De-Noising Electroencephalogram (EEG) Using Welch FIR Filter

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Abstract: The brain is one of the most important human organs that produce electrical signal. This signal is referred to as electroencephalogram (EEG). Electronic instrument used to measure, and record EEG is known as the electroencephalograph. The brain signal is used to diagnose, manage and treat brain related illness. Sometime EEG obtained from a patient may be deceptive to the physician because of the presence of some unwanted signals that may be recorded alongside with the EEG. These unwanted signals include 50Hz power line interference (PLI), electrooculogram (EOG), electrocardiogram (ECG) and electromyogram (EMG). Removal of these artifacts from EEG is key to the diagnoses and treatment of brain illnesses, hence the unwanted signals should be removed from the EEG. This work proposes the use of finite impulse response (FIR) filter modeled with Welch window to remove 50Hz power line interference (PLI) from EEG Signal. Comparison of EEG Signal before and after filtration was carried out with spectrum power magnitude response (dB) to evaluate the ability of the proposed filter in 50Hz PLI reduction and the extent the filter attenuated the noise.

Keywords: EEG Signals, 50Hz Power line interference, FIR filter, Welch Window, Noise Removal.

I. INTRODUCTION

Some organs of the mammals can generate electrical signals which are readable and recordable with appropriate electro-biomedical device. The brain is one of those organs, it produces electrical signal called the Electroencephalogram (EEG). EEG is measured and recorded in the human with a device known as the electroencephalograph. The first EEG was recorded on man in 1929 by Hans Berger [1]. The process of measuring EEG involves strategic placement of several flat metal disc (electrodes) on the human scalp. [2][3][4][5]. EEG obtained in this exercise provides vital information about the clinical state of the brain. When the signal has been recorded then the physician begins to use information from the signal to determine the wellness of the brain or otherwise. It is on this bases that the physician will prescribe measures to control and correct the situation. The EEG also provides information that helps to determine sleep disorder, seizure and other brain malfunctions [6].

Unfortunately, some unwanted signals are always recorded by the EEG electrode in the procedure making the EEG signal difficult to be used for its purpose. These unwanted signals are 50Hz power line interference (PLI), electrooculogram (EOG), electrocardiogram (ECG) and electromyogram (EMG) [5]. EOG is the electrical signal that is generated by the eye as a result of the movement of the eye as well as the blinking of the eye. Blood carrying veins near the brain transport electrical signal produced by the heart to the brain. This is called the ECG, while EMG is signal generated by the movement of the muscular tissues. PLI is electrical discharge due to the inductive-capacitive coupling effect of the electronic components used in the manufacturing of the EEG device. This is transferrable to the scalp through the electrodes. Because of the proximity of the agents of these unwanted signals to the brain, EEG signal is often corrupted by these other signals. It is imperative to free EEG of every noise to make it useful in its clinic analysis and applications. In this work, finite impulse response (FIR) filter modeled with Welch window is used to perform EEG signal de-noising. FIR filter are known for its linear phase response characteristic and its stability and well as its finite impulse responses.

II. REVIEW OF PAST WORKS

Different types of filters and techniques have been designed and proposed for signal enhancement in the field of digital signal processing (DSP). Several windows have been suggested for designing FIR filters. To evaluate the effectiveness of FIR filter, Sharma and Narwaria [7] used Gaussian, Bartlett and Hann windows to cancel out additive white Gaussian noise (AWGN) from ECG signal individually. The duo concluded that the Gaussian window-based FIR filter yielded the best filtration in the process. Chithra and Aparna [8] demonstrated that FIR filter modeled with windowing technique outperformed the adaptive filter in speech signal segmentation. The researchers used FIR filters designed with Hann, Hamming, Blackman, Kaiser, Rectangular, Triangular, Flat top and Gaussian windows as well as Welch and Nuttall windows in the exercise. Correa et al [9] used a three adaptive filter system in cascade to remove ECG, EOG and PLI from EEG signal. The authors concluded that the proposed cascade of three adaptive filters successfully reduced the common artifacts present in EEG signals without removing significant information embedded in the EEG records.

