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Research paper

Performance analysis of IIR filter in removing PLI from EEG signal

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Abstract

Electroencephalogram (EEG) is a non-incursive test and the electrical signals of the brain from the scalp is recorded by this test. Several diagnosis conditions (for example dizziness, epilepsy, head injuries, etc.) are checked by this test. Moreover, the information about the brain death is also be acquainted by the EEG test. EEG signals inherit the bandwidth of 1 to 50 Hz. So, these can be easily contaminated by different artifacts (such as power line interference (PLI), eye blink artifact, and electromyogram artifact). Out of these artifacts, 50 Hz PLI is the most salient. In this paper, IIR filters (Notch filter and Chebyshev type II filter) are configured to remove the PLI. Through the subsequent utilization of these filters, the artifact can be removed from the EEG signals in a notable amount. Thereby this approach will ensure the true information about detecting brain diseases and possibilities to know how many portions of the main signal is released from the artifact. Investigating the simulation results that includes the output waveforms and SNR values, it can be concluded that the Notch filter performs better than Chebyshev type II filter. This paper presents a comparison between two digital (Notch, Chebyshev type II) filters for removing PLI from EEG signal and helps to choose the best one from these two filters.

Keywords: *Chebyshev type II filter; EEG; Notch filter; PLI; SNR.*

1. Introduction

Electroencephalogram (EEG) is a biomedical electrical signal and the brains electrical activity is provided by this test. It results from the brains contraction and relaxation which is measured from the surface of scalp of human body. The recorded signal plays an important role for the doctors since essential information's of a patient's brain condition along with the status of general health is provided by this test [1]. EEG has several clinical works. It can monitor normal wakefulness, inflaming states, complicated clinical conditions (for example alertness, cognitive engagement, human and animal brain development, sleeping disorder and coma). Numerous parameters (for example low costs, relative ease of use and excellent time resolution) are considered as the key advantages of this signal [2]. Human EEG wave frequencies are categorized into four types. Alpha is the major rhythm. In normal relaxed adults, each side of the heads posterior regions it is best seen usually. It appears at the time of closing the eyes. This wave shows its existence throughout most of the lifetime, in particular after crossing thirteenth year. Beta is generally seen in the symmetrical distributions of the cortex on both sides, which is most obvious frontally. It appears when the subject opens eyes. In the areas of cortical damage, it may be absent or reduced. It is generally regarded as a normal rhythm. Theta presents some variations in different ages persons. At the time of sleeping Theta presents normal states on the children's up to the age of thirteen years, whereas on awake adults it shows abnormalities. It is an exposition of central subcortical lesions. It appears in sleep stage at any age. Delta waves are usual in neonatal and infant. With centrally subcortical lesions it may be occurred. If Delta EEGs appear by itself in an adult, it notifies about a cerebral injury. Delta appears during deep sleep in adults, infants, and children [3]. The frequency ranges of the above mentioned four types EEG signals are given in Table 1.

Table 1: Different EEG signal bands [4]

Name	Frequency Range (Hz)
Alpha (α)	8 ~ 12
Beta (β)	12 ~ 30
Theta (θ)	4 ~ 7
Delta (δ)	0.5 ~ 4

