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Reducing Powerline Interference in Electrocardiogram Signal using Optimized Trapezoid Window Based Digital Finite Impulse Response Filter

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ABSTRACT

Electrocardiogram (ECG) is a biomedical signal that provides vital information about the condition of heart. However, different artifacts such as powerline interference, electrode contact noise, motion artifacts, muscle contraction and base line drift usually distort the ECG signal leading to inaccurate diagnoses of patient ECG. The most significant interference that corrupts the ECG is powerline Interference. Hence, this paper present the design of finite impulse response (FIR) digital notch filter with optimized trapezoid window for the removal of power line noise from ECG signals. The three ECG signals records (100MLII, 124MLII and 200MLII) used for the simulation were taken from MIT-BIH Arrhythmia database. These ECG records were then corrupted with 50Hz powerline noise generated in MATLAB and filtered using the proposed filter. A comparative analysis of the FIR notch filter designed with the optimized trapezoid window with the FIR notch filters developed with the other window types shows that the proposed filter displays an improved signal to noise ratio (SNR) of 25.2070 dB, 31.9562 dB, 28.6152 dB for the three ECG signals records (100MLII, 124MLII and 200MLII) respectively.

***Keywords*:** Artifacts, ECG, FIR, Optimized trapezoid window, Powerline noise, SNR, Optimized trapezoid window, MIT-BIH Arrhythmia database

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1. INTRODUCTION

ECG signals provide important information about the functions and conditions of heart. Therefore, monitoring and recognition of ECG signals is a remarkable topic in the biomedical field. The frequency bandwidth for therapy of the ECG signal is from 0.5 Hz to 100 Hz, and the highest peak is about 1 Mv [3]. ECG signal is usually corrupted with different interferences which include the 50 Hz powerline noise, baseline wander noise with a frequency around 0.5 to 0.6 Hz, electromyogram (EMG) noise with maximum frequency of 10 KHz and electroencephalogram (EEG) with a frequency above 100 Hz.

From various artifacts that contaminate electrocardiogram (ECG) recording, the most common is the power line interference. The interference may be due to stray effect of the alternating current fields due to loops in the patient's cables. Other causes are loose contacts on the patient's cable as well as dirty electrodes. If the machine or the patient is not properly grounded, power line interference may even completely obscure the ECG waveform. Electromagnetic interference from the power lines also results in poor quality tracings. Electrical equipment such as air conditioner, elevators and X-Ray units draw heavy power line current, which induce 50 Hz signals in the input circuits of the ECG machine. Electrical power systems also induce extremely rapid pulse or the spike on the trace, as a result of switching action [5]. Care should be taken to suppress these transients.

Several researchers have applied different digital filters in eliminating or reducing the effect of 50 Hz powerline interference in ECG signal. Mahesh, Ragarwala and Uplane [9] designed and implemented digital FIR filter using rectangular window with a view to applying them in removal of power line interference (PLI) in ECG. Chinchkhede *et al.* [1] implemented FIR filter with Blackman, Kaiser, Blackman Harris and Gaussian windows for enhancement of ECG signal and compared their performances. Joshi, Vatti and Tornekar [4] have surveyed various noises that corrupt the ECG signal and various approaches based on fuzzy logic, FIR filter, Emperical mode decompositions used in filtering ECG signal. Their performances was also compared. Van Alste and Schilder [14] suggested a linear phase filtering for removal of powerline and baseline noise in ECG signal .The linear phase filtering was able to reduce the number of computation involved in digital filtering. Ziarani and Konrad [15] developed signal processing algorithm that is capable of extracting a specific component of a signal and also able to track any changes in the signal over time. The algorithm was then applied in elimination of noise under condition of varying powerline interference. Dhayabarani *et al*. [2] designed a digital FIR filter for reducing 50 Hz power line noise in ECG signal with different windowing methods using Hanning, Hamming, Kaiser and Butterworth filter.

Mahesh, Agarwala and Uplane [8] demonstrated how a Kaiser window can be used to obtain FIR digital filters for ECG signal processing. Panda and Pati [11] proposed a digital filter structure using a window based FIR filter to remove the noise in ECG signal. Mittal and Rege [10] designed and implemented digital FIR filter for reducing 50 Hz power line noise in ECG signal with different windowing methods using Hamming, Kaiser, and Chebyshev window. Sham, Kumar and Kumar [12] designed a Hamming window FIR filter for the removal of Power line and base line drift noises. Karmaker *et al*. [6] designed FIR low pass filter using a new adjustable window function, based on combination of Blackman window and Lanczos window for filtering ECG signal. Lin and Hu [7] proposed a novel power-line interference (PLI) detector that employs an optimal linear discriminant analysis (LDA) algorithm to make a decision for the PLI presence and also efficient recursive least-squares (RLS) adaptive notch filter was developed to suppressed the PLI in ECG signal. Thakor [13] proposed several adaptive filter structure to eliminate the powerline noise, baseline wander noise, muscle artifact and motion artifact that distort the ECG signal. The proposed filter was also used for arrhythmia detection.

The use of window method in designing FIR filter plays a vital role in reducing Gibb's phenomenon which is the ringing effect that occurs in transition width of the ideal filter as a result of truncating the impulse response coefficient of the ideal filter. Filtering ECG signal using FIR filter designed with optimized window helps to improve the SNR of the signal. Hence, this paper present the design of digital FIR filter with optimized trapezoid window function for filtering 50Hz powerline noise in ECG signal.

2. OPTIMIZED TRAPEZOID WINDOW

The simplest method of designing FIR filter is through the use of window function technique. Thus, the mathematical expression for trapezoid window function is expressed in (1) and the diagram for trapezoid window is shown in Fig. 1.

