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EVALUATION OF THE EFFECTIVENESS OF TRIANGULAR WINDOW-BASED FIR DIGITAL FILTER FOR ENHANCEMENT OF ECG SIGNAL

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Abstract: Biomedical signals carry important information about the behaviour of the parts of animals being studied. With proper analysis of electrocardiographic (ECG) signal, one can predict whether a patient has a heart problem or not, or monitor the recovery state of the patient after a heart attack. If these signals are properly processed, their physiological and clinical information are enhanced. The quality of biomedical signal is degraded mainly by many sources of noise which include: Powerline, baseline wander, electromyogram and electroencephalogram. The objective of this paper is to design and implement FIR digital filter based on triangular window function to overcome part of the degradation of ECG signal in man by removing the 50Hz powerline interference in the signal. In doing this, matlab is used to generate the signals and observe results. The performance of the triangular window is compared with that of an adaptive noise canceller.
Keywords: Triangular window, ECG, Powerline interference, periodogram.

1. Introduction

Electrocardiography (ECG) is the electrical activity of the heart. This electrical activity produces a waveform called the electrocardiographic (ECG) signal. This signal contains clinical information about the heart, and its acquisition and measurement is very important in determining the healthy conditions of the heart. Typically, an ECG signal is in the range of 2mv and requires recording bandwidth of 0.05 to 100Hz [1]. Under normal conditions features of an ECG signal can be correctly interpreted by a trained personnel and the condition of the heart ascertained from these features. Incidentally ECG is corrupt by some biomedical signals and powerline interference which degrade the quality of the ECG and under such condition it becomes difficult to correctly interpret the features of the ECG signal. Therefore these corrupting signals have to be filtered off. For a very stable power supply source a static coefficient notch filter can be used to eliminate the 50Hz powerline interference. But for power supply source that is not very stable, either due to loading or operational conditions, in which case the frequency can drift an adaptive filter is most

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suitable because it tracks the powerline frequency as it drifts. In this work a FIR digital filter that is based on triangular window is proposed.

In [2] Rahman *et al.* used signed LMS based adaptive filters which are computationally superior to cancel noise in ECG. The authors evaluated the SNR of the filtered ECG signal for each adaptive algorithm. Raj Kumar and Agarwal in [3] evaluated the performances of different adaptive algorithms which included LMS (Least Mean Square), NLM (Normalised Least Mean Square) and RLS (Recursive Least Square) algorithms, in cancellation of noise. Santpal and Chakrabarti [4], investigated the performance of adaptive IIR notch filter in removal of powerline interference from electrocardiogram. Suzanna *et al* [5] applied adaptive powerline interference canceller based on LMS algorithm, for electrocardiography. The authors investigated the tracking performance of the filter and found it satisfactory. Yatindra and Gorav in [6] did a performance analysis of adaptive filtering in addition to those of Wiener and notch filters in the powerline interference reduction in ECG. The authors evaluated the SNR of the filtered signal with respect to the different filtering techniques. In [7] Sachin and Yadav tried to evaluate the performance of adaptive filters based on LMS and RLS algorithms separately for ECG signal processing. The authors compared the output signal to noise ratio (SNR) of the ECG signal for the two adaptive algorithms. In [8] Aung Soe performed the evaluation of different digital filters aimed at cancelling noise in electrocardiogram. About six ECG signals from MIT-BIH database were used on the filters to do the evaluation. In [9] Sameni *et al.* employed a type of dynamic filter called the extended Kalman filter which is capable of tracking the noises that corrupt ECG signal shape. Hon Wan *et al*. [10] in their work made the step size parameter variable as a means of dynamically adjusting the filter coefficients of the LMS based adaptive filter and hence track the powerline interference in ECG signals, instead of the conventional means of the convolution of the reference input signal and the filter coefficients. We therefore propose to apply triangular window-based digital filter in this work with a view to determining its effectiveness in reducing 50Hz powerline interference in ECG.