III. FILTER MODELING

This work examines the removal of 50Hz PLI from EEG using FIR Welch window-based filter. The Welch window is mathematically expressed as in (1) [8].

$$W_{(n)} = 1 - \left(\frac{n - \frac{N-1}{2}}{\frac{N-1}{2}} \right)^2 \qquad (1)$$

Where N is the number of tabs of the window.
Fig 1 shows the graphical representation of the time and frequency domains of the Welch window for filter tap equal to 82. Fig 1 was obtained using the WINTOOL command in MATLAB environment.

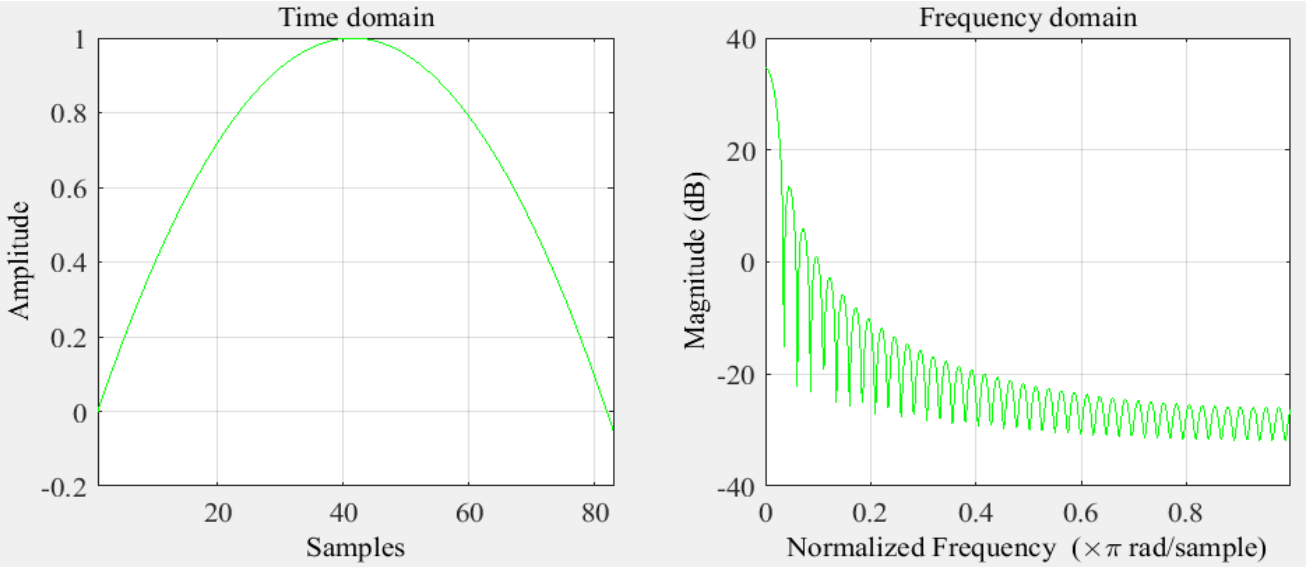

Figure 1. Graphics of Time domain and Frequency domain of Welch window of filter order 82.

In the process of FIR filter modeling, a window is necessarily needed to truncate the desired unit sample response $h_d(n)$ of the filter function. This is done to limit the impulse response of the filter to finite and known limits, hence the name finite impulse response. The limiting of the desired unit sample response is known as windowing in the field of DSP [10]. Windowing occurs when the desired unit

sample response $h_d(n)$ is multiplied by window function (W_n). The product is known as the unit sample response of a FIR filter h(n), and is shown in (2);

$$h(n) = h_d(n) * W_n \qquad (2)$$

Fig 2 shows the impulse and magnitude responses of FIR Welch window-based filter while fig 3 shows the phase response. The filter linearity characteristic shown in fig 3 indicates the filter is stable and good for FIR filter modeling.

