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REDUCTION OF POWERLINE NOISE IN ECG SIGNAL USING FIR DIGITAL FILTER IMPLEMENTED WITH HAMMING WINDOW

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Abstract: Electrocardiogram (ECG) signal plays a vital role in the monitoring and diagnosis of the health conditions of heart. The most significant noises that corrupt ECG signal are powerline interference, electromyogram, baseline wander and electroencephalogram. Designing digital filters to suppress these noises is very important in ECG signal processing. In this work a digital FIR filter for reducing 50Hz powerline noise in ECG signal is designed and implemented with Hamming window. FDA tool of matlab is used for generating the ECG signal and noise, and also observing the results. A comparison of the effectiveness of the filter designed with hamming window with that of an adaptive filter is also carried out.

Keywords: Hamming window, ECG, Notch filter, Frequency spectrum.

1. Introduction

Electrocardiographic (ECG) signal is very vital in the clinical monitoring and diagnosis of the health conditions of human heart. The most significant signals that corrupt ECG signal are powerline interference and biomedical signals such as electromyogram (EMG), baseline wander and electroencephalogram (EEG). For correct extraction of the features of the ECG signal, these significant signals that corrupt ECG signal have to be cancelled. Different types of digital filters can be used to achieve this cancellation of significant noises in ECG. In [1] Yatindra Kumar and Corav Kumar Malik did a comparison of the performances of FIR notch filter, Wiener filter and adaptive filter in reducing powerline interference in ECG. In [2] Kadam Geeta and Bhaskar P.C. used different FIR equiripple and least square filters, and FIR filters designed with Bartlett, Blackman, Hamming, Hanning, rectangular and Kaiser Windows to cancel these noises. Aung Soe Khaing and Zaw Min Naing [3] investigated the performance of FIR and IIR notch filters in reducing powerline noise in ECG. The authors applied mean square error (MSE) in assessing each filter's performance. Chavan Mahesh S *et al.* [4] presented the application of Butterworth and Elliptic IIR notch filters in suppressing powerline interference in ECG. In [5] Sachin Sing and Yadav K.L. did a performance evaluation of adaptive filters based of LMS and RLS adaptive algorithms, for ECG signal

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processing. Renumadhavi C. H. *et al.* in [6] investigated the performances of different IIR and FIR digital filters in removing 60Hz interference in ECG. Hon Wan *et al* in [7] applied variable step size LMS based adaptive filter in eliminating 50Hz powerline interference from ECG. The authors compared the convergence performance of the algorithm with those of normalized least mean square (NLMS) and S-function variable step least mean square (SVSLMS) algorithms. Mahesh S Chavan *et al.* in [8] studied comparatively the effectiveness of Chebyshev I and Chebyshev II in reducing noise in ECG signal. They compared the two filters with Butterworth and elliptic filters in terms of reducing noise in ECG. In [9] Manish Kansal *et al.* used Butterworth, Chebyshev I, Chebyshev II and elliptic IIR digital filters to individually remove powerline noise from ECG signal. In each filter the authors determined the performance when the hardware realization structure is direct form, cascade, parallel, continued fraction, ladder and wave digital. The authors also used FIR filters to remove powerline in ECG signal. Though some researchers have used Hamming window in removing powerline noise none showed the detailed waveform , this paper investigates the performance of Hamming window with detailed design and performance waveforms and responses using matlab generated data so as to confirm the suitability or otherwise of Hamming window in removing powerline noise. A typical ECG signal [10] generated by human heart is shown in fig. 1.