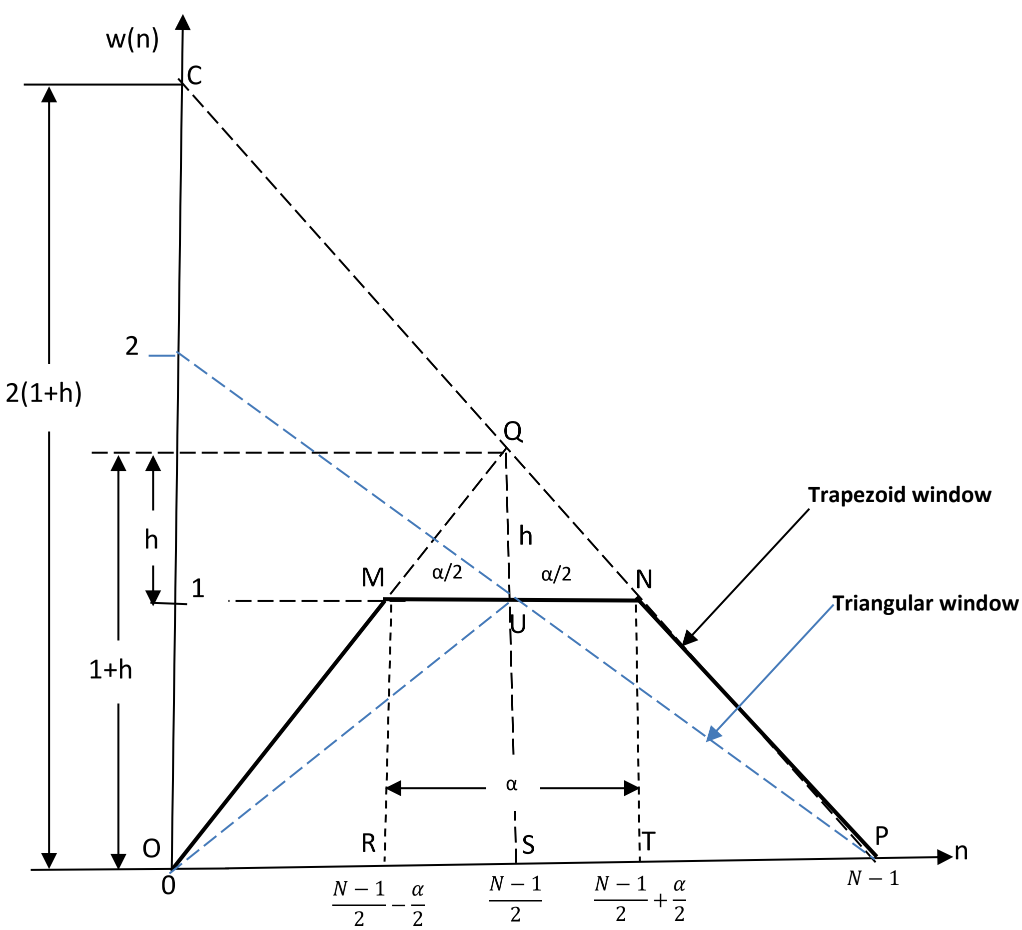

Fig. 1. Trapezoid Window

$$w_T(n) = \begin{cases} \frac{2n_1}{(N-1)-\alpha} ; 0 \le n \le \frac{(N-1)-\alpha}{2} \\ 1 ; \frac{(N-1)-\alpha}{2} \le 0 \le \frac{(N-1)+\alpha}{2} \\ \frac{-2n_3+2\mathrm{N}-2}{(N-1-\alpha)} ; \frac{(N-1)+\alpha}{2} \le 0 \le N-1 \end{cases} \quad . \quad (1)$$

where $w_T(n)$ is the trapezoid window function, $N-1$ is the window length, n is a variable that ranges from 0 to N-1 and α is the length of the upper base of a trapezoid window.

The trapezoid window reduces to a triangular window when $\alpha = 0$ and assumes the shape of a rectangular window when $\alpha = N-1$. However, the optimized trapezoid window function is achieved by determining the optimal value of alpha that yields best spectral characteristics of the trapezoid window for the value of N considered.

2. 1. Determining the optimal value of Alpha (α) for the optimized trapezoid window

Optimal value of α is obtained by simulating the trapezoid window function as expressed in (1) using MATLAB software for (N = 11) to (N = 103) and (α = 0) to (α = 102). The value of α that gave the best magnitude response in terms of sidelobe peak for each N value were recorded as represented in Table 1. Each value of N is plotted against its optimal alpha value using Microsoft Excel as shown in Fig. 2

Table 1. Different Optimal Alpha (α) values at Different values of N

Window length (N)	Optimal length of the upper base of a trapepezoid window (α)	Window length (N)	Optimal length of the upper base of a trapepezoid window (α)
11	2	59	10
13	2	61	10
15	2	63	10
17	2	65	10
19	2	67	10
21	4	69	10
23	4	71	12
25	4	73	12
27	4	75	12
29	4	77	12

31	4	79	12
33	6	81	14
35	6	83	14
37	6	85	14
39	6	87	14
41	6	89	14
43	6	91	14
45	8	93	16
47	8	95	16
49	8	97	16
51	8	99	16
53	8	101	16
55	8	103	16
57	10		

Fig.2. Graph of Alpha (α) Against the Window Length (N)

Hence, the slope $\gamma = \frac{\Delta\alpha}{\Delta N} = \frac{(14.8-4)}{(92-26)} = 0.1636 \approx 0.164$

Therefore, mathematical expression for obtaining the optimal length alpha (α) at which the trapezoid window displays it best spectral characteristics is given by (2).

$$\alpha = 0.164 * \mathrm{N} \qquad (2)$$

where N is window length or the number of samples.
Substituting (2) into (1) yield the optimized Trapezoid window function shown in (3).

$$w_{OT}(n) = \begin{cases} \frac{2n_1}{(N-1)-0.164\mathrm{N}} \; ; 0 \le n \le \frac{(N-1)-0.164\mathrm{N}}{2} \\ 1 \; ; \frac{(N-1)-0.164\mathrm{N}}{2} \le 0 \le \frac{(N-1)+0.164\mathrm{N}}{2} \\ \frac{-2n_3+2\mathrm{N}-2}{(N-1-0.164\mathrm{N} \quad)} ; \frac{(N-1)+0.164\mathrm{N}}{2} \le 0 \le N-1 \end{cases} \qquad (3)$$

3. DESIGN OF DIGITAL NOTCH FIR FILTER WITH OPTIMIZED TRAPEZOID WINDOW

Optimized trapezoid window function shown in (3) can improve the magnitude response of the filter in contrast to non-optimized trapezoid window function which may lead to wider transition width and poor stop band attenuation.