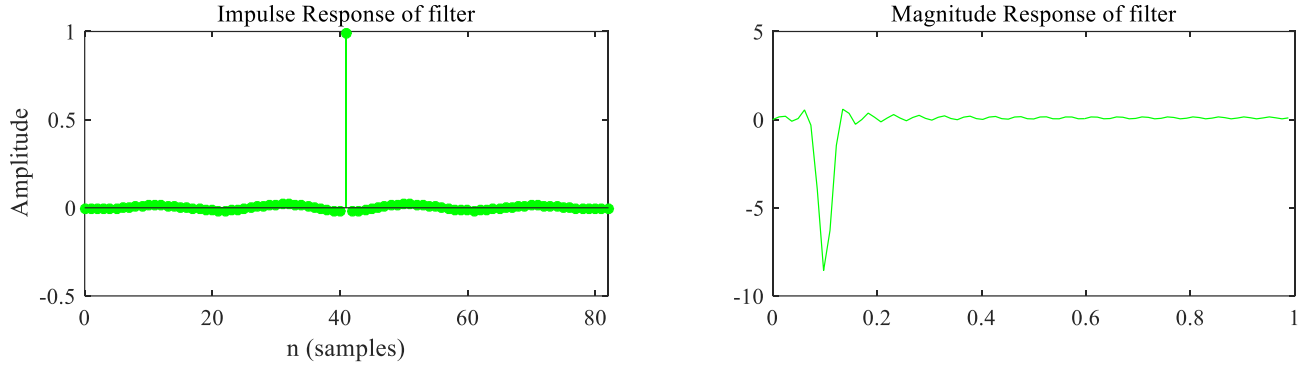

Figure 2. Impulse response and Magnitude response of FIR Welch windowed filter

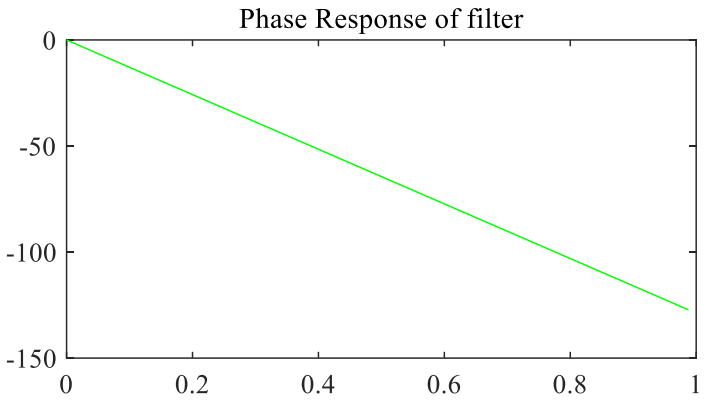

Figure 3. Phase response of FIR Welch windowed filter

The specifications of the modeled filter are filter type; band stop filter, window type; Welch window, filter order; 82 units, lower sideband cutoff frequency; 45Hz, upper sideband cutoff frequency; 55Hz, and sampling frequency; 1000Hz as well as 5mV 50Hz for PLI.

IV RESULTS

The Welch window-based FIR filter is used to remove 50Hz PLI from EEG. Fig 4(a) shows the graphics of real EEG signal obtain from a lady. The EEG was corrupted with a 5mV 50Hz PLI (fig 4(b)) generated with MATLAB application to produce a contaminated EEG signal shown in fig 4(c). After applying the Welch window-based FIR filter to the corrupted EEG, a filtered EEG very akin to the EEG obtained from our patient was produced as shown in Fig 4(d). With the results obtained, it is evident that the Welch windowed FIR filter effectively removed the 50Hz for PLI from the EEG thereby successfully enhancing our patient's EEG signal. Furthermore, spectrum power magnitude response (dB) in MATLAB was used to evaluate the filter. The outcome further shows the effectiveness of the filter in EEG signal enhancement. Fig 5 displays magnitude response of EEG signal while fig 6 and fig 7 show magnitude responses of PLI and contaminated EEG signals respectively. The magnitude responses of filtered EEG is shown in fig 8. A careful comparison of fig's

