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POWERLINE INTERFERENCE REDUCTION IN ECG USING HANNING WINDOW-BASED FIR DIGITAL FILTER

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Abstract: Electrocardiogram (ECG) wave suffers from several noise and interferences. The noise and interferences include powerline noise, baseline wander, electromyogram and electroencephalogram as the significant ones. The use of filters considerably improves signal quality during recording. The objective of this work is to design and implement FIR digital filter for reducing 50Hz interference, with hanning window function. Matlab simulated results are presented.

Keywords: Hanning window, Powerline interference, FIR filter, ECG, Periodogram.

1. Introduction

Electrocardiogram (ECG) is a biomedical signal and an electrical manifestation of the contractile activity of the heart [1]. ECG is a periodic and rhythmic signal, synchronized by the function of the heart, which acts as the generator of biomedical events. The ECG signal is a very weak time varying signal with an amplitude of about ImV and has a frequency of between 0.5Hz and 100Hz. Normally, one of the interferences that contaminate ECG during recording is powerline interference. This interference has to be removed for the ECG to convey the correct clinical information about the patient's heart condition. Digital filters considerably remove this interference and improves the quality of the ECG signal.

Various filters have been used by researchers for this improvement of a noisy ECG signal. In terms of windows, Renumadhavi *et al.* [1] used Hamming and triangular windows to remove powerline interference from ECG signal. Islam M. K *et al.* in [2] used Classical Filter Design Express IV tools to design and implement FIR and IIR filters for denoising ECG. The authors also used Wavelet Transform approach, which is not hardware digital filter, for denoising ECG signal. In [3] Chinchkhede K. D. *et al.* evaluated the performances of FIR digital filters designed and implemented with four different windows including Kaiser, Blackman, Blackman Harris and Gaussian windows. Rajkumar Thenua and Agarwal S. K. in [4] used adaptive filter in reducing the noise in ECG. The authors considered LMS, NLMS and RLS algorithms in the work. Rahman Md. Zia *et al* [5] carried out cancellation of

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powerline noise in ECG with computationally adaptive filtering techniques. The authors investigated four adaptive algorithms and they are least mean square (LMS), sign least mean square (SLMS), signed-regressor least mean square (SRLMS) and Sign-Sign Least Mean Square (SSLMS) algorithms. Suzanna M. M. Martens *et al.* [6] employed adaptive canceller based on LMS adaptive algorithm to improve the cancellation of powerline interference in ECG. The authors went further to compare the performance of this canceller with that of a narrow and a wide notch filter in suppressing the fundamental powerline interference component and harmonics in electrocardiogram recordings. In [7] Santpal Singh Dhillon and Saswat Chakrabarti used adaptive IIR notch digital filter to remove powerline interference from electrocardiogram. In [8] Chinmay Chandrakar and Kowar M. K denoised the ECG signal of powerline noise by using adaptive IIR filter with RLS algorithm. In [9] Sonal K. Jagtap and Uplane M.D. applied Chebyshev II digital filter in removing noises including powerline noise from ECG. In [10] Manpreet Kaur and Birmohan Singh used a combination of moving average method and IIR notch filter in powerline interference reduction in ECG. Some researchers have used Hanning window in reducing powerline interference but none showed the detailed responses of the filter designed with it. In this work we investigate the performance of Hanning window with detailed design and performance responses and waveforms, using matlab generated data, and can therefore determine the suitability or otherwise of Hanning window in reducing powerline noise. Fig. 1 depicts an uncorrupt ECG signal from human heart [11].