The design of digital notch filter with the optimized trapezoid window involves the multiplication of the frequency response of the ideal notch filter($h_{d[n]}$) with the window coefficient of the optimized trapezoid window ($w_{OT}(n)$). Thus, the mathematical expression for the frequency response of the notch FIR filter designed with optimized trapezoid window is shown in (4).

$$h_{[n]} = h_{d[n]} * w_{OT}(n) \qquad (4)$$

where $h_{[n]}$ is the frequency response of the desired notch FIR filter, $w_{OT}(n)$ is the window coefficient for the optimized trapezoid window and $h_{d[n]}$ is the frequency response of the ideal notch filter which is expressed in (5).

$$h_d(n) = \begin{cases} \frac{\sin\left(\omega_{c_1}(n-M)\right)}{\pi(n-M)} - \frac{\sin\left(\omega_{c_2}(n-M)\right)}{\pi(n-M)} ; \; for \;\; n \ne M \quad (0 \le n \;\; \le 2M) \\ 1 - \frac{\omega_{c_2}-\omega_{c_1}}{\pi} \; ; \qquad n = M \end{cases} \qquad (5)$$

M is a constant which can be expressed as $M = (\frac{N-1}{2})$, N is the filter order, n is a variable that ranges from 0 to N, ω_c is the angular cut off frequency $\omega_{c1}$and ω_{c2} is the passband edge frequency and stopband edge frequency.

The parameters used to design the notch filter presented in this work include: sampling frequency = 360 Hz, powerline frequency = 50 Hz, Filter order (N) =301, and $\alpha = 0.164 * 301$.

