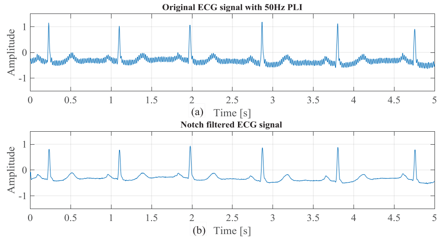

Fig. 5. (a) Noisy and (b) Notch filtered ECG signal in time domain

At the time of passing through the Notch filter of the noisy ECG signal the obtained output is referred to as the Notch filtered ECG signal, and these are respectively plotted in Fig. 5(a) and (b).

At last, noisy ECG signal is passed through the Chebyshev type II filter and the filtered output is attained which is referred to Chebyshev type II filtered ECG signal and these outputs are plotted in Fig. 6(a) and (b) respectively.

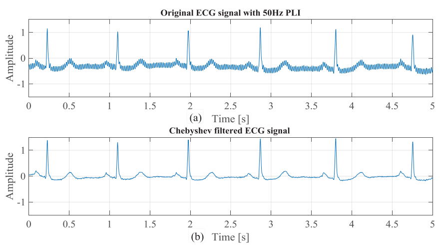

Fig. 6. (a) Noisy and (b) Chebyshev type II filtered ECG signal in time domain

Now, a comparison between the original ECG signal and these three filtered ECG signals are made for comparing the results and these are respectively given in Fig. 7 (a), (b), (c) and (d).

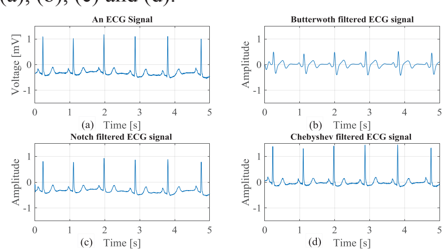

Fig. 7. (a) Original, (b) Butterworth, (c) Notch, and (d) Chebyshev type II filtered ECG signal in time domain

From the initial view of these output waveforms, it is seen that, in Butterworth filtered signal some important information about the QRS complex is missed out, in Chebyshev type II filtered signal it is almost similar to the original ECG signal but it added a little amount of noise in the R component to the main ECG signal. However, if seen from the Notch filtered output in Fig. 7(c), it reveals that it is perfectly suited with the original ECG signal. So, it can be concluded that the Notch filter has completely eliminated the PLI signal of 50 Hz from the noisy ECG signal.

Now for the accurate analysis of the information gained from the above-mentioned figures (Fig. 3 to Fig. 7), re-examination in the frequency domain and their corresponding outputs are plotted sequentially. At first, the original, noise and noisy ECG signals are plotted in the frequency domain in Fig. 8(a), (b), and (c) sequentially.

Then, the noisy and Butterworth filtered ECG signals are sequentially plotted in Fig. 9(a) and (b) on their corresponding frequency domain. Also, the frequency domain outputs of noisy and Notch filtered ECG signal are plotted in Fig. 10(a) and (b) sequentially. Again, the noisy and Chebyshev type II filtered ECG signal are sequentially plotted in Fig. 11(a) and (b) in the frequency domain.

Finally, a comparison of the original and these three filtered ECG signal in the frequency domain is made and these are respectively plotted in Fig. 12 (a), (b), (c) and (d).