Because of very low amplitude EEG signals are addicted to artifacts. The signal mixing with artifacts reveals that the total portion of the EEG recording taken place that time has not appeared from the brain. EEG signals can be contaminated by artifacts such as eye blink artifact, eye movement artifact, muscle activity artifact, PLI, and pulse artifact during its recording. PLI provides the most noticeable amount of contamination among the artifacts. Presence of PLI can be investigated in the recordings of raw EEG data. The 50 Hz PLI signal may be generated from faulty wires, light fluorescent and from other measuring apparatuses. EEG signal is a part of biological records are often contaminated with that PLI signal and it is received by the electrodes connected on the scalp at the time of recording. During the transition of the EEG signal from the electrodes located on the scalp to the machine which can record that signal, can also be corrupted by the strong signals came from AC power supplies [5]. Different EEG signals are collected from the MIT-BIH arrhythmia database, filters are designed using MATLAB and the filtered waveforms are obtained on its window. A filter is a tool that can reject unwanted frequency signal from the noise contaminated signals. This is a device that can give the signal a desired form by changing its shape, amplitude, frequency or phase. It is usually used to remove the artifact from single or separate or more combined signals [6]. To remove these artifacts and to obtain a feasible EEG signal, some digital filters can be utilized [7-9]. Between the two filters finite impulse response (FIR) filter and infinite impulse response (IIR) filters, here we have chosen IIR filters because of its inherent non-linear characteristics, infinite system response, better lower-order monitoring capability, limit cycles and above all these types of filters are recursive and can be used as an alternate [10]. For real-time digital filter calculation channels, IIR filters can be set up where FIR filter is available only in software [11]. In this paper, IIR Notch filter and IIR Chebyshev type II filter has been configured and utilized to eliminate the interference introduced by power transmission lines. Here we have chosen Notch filter as it has the capability to filter-out only the specific frequencies [12] and IIR Chebyshev type II filter as it has less ripple in passband than stopband [13], since passband ripple illustrates the amount of variation in the amplitude, within the assigned passband of the filter, and stop band ripple represents the minimum attenuation level within the assigned rejection band of the filter. All the simulation results and the SNR values are extracted from MATLAB, which is regarded as the most advanced tool for DSP applications [14].

2. Literature review

Due to the presence of various noises in EEG, its analysis becomes difficult for the clinical valuation. As a result, the recorded signal can be misguided to clinical evaluation. The interpretation and analysis of EEG recordings have been faced many difficulties since a long ago due to the existence of numerous artifacts. To deal with these artifacts, there are various methods evolved by different researchers. For over 25 years several methods have been proposed and applied to remove different types of noises from EEG signals. An adaptive digital notch filter is proposed by M. Ferdjallah and R.E. Barr in order to make biomedical signals free from power line noise in the year 1994 [15]. In 2005, W. Zhou et al. proposed an independent component analysis (ICA) method, which is an effective technique that has been used to remove biomedical artifacts [16]. An automatic EEG noise removal method for coherence analysis based on an adaptive filter is proposed by J. Kang et al. in 2014 [17]. In the same year, a DSP system was proposed by R. Bindal et al. that consists of two processors (ADC and DAC) [18]. In the year 2015, several methods are proposed for removing these artifacts. Among them, blind source separation (BSS) is a method which provides data processing that are collected from an adequate number of channel approaches along with an off-line analysis. Wavelet analysis and BSS approach is proposed by S.A. Sekyere and motivated by the potency of the ensemble empirical mode decomposition algorithm in decomposing a signal into amplitude–frequency modulations [19]. Also, S.M.M. Islam and M.S.U. Farid proposed the architecture of an adaptive filter using least mean square (LMS), normalized least means square (NLMS) and recursive least square (RLS). The prediction of the amount of noise in the primary signal and the subtraction of these noises is considered as the mechanism of an adaptive filter. Least square algorithms aims to minimize the sum of the squares of the difference between the desired signals and model filter output when new samples of the incoming signals are received at every iteration [20]. Besides, a multi-resolution method called wavelet transform (WT) which can be analyzed in both of the domains (time and frequency) and an independent component analysis (ICA) method is proposed by G. Kaushal et al. [21]. Here, in order to reject the power line noise of 50 Hz, WT is used to decompose the signal, two additional channels of artificial power line signals and the EEG recordings are used in ICA (a multichannel technique) in order to form a new data set which will be regarded as its input. An operative artifact removal technique (ART) which eliminates or reduces the impact of the artifacts was proposed in 2017 by A. Khatter et al. [22], this technique compares its results with different artifact removal techniques.

3. Materials and methods

Removal of PLI is a momentous challenge for the diagnostic purpose of the EEG data. In order to eliminate the PLI and reform the EEG signal from the corrupted signal, an IIR Notch filter and Chebyshev type II filter is designed, as seen in Figure 1.

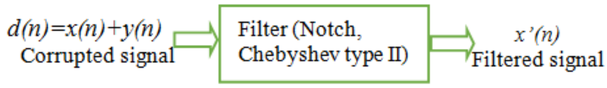

Fig. 1: A basic block diagram of the filtering.