5, 6, 7 and 8 reveals that at normalized frequency of 0.1 π rad/sample, the magnitude response of the EEG is 62.249dB while that of 50Hz PLI is 69.283dB. When the two signals were mixed together to form the contaminated EEG, the magnitude response increased to 71.175dB at the same normalized frequency of 0.1 π rad/sample. But on the application of the Welch window-based FIR filter on the noisy EEG, the magnitude response of the spike dropped to 62.244dB in the filtered EEG, a difference of 0.005dB compared to the EEG signal. This shows that the filter yielded a very good result in the artifact removal process. More so, Table 1 show results obtained with the filter using different filter orders. It is clearly shown in Table 1 that filter order 82 tabs produced the best output for the filter.

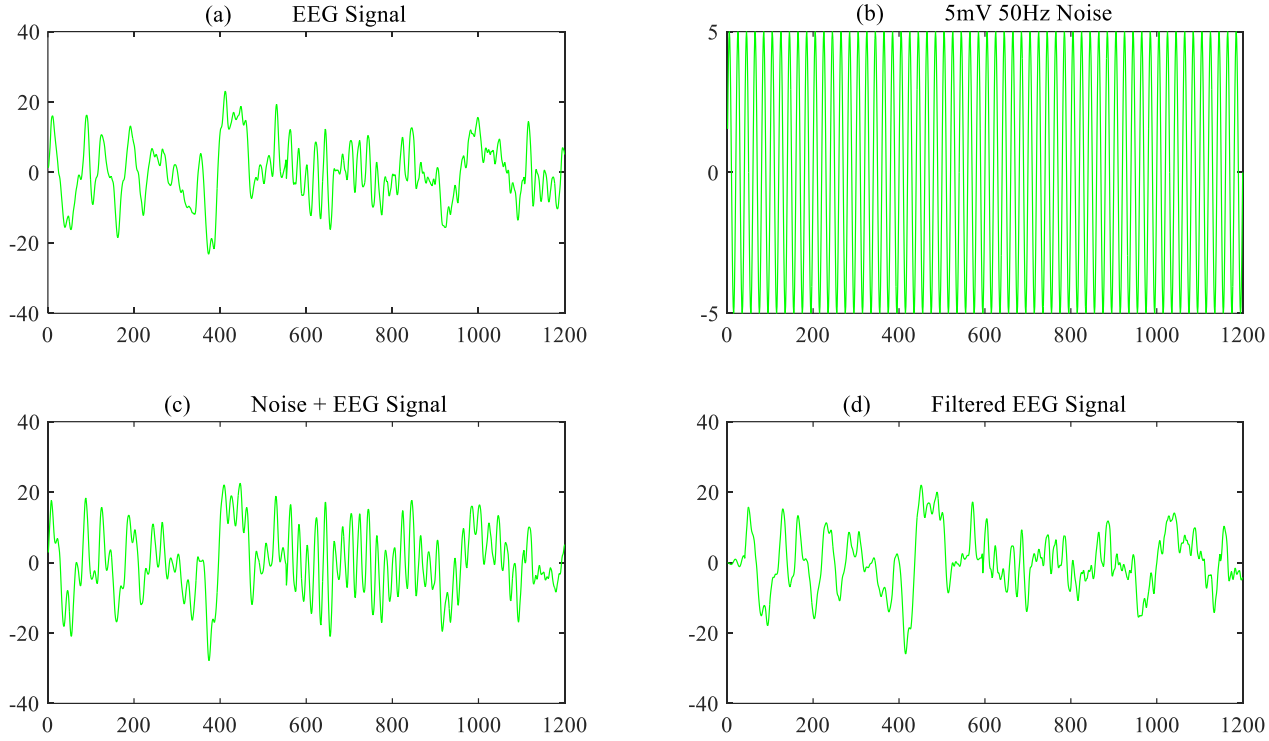

Figure 4. (a) Clean EEG, (b) 5mV 50Hz PLI, (c) contaminated EEG and (d) filtered EEG