2. Triangular Function

A triangular window function is shown in fig. 1 while the mathematical model is presented as in equation (1)

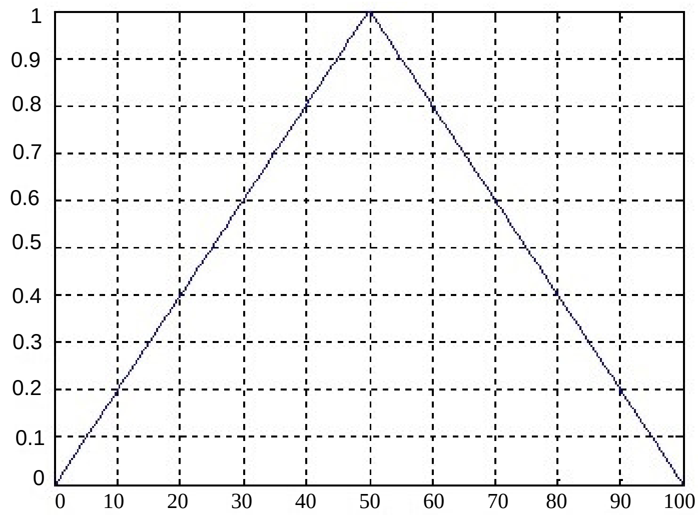

Fig. 1: Triangular Window

$$w(k)=\begin{cases}2k/(M-1), & 0\le k\le (M-1)/2\\ 2-2k/(M-1), & \dfrac{(M-1)}{2}\le k\le M-1\end{cases} \quad (1)$$

Where M is the number of samples of the filter, while the order of the filter L=M-1. Also K varies from 0 to M-1.

3.0 Design of Digital Notch Filter With Triangular Window

In this design the order of the filter is 100 and hence M=101. Substituting the value of M in (1) results in (2) below.

$$w(k)=\begin{cases}2k/100, & 0\le k\le 50\\ 2-2k/100, & 50\le k\le 100\end{cases} \quad (2)$$

The sampling frequency here is 1000Hz and the powerline frequency is 50Hz. Using the window of (2) in weighting the notch filter gives the impulse response, magnitude response and phase response of the filter as presented in figures 2, 3 and 4 respectively.

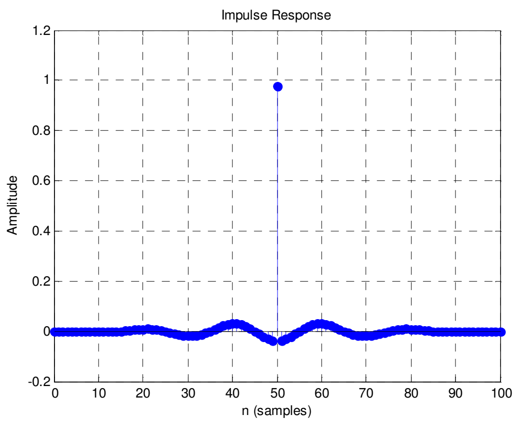

Fig. 2: Impulse response of the Notch Filter

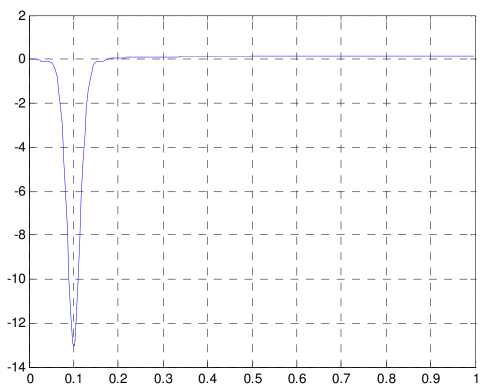

Fig. 3: Magnitude Response of the Notch Filter

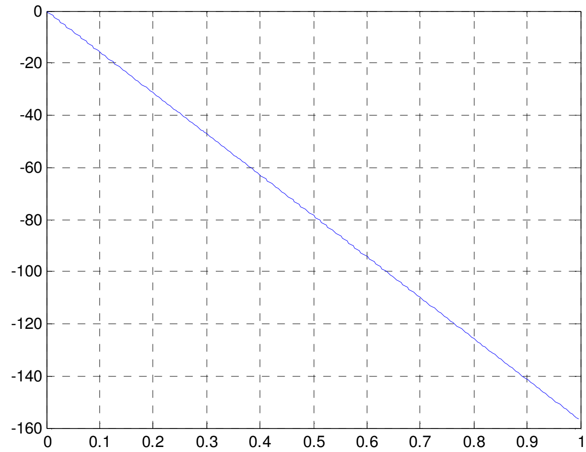

Fig. 4: Phase Response of the Notch Filter

3. Results

Fig. 5 below shows a normal noise-free ECG generated by Matlab. The signal is corrupt with 50Hz powerline and the corrupt signal is shown in fig 6. The periodogram of the corrupt ECG is recorded in fig 7. From fig 7, the average power of the corrupt ECG at 50Hz is **+4.2dB**. The corrupt signal is filtered using the implemented FIR notch filter and the filtered ECG signal is recorded in fig 8. The periodogram of the filtered ECG signal is recorded in fig 9. From fig 9 the average power of the filtered ECG signal at 50Hz is brought down to **-8.5dB** by the filter. From the recordings the average power of the filtered ECG signal at 50Hz is less than that of the corrupt signal at 50Hz. Therefore the notch filter has actually removed some quantity of the 50Hz powerline corrupting noise.