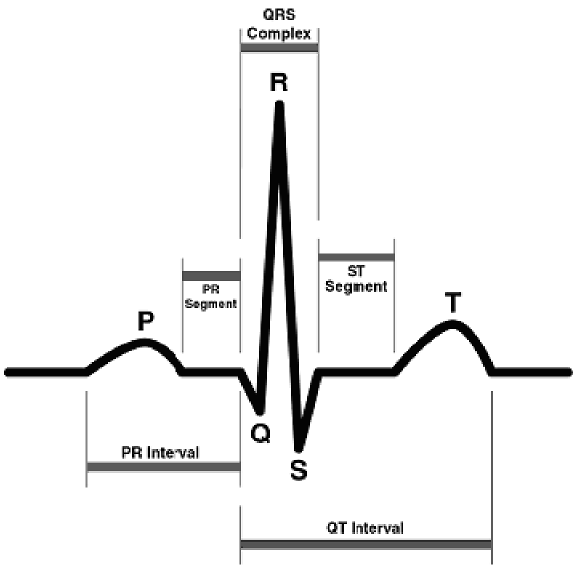

Fig. 1: Normal ECG Signal (Source: [11])

2.0 Design of Digital NotchFilter With Hanning Window

A Hanning window function is depicted in fig 2 below [12]. The mathematical model is as in eqn (1)

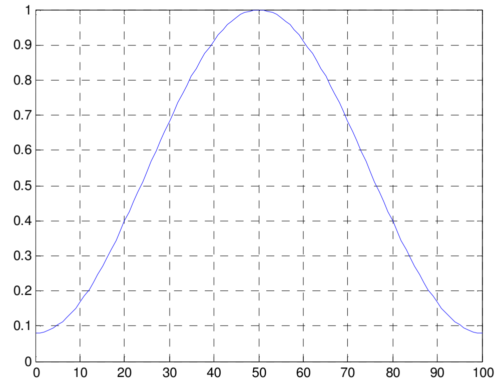

Fig. 2: Hanning Window Function

$$w(k) = 0.54 - 0.46\cos\left[\frac{2\pi k}{(M-1)}\right], 0 \le k \le M-1 \qquad (1)$$

Where M is the number of taps of the FIR filter. In this design, the order of the filter is 100. The powerline frequency is 50Hz and the sampling frequency is 1000Hz. If the order of the filter is L, then M = L + 1, that is M = 101. Substituting the value of M in (1) results to the expression of (2)

$$w(k) = 0.54 - 0.46\cos\left[\frac{2\pi k}{100}\right], 0 \le k \le 100 \qquad (2)$$

Using (2) to design a notch filter for 50Hz powerline reduction in a matlab environment provides impulse, magnitude and phase responses of the filter as shown in figures 3, 4 and 5respectively.