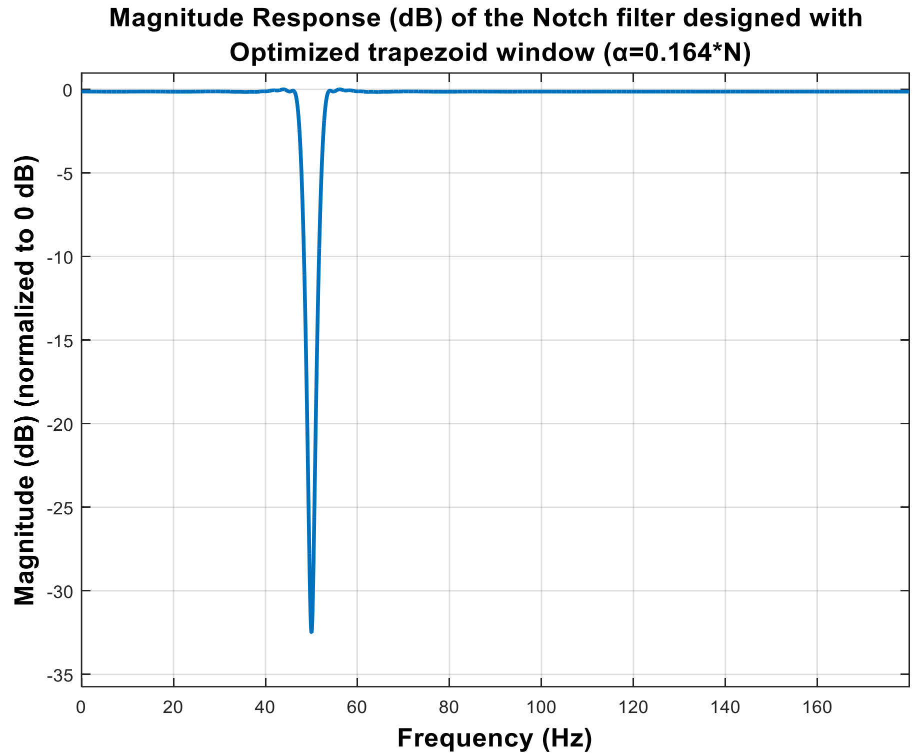

Fig. 3. Magnitude Response of the Notch Filter

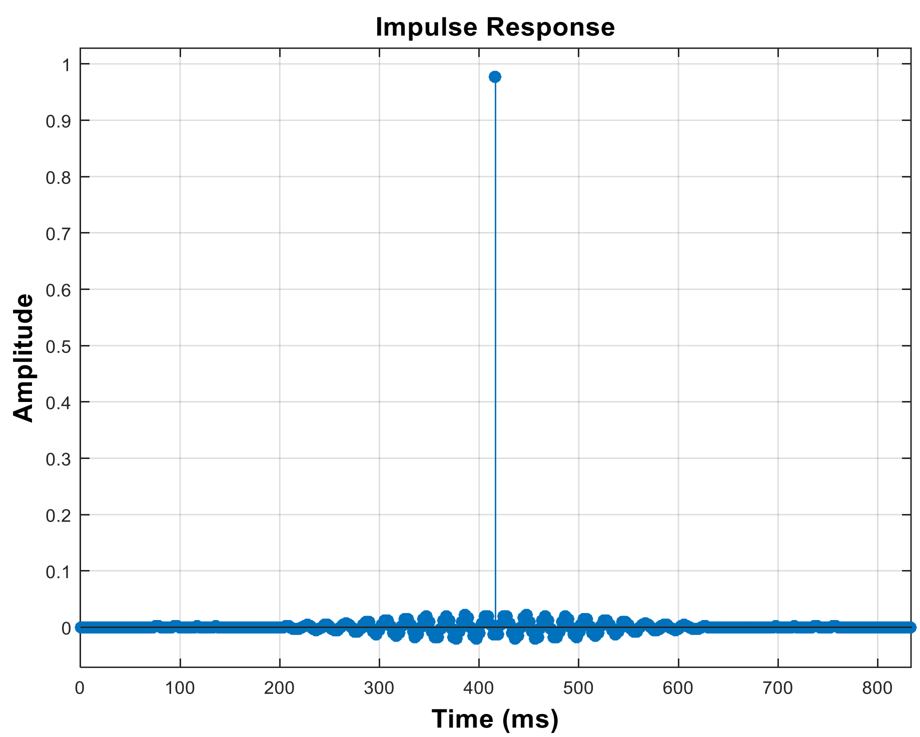

Fig. 4. Impulse Response of the Notch Filter

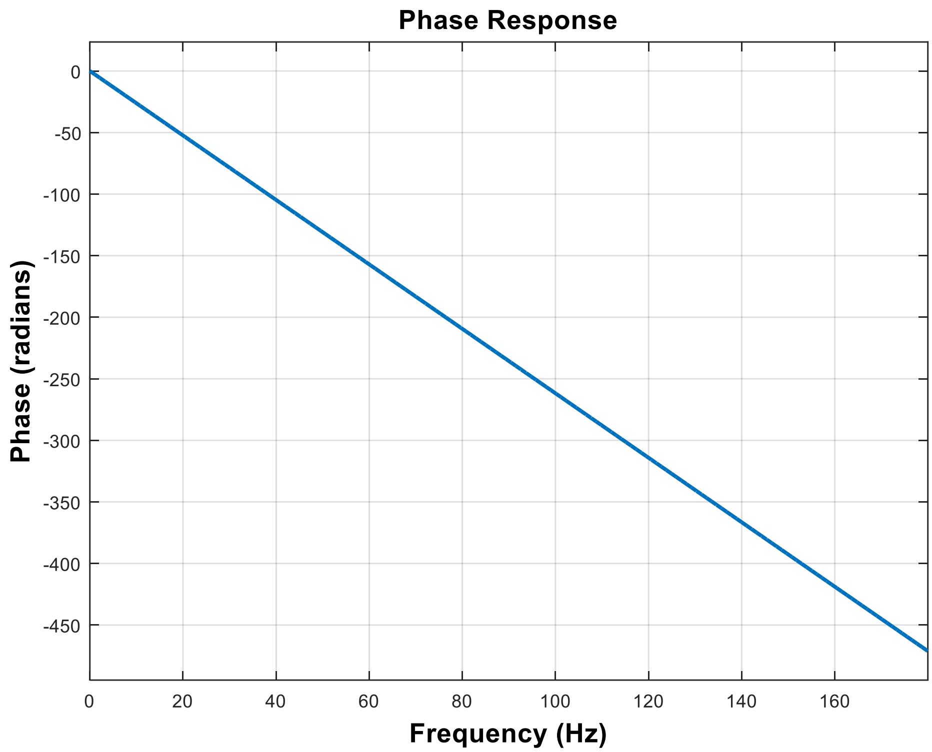

Fig. 5. Phase Response of the Notch Filter (c).

The designed notch filter is simulated in MATLAB .The magnitude, impulse and phase response of the designed notch filter are shown in Fig. 3 - Fig. 5 respectively.

4. RESULTS

The ECG sample records 100, 124 and 200 MLII with 1080 samples were collected from MIT- BIH Arrhythmia database and simulated in MATLAB as shown in Fig. 6 – Fig. 8. The simulated ECG signals of records 100, 124 and 200 MLII are corrupted with 0.3 mV, 0.4 mV and 0.3 mV 50 Hz powerline noise respectively as depicted in Fig. 9 - Fig. 11. The corrupt ECG signals are applied to the implemented notch filter designed with optimized trapezoid window and the output is recorded.

The corrupt ECG signals of Fig.9-Fig.11 are also applied to FIR notch filter designed with Triangular window, Rectangular window, Han window and Hamming window and the outputs are recorded. The original ECG signal of record 100 is then compared with the ECG signal filtered with the proposed window and the other window types as depicted in Fig. 12. - Fig. 16.

The numerical results for the performance of FIR filter designed with optimized trapezoid window and the other windows used in removing the 50 Hz PLI noise for the three records in terms of SNR are recorded in Table 2.