One or more deep notches, or perfect nulls in the frequency response characteristic are included within a Notch filter [9]. Another name of this filter is bandstop filter. In Notch filters, a particular frequency of the noisy signal will be eliminated, whereas other constituents remains unaffected. Here, equation (1) represents the frequency response of an ideal Notch filter.

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

Where, ω_0 is the notch filter centre frequency [23].

The Z-transfer system function of IIR digital filter for second order system is given in equation (2),

$$H(z) = \frac{(z - e^{j\omega_0})(z - e^{-j\omega_0})}{(z - re^{j\omega_0})(z - re^{-j\omega_0})} \tag{2}$$

Where, $e^{j\omega_0}$ and $re^{j\omega_0}$ respectively represent zeros and poles.

Reversely, for designing a Notch filter in accordance with the frequency response of the zero and pole allocation,

Let $z = e^{j\omega_0}$, when $\omega = \omega_0$, infinite attenuation

Using Euler's formula, $e^{jx} = \cos x + j\sin x$, the simplified equation becomes,

$$H(z) = \frac{1 - 2\cos\omega_0 z^{-1} + z^{-2}}{1 - 2r\cos\omega_0 z^{-1} + r^2 z^{-2}} \tag{3}$$

The linear differential equation for the Notch filter is given by,

$$y(n) = 2r\cos\omega_0 y(n-1) - r^2 y(n-2) + 2\cos\omega_0 x(n-1) + x(n-2)$$

The transfer function of an IIR filter (may be implemented as either analog or digital filters) is given below,

$$h(z) = \frac{\sum_{k=0}^{N} b_k z^{-1}}{1 + \sum_{k=0}^{N} a_k z^{-1}} \tag{4}$$

Among various digital filters we choose Chebyshev type II filter for the characteristic of equiripple in the stopband. Minimization of errors between the characteristics of idealized and actual filter is a feature of this filter. Its magnitude response is shown in equation (5),

$$|H(j\omega)| = \frac{1}{1 + \varepsilon^2 \left| \frac{C_N^2(\frac{\omega_s}{\omega_p})}{C_N^2(\frac{\omega_s}{\omega})} \right|} \tag{5}$$

Here, ε is a constant that can control the amount of passband ripple, ω_p and ω_s represents the passband and stopband edge frequency respectively, N is the filter order and $C_N(\omega)$ is the Chebyshev polynomial [24]. The equation of the first kind of N^{th} order polynomial is shown below,

$$C_N(\omega)=\begin{cases}\cos(N\cos^{-1}\omega), & \text{for } |\omega|\le 1\\ \cos(N\cosh^{-1}\omega), & \text{for } |\omega|\ge 1\end{cases} \tag{6}$$

In fast Fourier transform (FFT) algorithm, a signal is sampled over a period of time and divided into its frequency components. Frequency domain representation provides more information about signal than time domain representation. The mathematical analysis of the signal is clearly calculated in the frequency domain. It provides more flexibility than time domain analysis, noises and interferences are best understood with several parameters like Bandwidth, resonant peak overshoot, resonant frequency, Gain Margin, Phase Margin, etc.

The level of the desired signal to the level of background noise is measured and compared by SNR in the field of science and engineering. A ratio greater than 1, indicates that there exists more signal than noise. SNR is calculated by the following equation,

$$SNR_{dB}=10\log_{10}\frac{Signal\,power}{Noise\,power} \tag{7}$$

If signal power and noise power are the same, then the SNR attains a value of zero and the signal borders are on unreadable state. If there exists a standard difference between the signal and noise power, then the signal is being clearly readable. If the signal is much weaker but not lower than noise power, then it will be called marginal. Again, in the situations where the noise power is greater than the signal power, then the value of SNR will be negative. In this type of situation, reliable communication is quite impossible [25].

All the analyses are accomplished both in the domains (time and frequency). For this purpose, the signal processing toolbox of MATLAB has been used. The completed algorithm is given in Figure 2.