The corrupt ECG signal of fig. 6 is applied to an FIR adaptive notch filter as a way of comparing the performances of FIR notch filter designed with triangular window and adaptive notch filter in removing powerline interference in ECG signals. The adaptively filtered ECG signal is recorded in fig. 10 while the periodogram is shown in fig. 11. From fig. 11 the average power of the ECG signal filtered with adaptive notch filter at 50Hz is interestingly -34.2dB. Note that 50Hz here corresponds to 0.1rad in the normalized frequency scale.

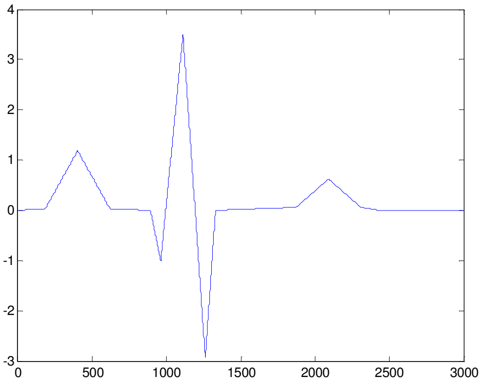

Fig 5: Normal ECG from Matlab

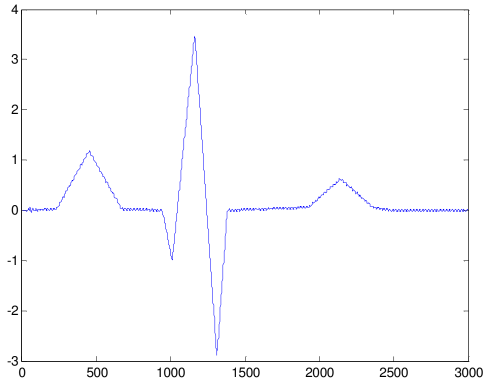

Fig. 8: Filtered ECG Signal

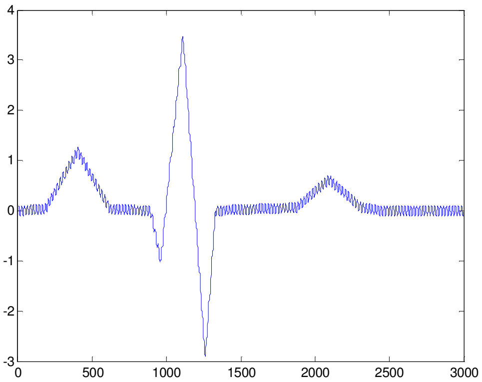

Fig. 6: Corrupt ECG Signal

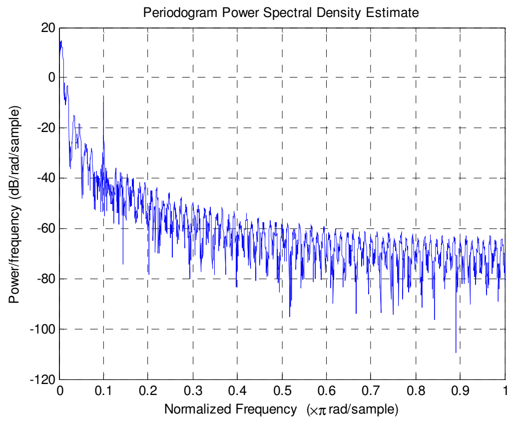

Fig. 9: Periodogram of Filtered ECG Signal

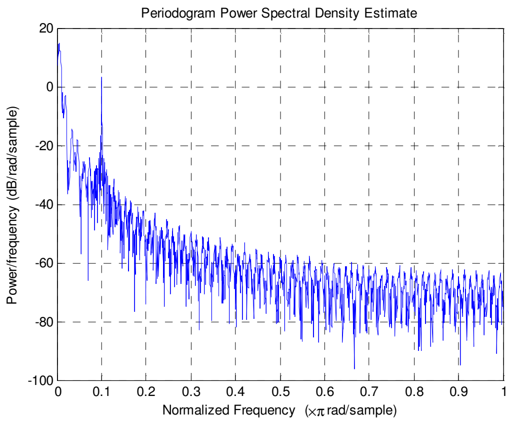

Fig. 7: Periodogram of Corrupt ECG Signal

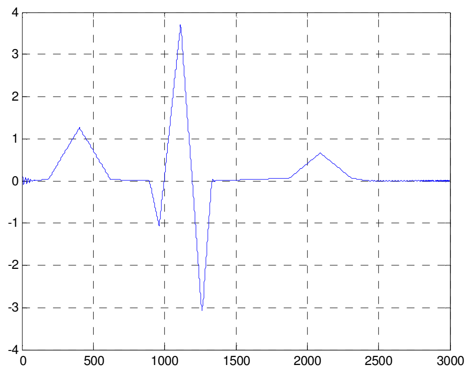

Fig 10: Adaptively Filtered ECG Signal

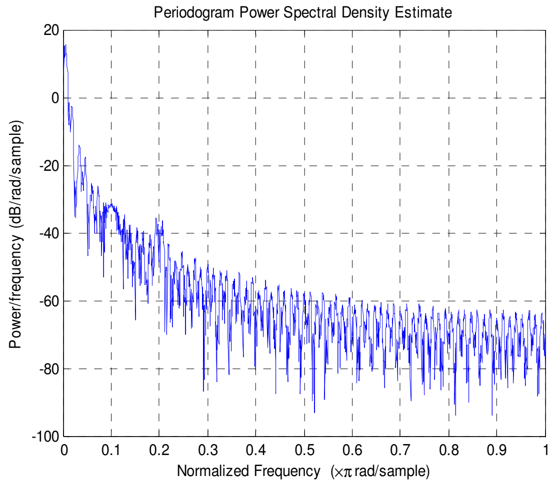

Fig. 11: Periodogram of Adaptively Filtered ECG Signal

4. Matlab Progam

The matlab program for designing the digital FIR notch filter and filtering the 50Hz powerline interference is presented here[11],[12].

fs=1000;f1=40;f2=60; % sampling, lower and upper cutoff frequencies in Hz respectively;

w1=2*f1/fs; % computes normalized digital lower cutoff frequency;

w2=2*f2/fs % computes normalized digital upper cutoff frequency;

L=100; % order of the filter;

Wn=[w1 w2]; % if the programmer desires to define the two cutoff frequencies by one symbol;

b = fir1(L,wn,'stop',triang(L+1)); % creates the object of the notch filter weighted with triangular;