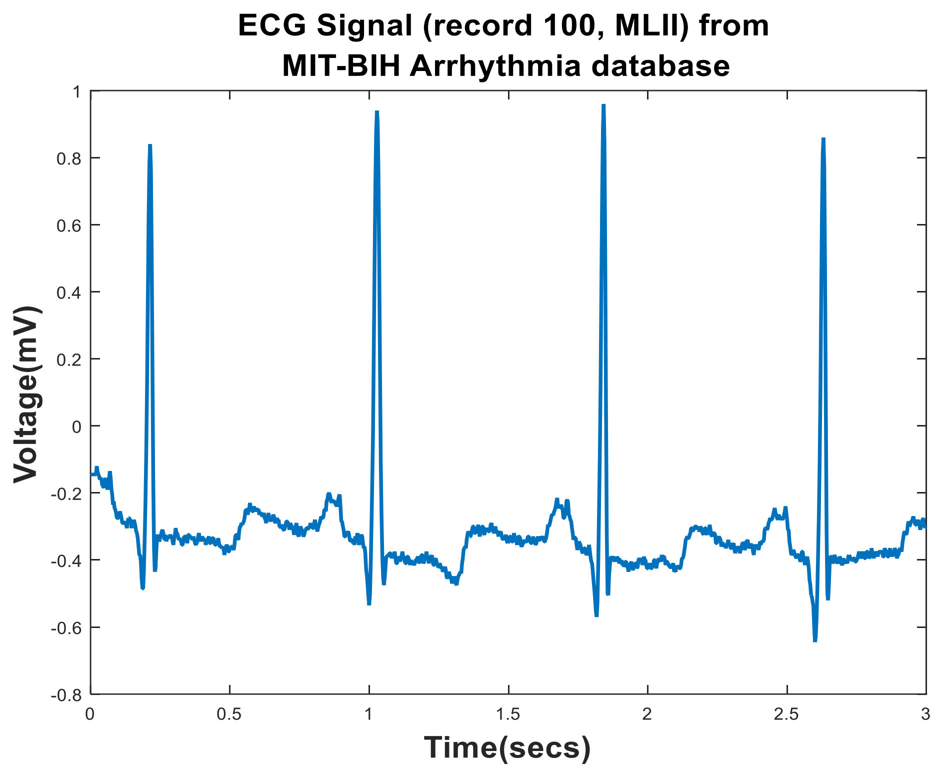

Fig. 6. Sample Record 100

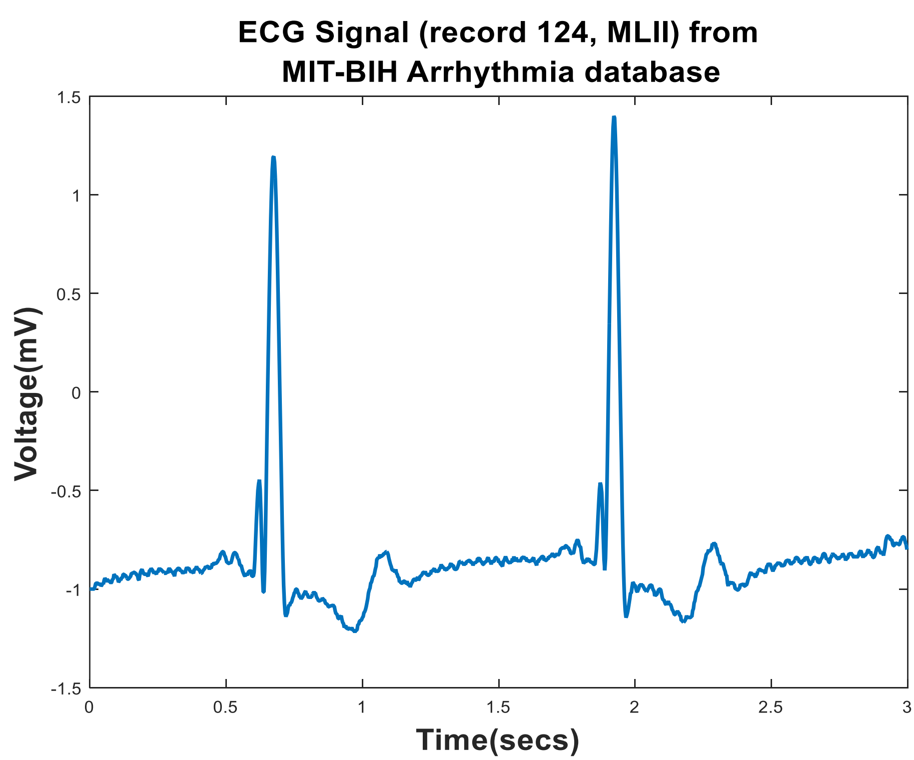

Fig. 7. Sample Record 124

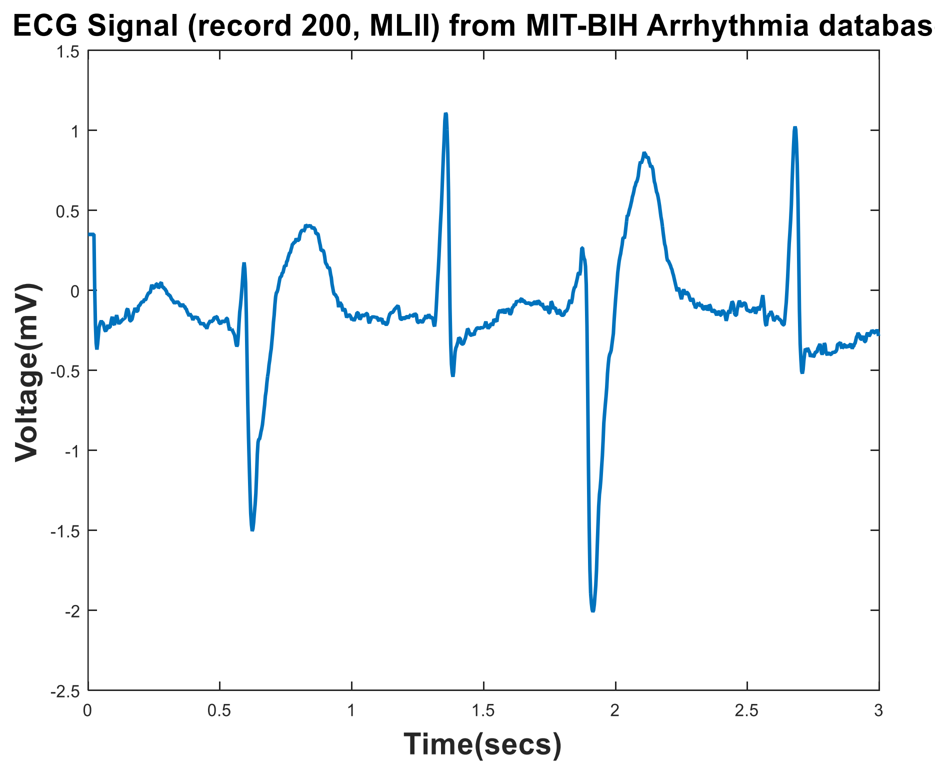

Fig. 8. Sample Record 200

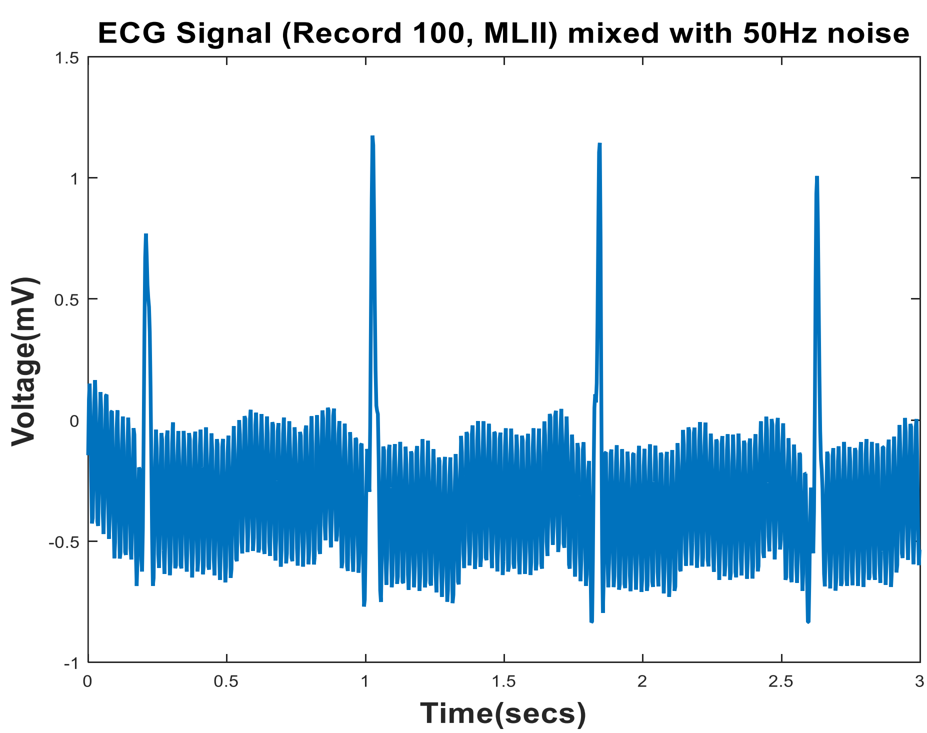

Fig. 9. ECG Signal Record 100 Corrupted with 0.3mV/50 Hz powerline Noise