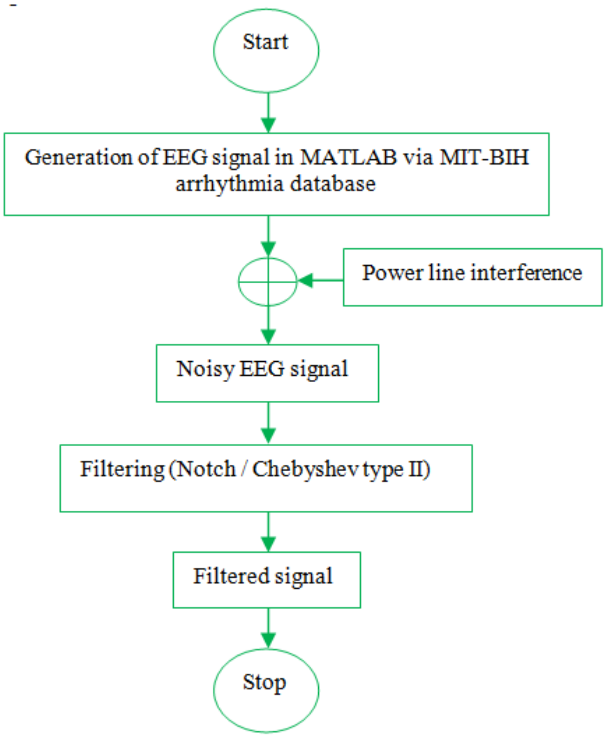

Fig. 2: Flowchart of the overall process.

EEG data has been downloaded and extracted from the MIT-BIH arrhythmia database [26]. After extracting, power line interference of 50 Hz has been added with the extracted signal through electronic adder. For experimenting the filtering process, noisy signal is passed through the designed filters and outputs are obtained through MATLAB window. To analyze the performance, SNR has also been calculated.

4. Results and discussion

EEG data has been collected from the benchmark MIT-BIH database to verify the usability of the designed filters. The PLI signal (50 Hz sinusoidal signal) is generated using MATLAB. Then adding it with the collected EEG signal, a noisy EEG signal is acquired. Original, noisy and filtered EEG signals are represented in both of the domains (time and frequency). In Figure 3(a), 3(b) and 3(c), the original EEG signal, noise signal, and noisy EEG signals are respectively illustrated in time domain.

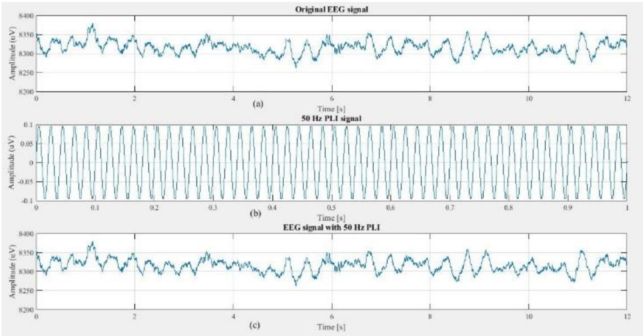

Fig. 3: Illustration of (a) original, (b) noise and (c) noisy EEG signal in time domain.

Notch filtered output is attained by passing the noisy EEG signal through a Notch filter, these are plotted in Figure 4(a) and 4(b) respectively.

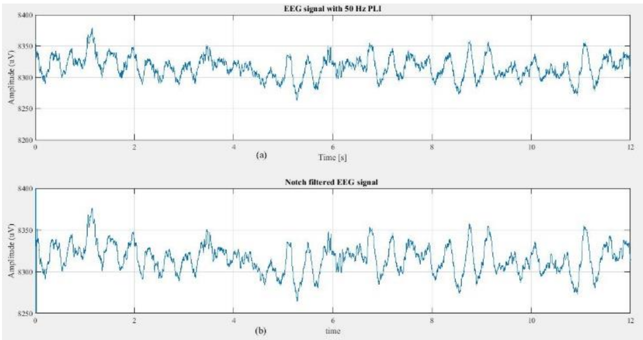

Fig. 4: Illustration of (a) noisy and (b) Notch filtered EEG signal in time domain.