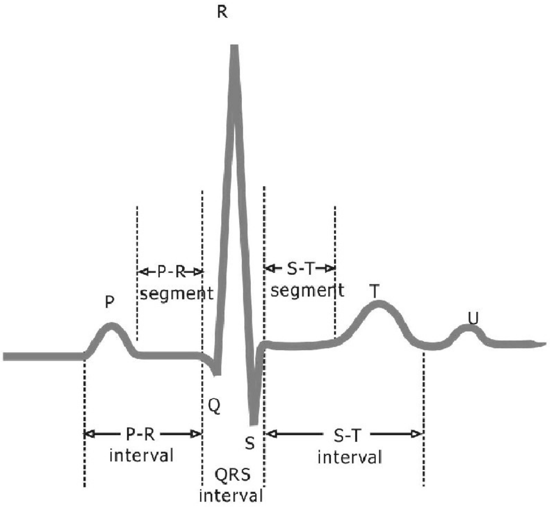

Fig. 1: Typical ECG Signal
Source: [10]

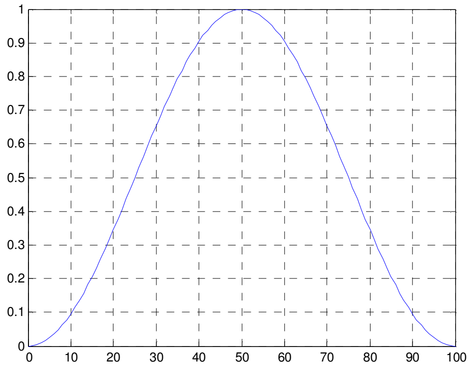

Fig. 2: Hamming Window Function

2.0. Design of Digital Notch Filter With Hamming Window

A Hamming window function is shown in Fig. 2. The mathematical expression is given [11] in equation (1)

$$w(k)=\frac{1}{2}\left[1-\cos\left(\frac{2\pi k}{(M-1)}\right)\right], 0\leq k\leq M-1 \tag{1}$$

where M is the number of taps of the FIR filter. In this design the order of the filter is L= 100 and the powerline noise to be filtered is 50Hz in frequency value. M = L + 1 = 101. Using the value of M in (1) gives (2)

$$w(k)=\frac{1}{2}\left[1-\cos\left(\frac{2\pi k}{100}\right)\right], 0\leq k\leq 100 \tag{2}$$

Applying (2) in the design of the notch filter will give the impulse, magnitude and phase responses of the filter as depicted in figure 3, 4 and 5 respectively.