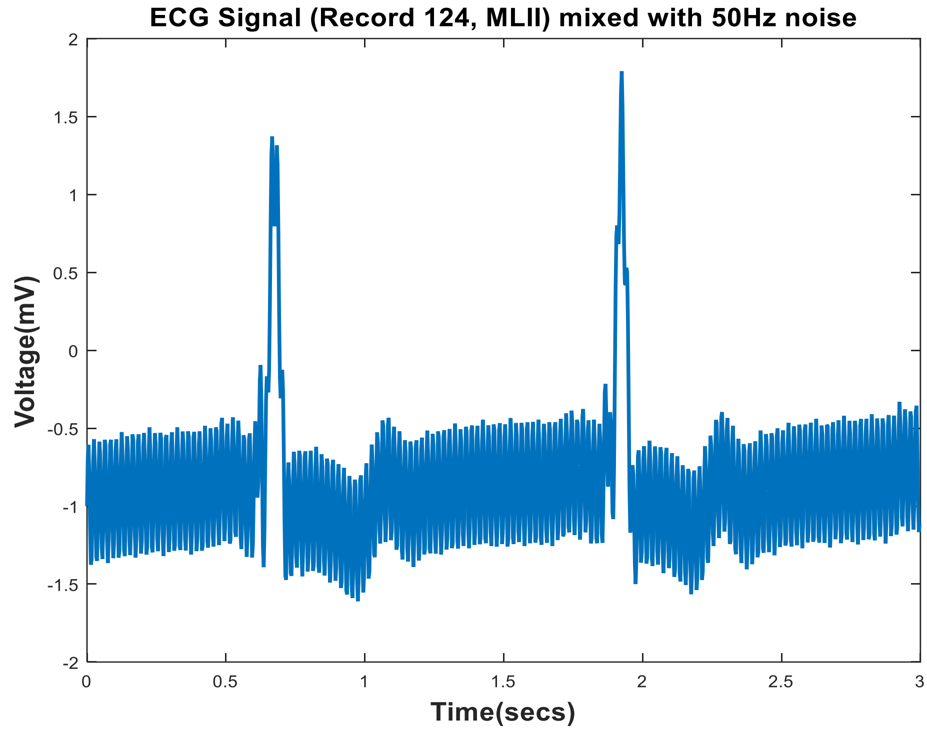

Fig. 10. ECG Signal Record 124 Corrupted with 0.4mV/50Hz powerline Noise

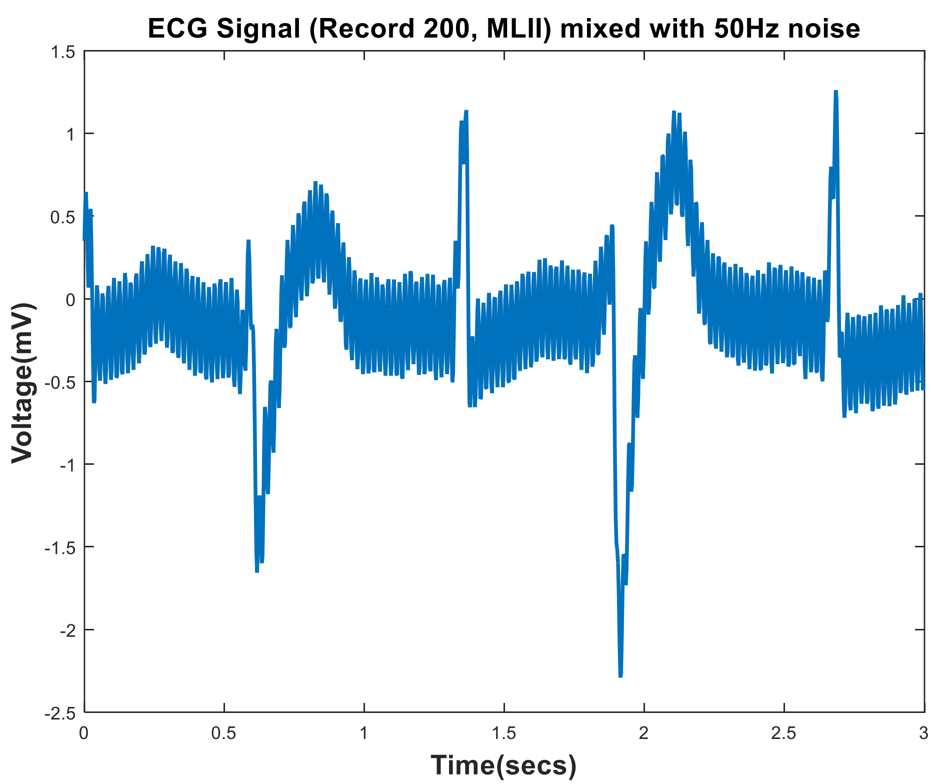

Fig. 11. ECG Signal Record 200 Corrupted with 0.3mV/50Hz powerline Noise

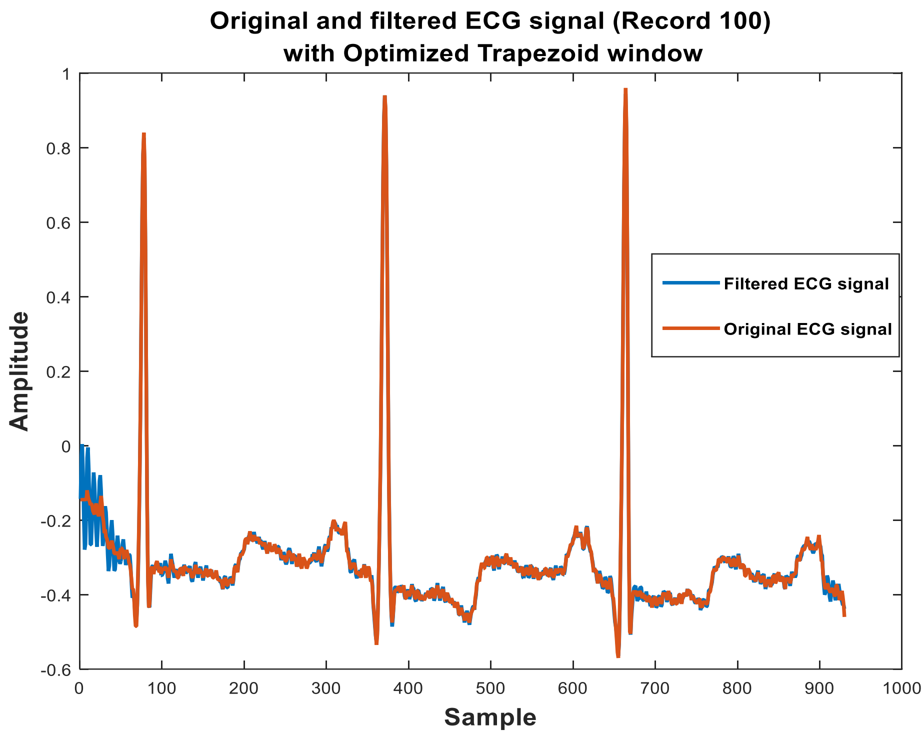

Fig. 12. Comparison of the Original and Filtered Signal of ECG Record 100 with the Optimized Trapezoid Window