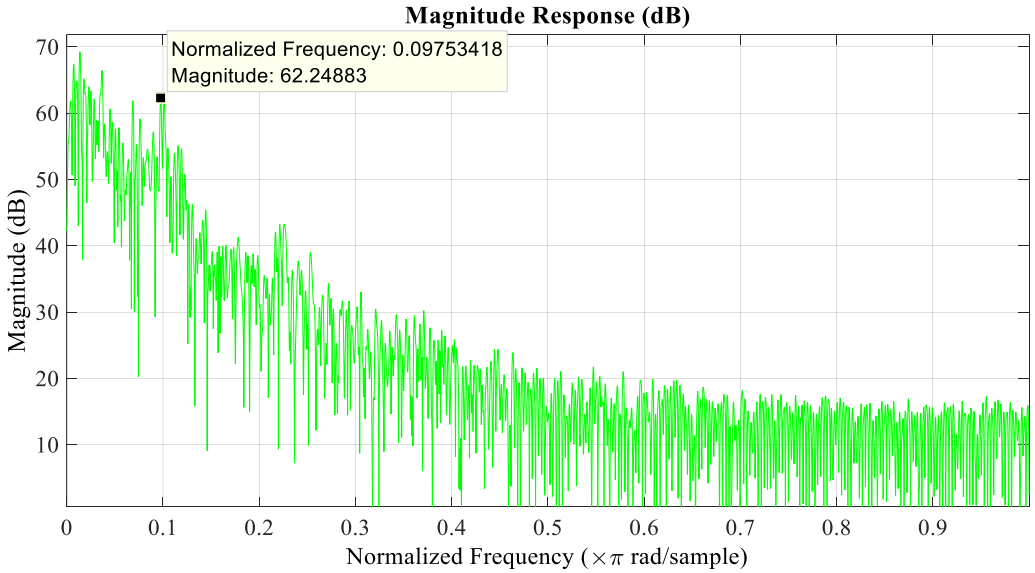

Figure 5. Magnitude response of EEG signal

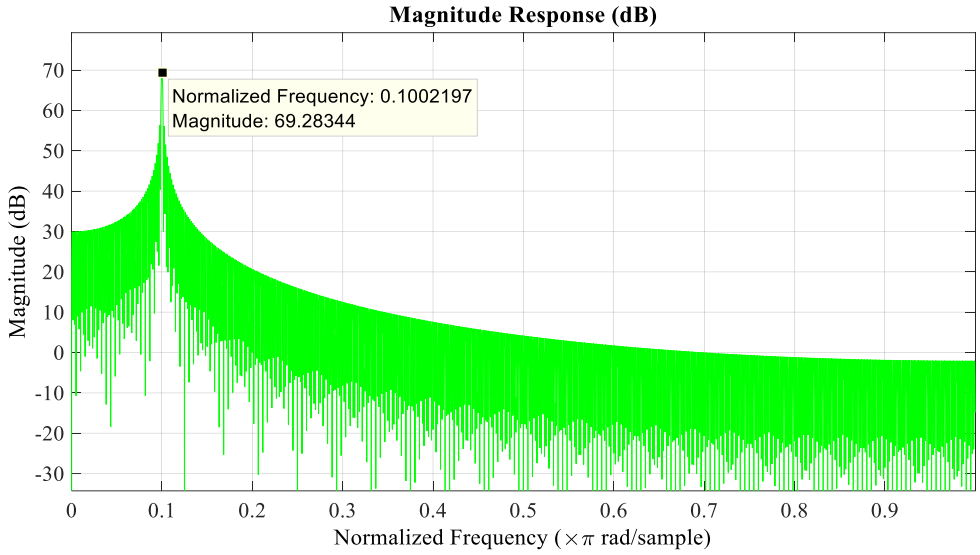

Figure 6. Magnitude response 5mV 50Hz PLI

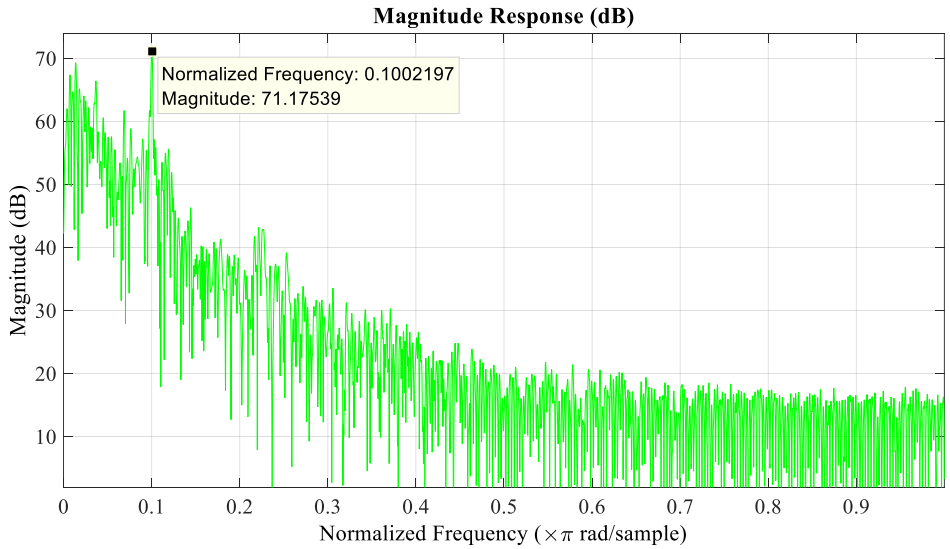

Figure 7. Magnitude response contaminated EEG

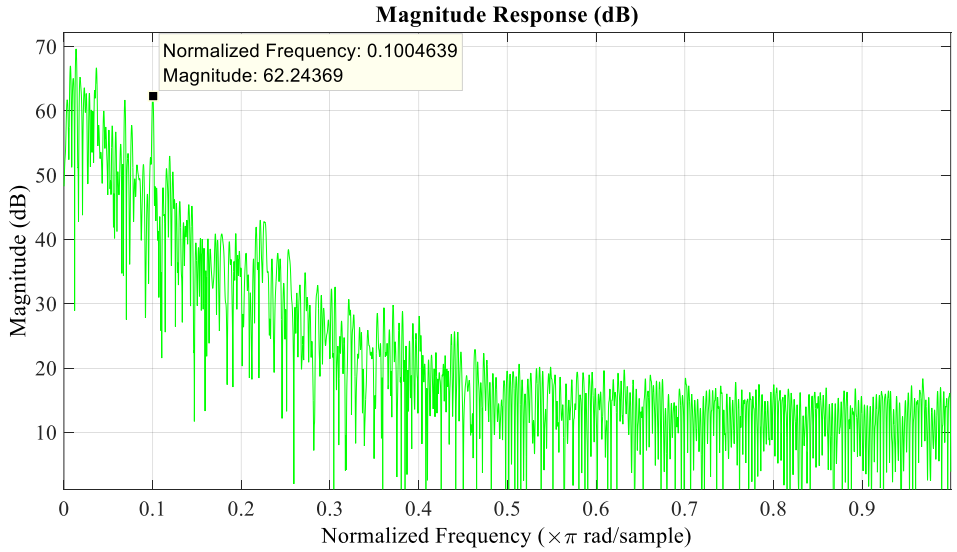

Figure 8. Magnitude response filtered EEG

Table 1. Magnitude response for different filter orders

Filter order	*100*	*90*	*88*	*86*	*84*	*82*	*80*
Mag. Response (dB)	59.247	61.553	61.700	61.831	62.215	62.244	62.720

V CONCLUSION

50Hz PLI has been effectively reduced in EEG with the designed FIR Welch windowed filter. The filter shows a very good stability and phase response linearity characteristics. It is recommended that Welch window shall be added in the list of windows used in FIR filter modeling since its viability in 50Hz PLI removal from EEG has been evidently shown. Filter order 82 units is also recommended in the design of Welch windowed FIR filter. This is evident with the results shown in this work.

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This volume is dedicated to Late Sh. Ram Singh Phanden, father of Dr. Rakesh Kumar Phanden.