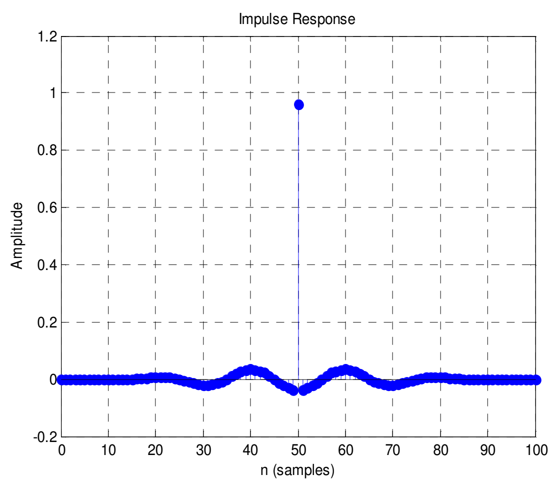

Fig 3: Impulse Response of the Notch Filter

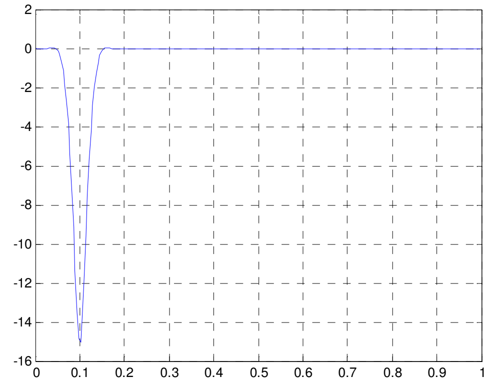

Fig. 4. Magnitude Response of the Notch Filter

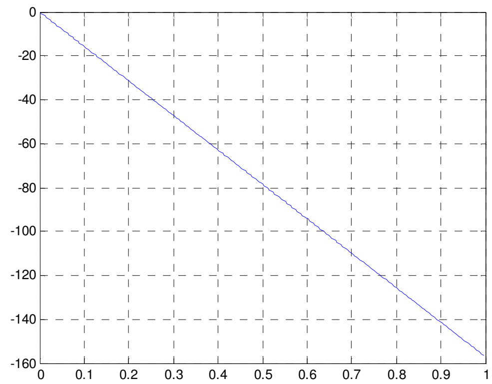

Fig. 5: Phase Response of the Notch Filter

3. Results

A 3.5mV ECG signal that is normal and devoid of any noise as generated by matlab is presented in fig. 6 below. The noise-free ECG signal of fig 6 is contaminated with 50Hz powerline of 0.1mV and presented in fig 7. The periodogram of the contaminated ECG signal is depicted as fig 8. From fig 8, the average power of contaminated ECG signal at 50Hz is +4.2dB. The implemented FIR notch filter is used on the contaminated ECG signal and the output which represents the filtered signal is recorded in fig 9. The periodogram of the filtered ECG signal is also recorded in fig 10. From fig 10 the average power of the filtered ECG signal at 50Hz is -12.5dB. From the recordings the power of the filtered ECG signal at 50Hz is lower than that of the contaminated ECG signal at 50Hz. This means that the applied notch filter filtered a large proportion the contaminated ECG signal at 50Hz.

The corrupt ECG signal of fig. 7 is applied to an FIR adaptive notch filter as a way of comparing the performances of FIR notch filter designed with hanning window and adaptive notch filter in removing powerline interference in ECG signals. The adaptively filtered ECG signal is recorded in fig. 11 while the periodogram is shown in fig. 12. From fig. 12 the average power of the ECG signal filtered with adaptive notch filter at 50Hz is further reduced to -34.2dB. Note that 50Hz here corresponds to 0.1rad in the normalized frequency scale.