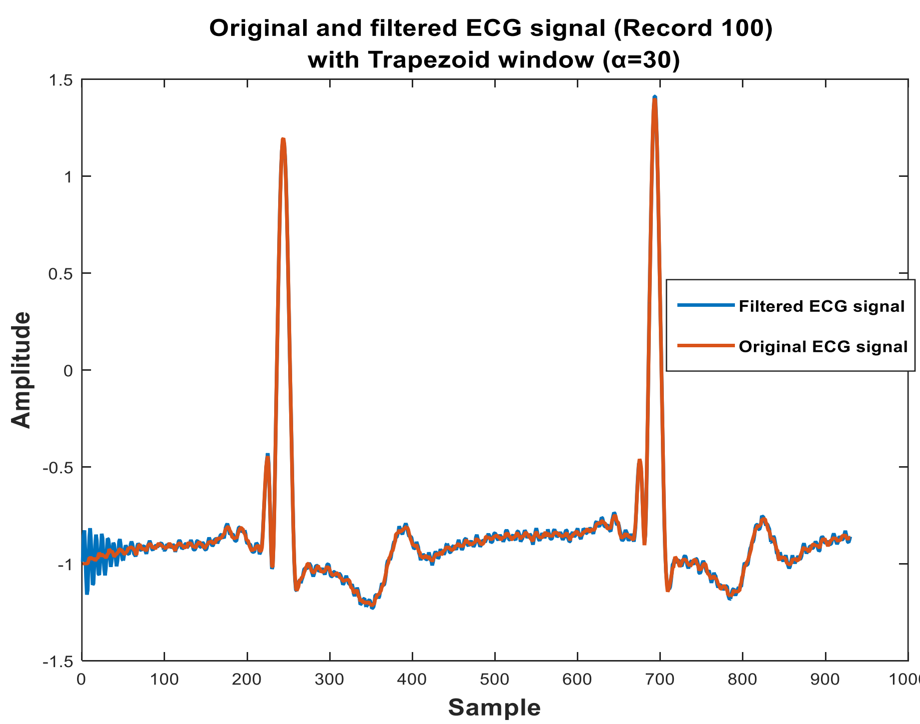

Fig. 13. Comparison of the Original and Filtered Signal of ECG Record 100 with the Trapezoid Window

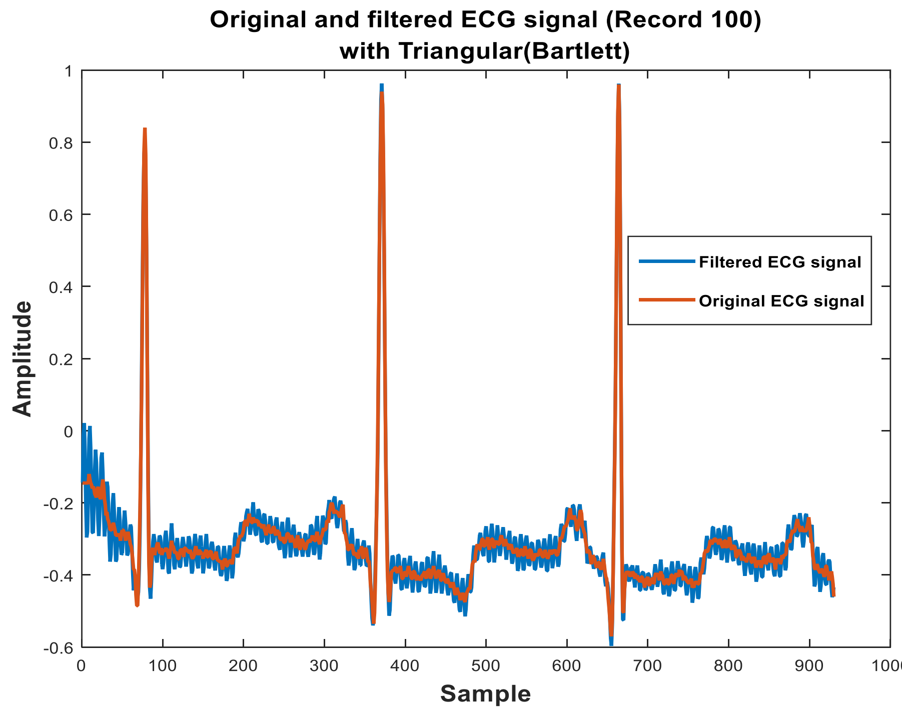

Fig. 14. Comparison of the Original and Filtered Signal of ECG Record 100 with the Triangular Window