% window;

[h,w] = freqz(b,1,256); % returns 256 samples of the frequency response vector h and the;

% corresponding frequency vector w, between 0 and **π**;

HdB = 20*log10(abs(h)); % computes the magnitude vector in dB;

Phaseangle = unwrap(angle(h)); % computes unwrap phase angle vector;

impz(b) % plots the impulse response of the filter;

plot(w/pi,HdB) % plots the magnitude response of the filter in dB;

plot(w/pi,phaseangle) % plots the phase response of the filter;

k=1:3000;

x1=0.1*sin(2*pi*50*(k-1)/fs); % sampled 0.1mV/ 50Hz powerline noise;

```
x=3.5*ecg(3000); % sampled 3.5mV ecg signal;
d=x1+x; % contaminated ecg signal;
si=zeroes(1,L); % initializes all filter taps to zero;
y=filter(b,1,d,si);   %  filters the ecg signal;
plot(k-1,x)  % plots the clean ecg sigal;
plot(k-1,d)   % plots the contaminated ecg signal;
periodogram(d)  % plots the frequency spectrum of the contaminated ecg signal;
plot(k-1,y)   % plots the filtered ecg signal;
periodagram(y)  % plots the frequency spectrum of the filtered ecg signal;
```

5. Conclusion

The filter is stable based on the impulse and magnitude responses because the oscillations decayed quickly. The phase response exhibits linear characteristics and this linearity is good for filtering ECG signal as there will be no distortion. 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 performances of the triangular window-based filter and that of adaptive filter, as can be deduced from figures 10 and 11, shows that the adaptive filter is far much better in ECG processing with a view to removing powerline interference and, good enough for correct clinical interpretations.

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