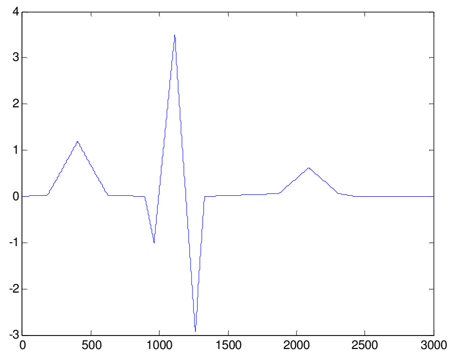

Fig. 6: Noise-Free Normal Signal From Matlab

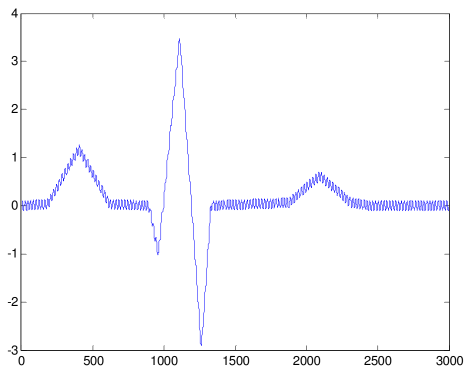

Fig. 7: ECG Signal Contaminated with 50Hz Powerline

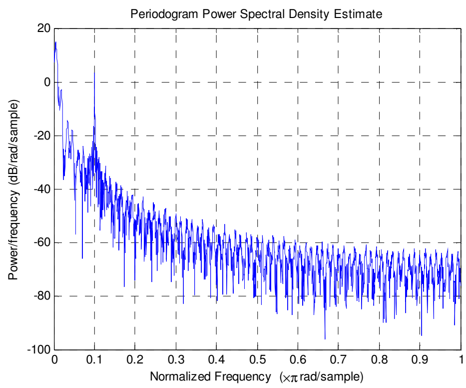

Fig. 8: Periodogram of the Contaminated ECG Signal

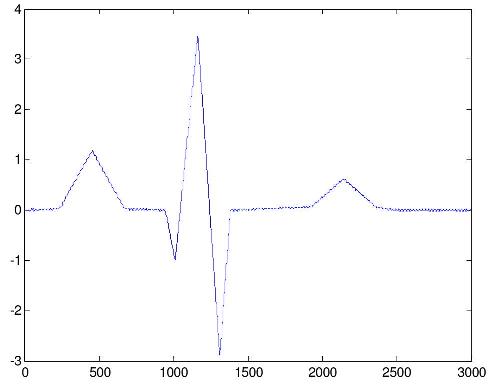

Fig. 9: Filtered ECG Signal

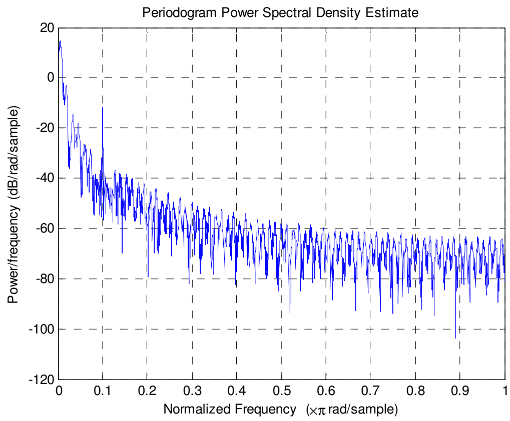

Fig. 10: Periodogram of the Filtered ECG Signal

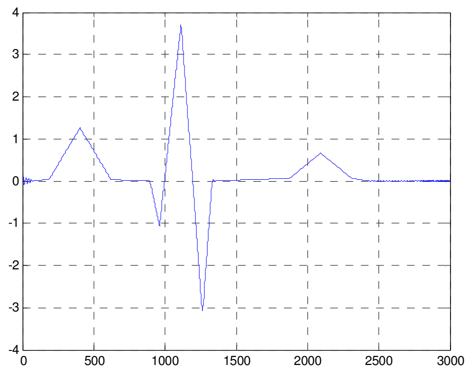

Fig. 11: Adaptively Filtered ECG Signal

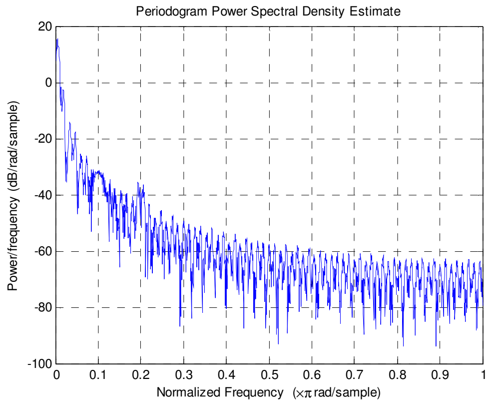

Fig. 12: Periodogram of Adaptively **Filtered ECG Signal**

4. Conclusion

The impulse and magnitude responses of the filter show that the filter is stable. No oscillations are sustained in the magnitude response, which implies stability. The phase response is linear which is very desirable for ECG filtering. Comparing the average power of the filtered ECG signal with that of the corrupt signal shows that the notch filter has actually removed a reasonable quantity of the 50Hz powerline interference. Comparing the performance of the hanning-windowed filter with that of adaptive filter, as can be deduced from figures 11 and 12, shows that the adaptive filter is better in ECG processing with a view to removing powerline interference.

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