Again the same noisy EEG signal is processed through Chebyshev type II filter and its corresponding output is shown in Figure 5(b).

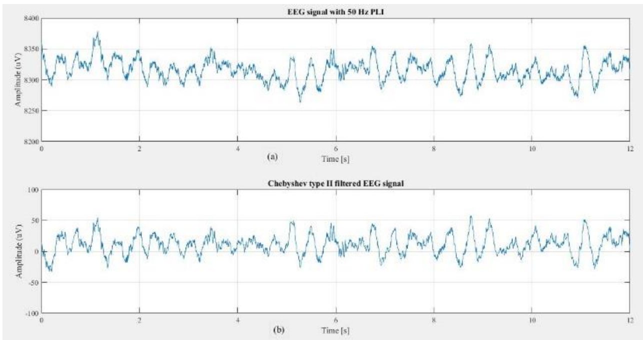

Fig. 5: Illustration of (a) noisy and (b) Chebyshev type II filtered EEG signal in time domain.

A comparison among the original, Notch filtered and Chebyshev type II filtered EEG signals is given respectively in Figure 6(a), 6(b) and 6(c).

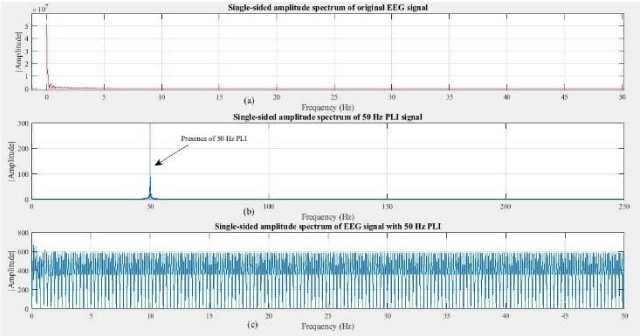

Fig. 6: Illustration of (a) original (b) Notch filtered, and (c) Chebyshev type II filtered EEG signal in time domain.

From the primary point of view the Notch filtered output is almost similar with the original EEG signal, but the Chebyshev type II filtered output is changed during its filtering process, its output is diversely oscillated. As a result we can conclude that Notch filter properly reduced the 50 Hz PLI.
In order to obtain the desirable results more accurately, all the information's obtained from the above figures (Figure 3 to Figure 6) are then plotted in frequency domain. In Figure 7(a), 7(b) and 7(c), the original EEG signal, noise signal, and noisy EEG signals are respectively illustrated in frequency domain.

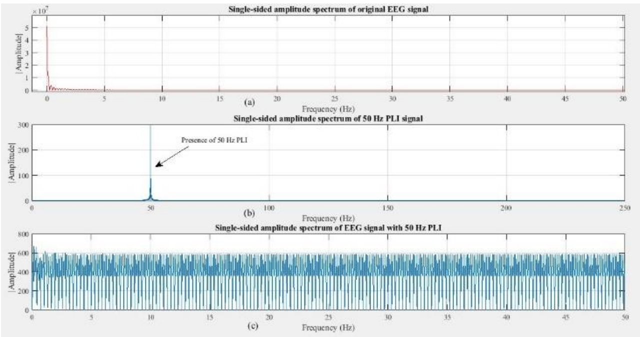

Fig. 7: Illustration of (a) original, (b) noise and (c) noisy EEG signal in frequency domain.

Noisy and Notch filtered EEG signals frequency spectrums are plotted in Figure 8(a) and 8(b) respectively.

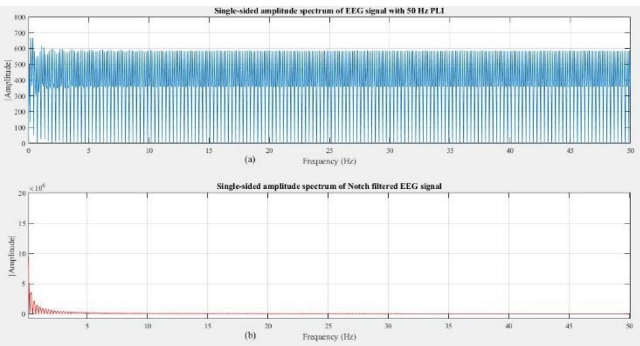

Fig. 8: Illustration of (a) noisy and (b) Notch filtered EEG signal in frequency domain.