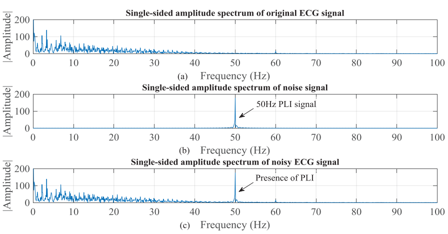

Fig. 8. (a) Original, (b) noise, and (c) noisy ECG signals in frequency domain

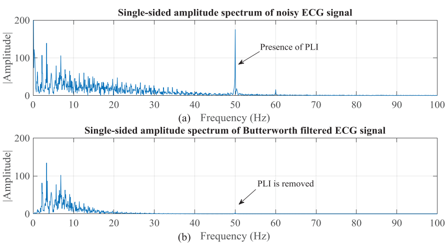

Fig. 9. (a) Noisy and (b) Butterworth filtered ECG signal in frequency domain

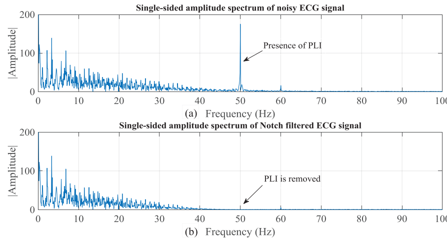

Fig. 10. (a) Noisy and (b) Notch filtered ECG signal in frequency domain

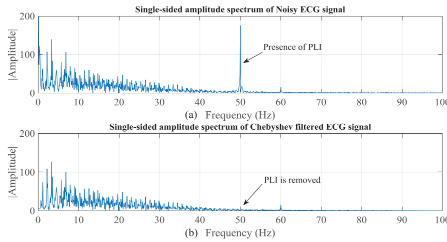

Fig. 11. (a) Noisy and (b) Chebyshev type II filtered ECG signal in frequency domain

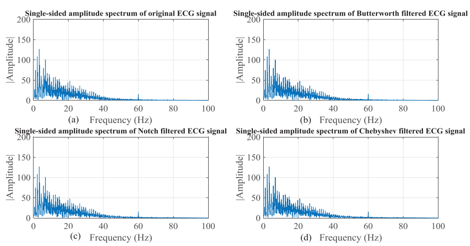

Fig. 12. (a) Original, (b) Butterworth, (c) Notch, and (d) Chebyshev type II filtered ECG signal in frequency domain

After observing all the frequency spectrums, it is seen that there exist a little bit dissimilarities of the spectrums of the filtered outputs of the filters that are examined compared to the original spectrum of the ECG signal. From a close view, it is found that, while filtering with Butterworth filter a piece of major information is lost from the total frequency spectrum. Again, it is seen from the frequency spectrums of the Chebyshev filtered signal that, it removes the PLI but there exist a little noise peak at some specific frequencies. Now, moving towards the frequency spectrums of the Notch filtered output, it is obvious that the PLI is perfectly removed without having any degradation of the main signal spectrum. There are also exist no other extra noise peaks. So, finally, it can be stated that the Notch filter performs well compared with the all other filters. It is also evident from the obtained SNR values, which are given in Table. I.

TABLE I
OBTAINED SNR VALUES

Types of Filters	SNR (dB)
Butterworth	5.8910
Notch	14.2404
Chebyshev type II	8.7115

V. Conclusion

Firstly, a raw ECG data signal is taken from the benchmark MIT-BIH arrhythmia database. After that, the collected data is mixed with a PLI signal of 50 Hz. Then the noisy ECG signal is passed through several IIR filters (Butterworth, Notch, and Chebyshev type II filter). The results are evaluated by examining the time domain and frequency domain characteristics for both the noisy and different filtered ECG signals to figure out its corresponding waveforms. All the simulation results are obtained from MATLAB. From these analysis, it is seen that the IIR Notch filter effectively performs better than the other examined filters. While in Butterworth filtering some major information about the QRS complex of the ECG signal are missed out, in Chebyshev filtering technique, PLI is removed but this filtering technique degraded the main signal components (QRS complex of the main ECG signal), where at the same time there exists a little amount of noise. The Notch filter effectively removes the 50 Hz PLI signal from the raw ECG signal without degrading the main signal components. Besides, it is evident from the obtained SNR values that the IIR Notch filter performs the best. Finally, based on the evaluated results, it is strongly recommended that IIR Notch filter has the superior performance than any other filters that are examined in this research work.

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