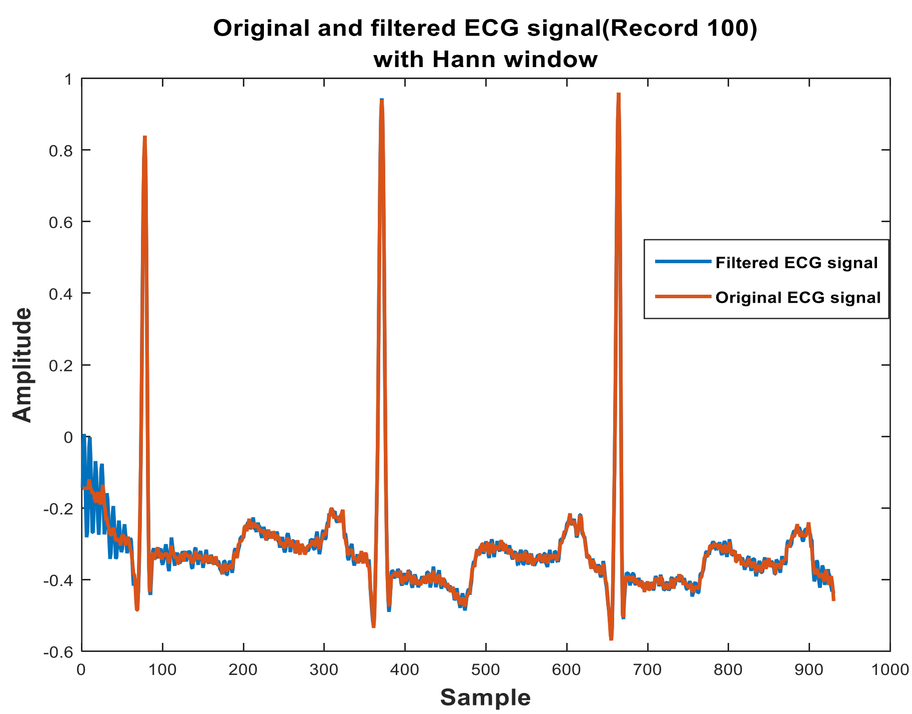

Fig. 15. Comparison of the Original and Filtered Signal of ECG Record 100 with the Hann Window

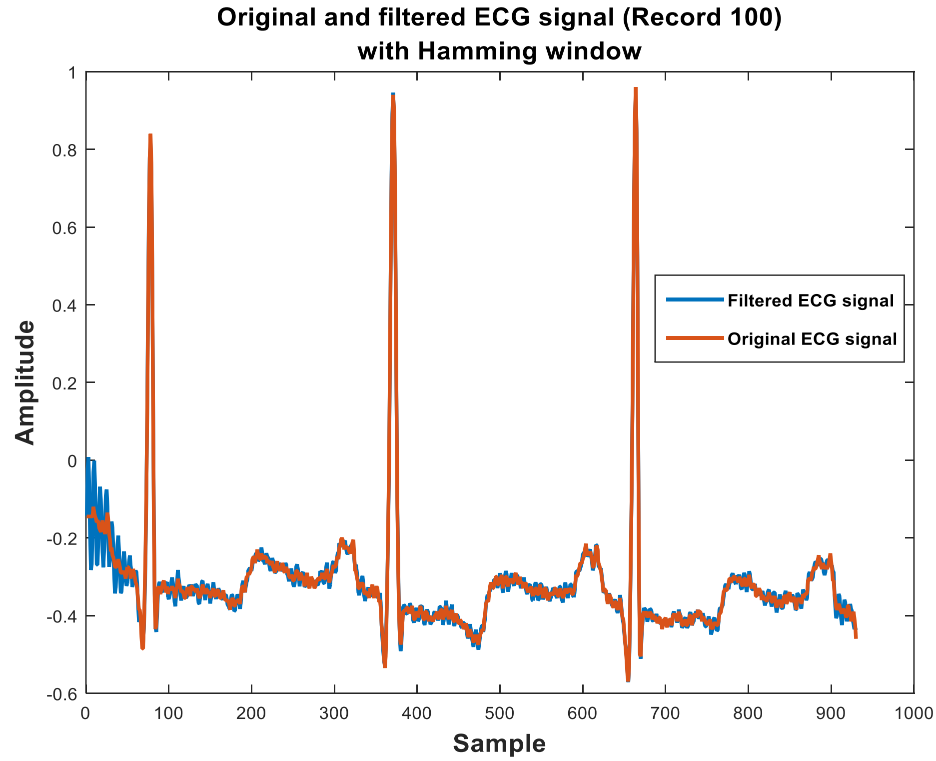

Fig. 16. Comparison of the Original and Filtered Signal of ECG Record 100 with the Hamming Window

Table 2. The Numerical Results of the SNR of the FIR Notch Filters for the Three ECG Records

Window Types	SNR (dB) for ECG record 100	SNR (dB) For ECG record 124	SNR (dB) for ECG record 200
Optimized trapezoid window (α = 0.164*301)	25.2070	31.9562	28.6152
Trapezoid window (α = 30)	24.0478	29.9301	25.8921
Han window	25.1843	31.0806	27.3800
Hamming window	24.9031	30.7900	26.9870
Triangular window	20.0409	25.9084	21.3605

5. DISCUSSIONS

The magnitude, impulse and phase responses shown in Fig. 3 - Fig. 5, shows that the notch filter is stable and also exhibits linear phase characteristics. Also, in the comparison of the original and filtered ECG signal shown in Fig. 12 - Fig.16, it was obvious that the notch filter designed with proposed window filtered the 50 Hz powerline noise better than the notch filter designed with the other window types. Analysis of Table 2 clearly shows that notch filter designed with proposed window has the highest SNR followed by Han window while the Triangular window has the lowest signal to noise ratio for all the three ECG signal records considered in this work.

6. CONCLUSION

The notch filter designed with the optimized trapezoid window has successfully filtered 50Hz powerline noise present in the ECG signals for the three ECG signal records simulated in this work. This can be confirmed with the performance measure using SNR for the FIR notch filters designed with various windows for all the three records taken from MIT-BIH Arrhythmia database as depicted in Table 2.

Lastly, we recommend that the new window should be applied in processing other signals such as electroencephalographic (EEG) and electromyographic (EMG).

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