IMPLEMENTATION OF FIR DIGITAL FILTER WITH BLACKMAN WINDOW FOR IMPROVEMENT OF ECG SIGNAL QUALITY

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Abstract: Powerline interference corrupts biomedical recordings. A notch filter is one of the filters that are suggested to suppress the fundamental powerline interference and its harmonics in electrocardiographic recordings. The aim of this paper is to design and implement digital FIR notch filter for suppressing the 50Hz powerline interference, with Blackman window function in electrocardiographic (ECG) signal recordings. Matlab is used to generate simulated results.

Keywords: Blackman window, ECG, Powerline interference, notch filter.

1. Introduction

Powerline interference is a significant signal in electrocardiography. Though there is need for proper recording environment during ECG measurement, this proper environment may not be sufficient to avoid this interference. For correct clinical information to be obtained from an ECG the amplitude of the powerline interference should be less than 0.5% of the peak-to-peak QRS amplitude [1]. This corresponds to signal to noise ratio (SNR) of about 30dB. The powerline interference can contain the fundamental component and higher harmonics. Therefore our expression of powerline interference in this paper is a combination of the fundamental powerline interference component and the harmonics. Naturally, ECG signal exists in analogue form. For convenience of processing and analysis, the ECG signal is converted to digital form. If the sampling frequency is sufficiently high the resulting digital signal preserves all the information of the analogue one. Notch filters reduce the powerline interference by suppressing predetermined frequencies. Adaptive cancellers can also reduce the powerline interference by tracking the interference frequency. In [2] Ferdjallah M. and Barr R.E. used frequency domain digital filtering approaches to reduce powerline noise in ECG. Sorensen J.S. et al [3] did a comparison of 11R filters and wavelet transform in reducing powerline noise in ECG. Mahesh et al in [4] investigated the application of Chebyshev I. digital filter in removal of interference in ECG signal, on real time basis. In [5] Guatam et al effected removal of powerline noise and other noises with asynchronous averaging and filtering algorithms. Mbachu C.B. et al in [6] processed ECG signal with FIR digital filters implemented with Kaiser Window function. In [7] Luo S. and Jhonston P. investigated how efficient interpretation and diagnosis can be facilitated with regards to ECG signals. They considered issues that are related to the inaccuracy of ECG preprocessing filters. Mbachu et al [8] investigated the filtration effectiveness of digital FIR filters implemented with rectangular window in processing ECG signal. Sonal K Jagtap and Uplane M. D. [9] did a real time approach of ECG noise reduction using Chebychev type II digital IIR filters. In [10] Chinchkhele et al evaluated the performances of Kaiser, Blackman, Blackman Harris and Gaussian windows in implementing FIR digital filters for enhancement of ECG signal. In this paper we are proposing to use Blackman window to design and FIR filter for suppression of powerline interference in ECG. By this we determine the suitability or otherwise of Blackman window in this suppression.

Fig 1: Shows a typical ECG signal free from corruption [11].

2. Design of Digital Notch Filter With Blackman Window

Fig 2: Represents a Blackman window function. The mathematical model is represented [12] in equation (1).
Fig 2: Blackman Window Function

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\begin{align*}
  w(k) &= 0.42 - 0.5 \cos\left(\frac{2\pi k}{M-1}\right) + 0.08 \cos\left(\frac{4\pi k}{M-1}\right) \\
  0 &\leq k \leq M - 1
\end{align*}
\]  

(1)

Where M is the number of samples of the FIR filter. In this design, we have the order L of the filter as 100 and L = M-1. The sampling frequency of 1000Hz is sufficiently high for the digitized signal to preserve all the information of the analogue ECG signal. If we substitute the value of M in (1) the expression of (1) becomes that of (2).

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\begin{align*}
  w(k) &= 0.42 - 0.5 \cos\left(\frac{2\pi k}{100}\right) + 0.08 \cos\left(\frac{4\pi k}{100}\right) \\
  0 &\leq k \leq 100
\end{align*}
\]  

(2)

Designing a notch filter for 50Hz powerline noise suppression, with the expression of (2), the impulse, magnitude and phase responses of the filter are presented in figures 3, 4 and 5 respectively.

Fig 3: Impulse Response of the Notch Filter

Fig 4: Magnitude Response of the Notch Filter

Fig. 6 Normal ECG Signal From Matlab

Fig. 7 ECG Signal Contaminated with 50Hz Powerline Noise

3. Results

A normal noise-free ECG generated by matlab is shown in fig 6 below. The normal ECG signal of fig 6 is contaminated with 50Hz powerline and the contaminated signal is shown in fig 7. The periodogram of the contaminated ECG is recorded in fig 8. From fig 8, the average power of the contaminated ECG at 50Hz is +4.2dB. The contaminated signal is filtered using the implemented FIR notch filter and the filtered ECG signal is recorded in fig 9. The periodogram of the filtered ECG signal is recorded in fig 10. From fig 10 the average power of the filtered ECG signal at 50Hz is -8dB. From the recordings the average power of the filtered ECG signal at 50Hz is less than that of the contaminated signal at 50Hz. Therefore the notch filter has actually removed a substantial quantity of the 50Hz powerline noise.

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 Blackman 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 drops to -34.2dB. Note that 50Hz here corresponds to 0.1rad in the normalized frequency scale.
4. Conclusion

The filter is stable based on the impulse and magnitude responses because there are no sustained oscillations in them. The phase response exhibits linear characteristics. 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, though not good enough for correct clinical interpretations. Comparing the performance of the Blackman-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 and good enough for correct clinical interpretations.

References