Also the frequency spectrum of noisy and Chebyshev type II filtered EEG signals are respectively plotted in Figure 9(a) and 9(b).

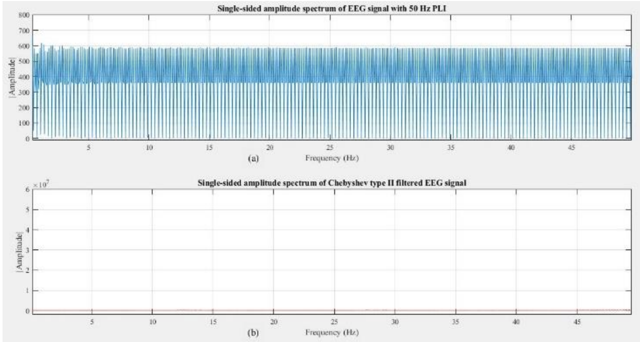

Fig. 9: Illustration of (a) noisy and (b) Chebyshev type II filtered EEG signal in frequency domain.

At the end, a comparison of the frequency spectrum is made among the original, Notch filtered and Chebyshev type II filtered EEG signals is given respectively in Figure 10(a), 10(b) and 10(c).

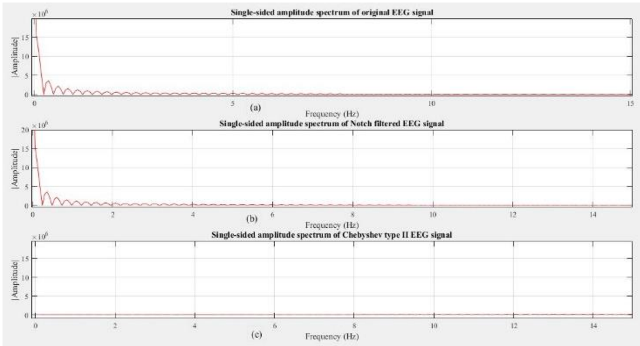

Fig. 10: Illustration of (a) original (b) Notch filtered, and (c) Chebyshev type II filtered EEG signal in frequency domain.

After analyzing Figure 10(a), 10(b), and 10(c) it is clear that all the points in the Notch filtered output is analogous with the original frequency spectrum of the raw EEG signal, whereas in the Chebyshev type II filtered outputs some portions of the original EEG signal is lost and there exists a little fluctuations on the flat responses. Finally, it can strongly be concluded that the 50 Hz PLI is clearly dispelled from the EEG signal with the use of Notch filtering technique.
For more clearance, the SNR values are calculated for both the outputs attained from Notch filter and Chebyshev type II filter. The obtained values of SNR are given in Table 2.

Table 2: Calculated values of SNR

Filter Type	SNR (dB)
Notch	101.4064
Chebyshev type II	47.0084

In this work, it is found that for Chebyshev type II filter, the filtered output is almost good as expected whereas, for Notch filter, the filtered signal is as good as expected. As evident from the results, it can be concluded that Chebyshev type II filter is less perfect for removing PLI comparing with Notch filter, because Notch filter meets up the expectations and provides with the maximum important information at the filter output.

5. Conclusion

The raw EEG data is taken from the MIT-BIH arrhythmia database, then it is mixed with 50 Hz PLI and then it is passed through different IIR filters (Notch filter and Chebyshev type II filter) and its corresponding outputs are evaluated. The complete analysis for the removal of that PLI from EEG signal in time and frequency domain reveals that IIR Notch filter performs more efficiently than Chebyshev type II filter. Besides, in the perspective of SNR values, again IIR Notch filter plays a better role than Chebyshev type II filter. The digital filter algorithms are also implemented in this work, which notifies that the work is successfully completed. Finally, from the above operations, it can be concluded that IIR Notch filter is the best suited for the removal of PLI from EEG signal than Chebyshev type II filter.

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