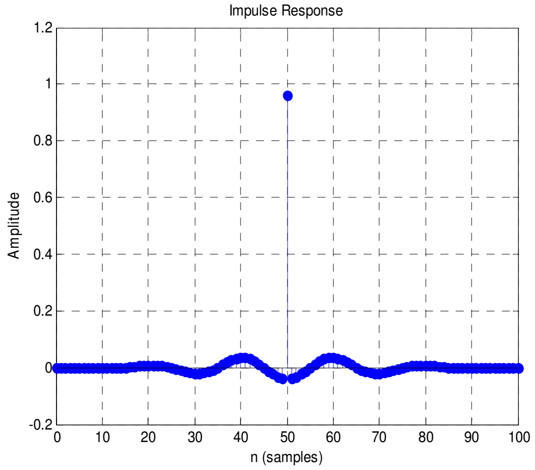

Fig. 3: Impulse Response of the Notch Filter

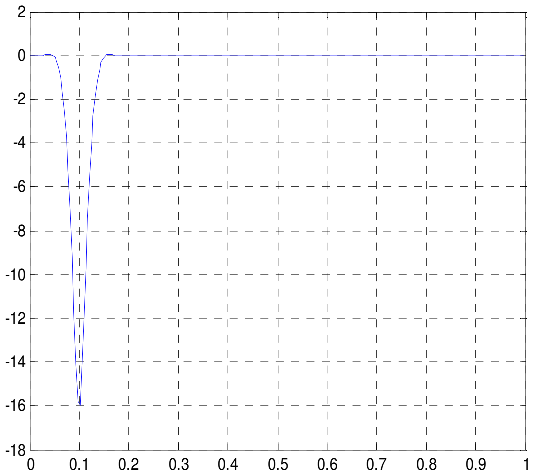

Fig.4: Magnitude Response of the Notch Filter

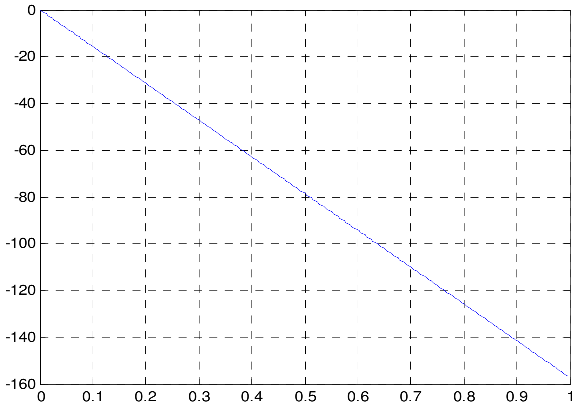

Fig. 5: Phase Response of the Notch Filter

3. Results

A clean ECG signal generated by matlab is shown in figure 6. The normal clean ECG signal of 3.5mV amlpitude is contaminated with 0.1mV/ 50Hz powerline noise and the corrupt signal is recorded in fig. 7. The frequency spectrum of the corrupt ECG signal is also recorded in fig. 8. From fig 8 the average power of the corrupt ECG signal at 50Hz is +4.2dB. The corrupt ECG signal is now filtered with the designed FIR notch filter and the filtered output is shown in fig. 9. The frequency spectrum of the filtered ECG signal is shown in fig 10. From fig 10, the average power of the filtered ECG at 50Hz is -14.3dB. It can be observed that the power of the filtered ECG signal at 50Hz is less than that of the corrupt ECG signal at 50Hz. This shows that there is a filtration of the corrupt 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 hamming window and adaptive notch filter in removing powerline interference in ECG signals. The adaptively filtered ECG signal is recorded in fig. 11 while the frequency spectrum is shown in fig. 12. From fig. 12 the average power of the ECG signal filtered with adaptive notch at 50Hz is further reduced to -34.2dB. Note that 50Hz here corresponds to 0.1rad in the normalized frequency scale.

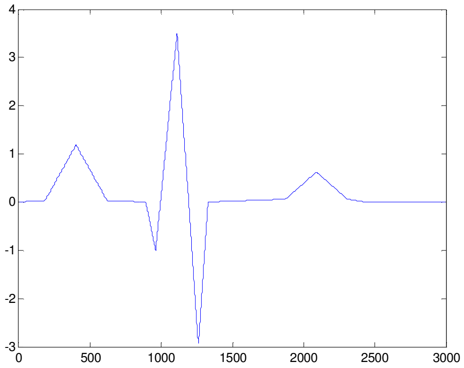

Fig. 6: Normal ECG Signal From Matlab

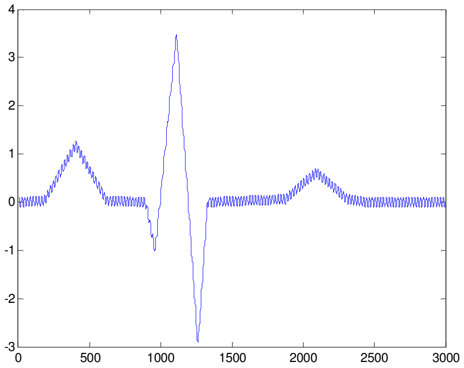

Fig. 7: ECG Signal Corrupt with 50Hz Poweline

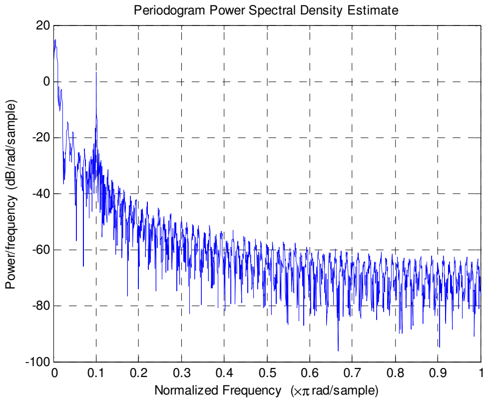

Fig. 8: Frequency Spectrum of ECG Corrupt with 50Hz Powerline Noise

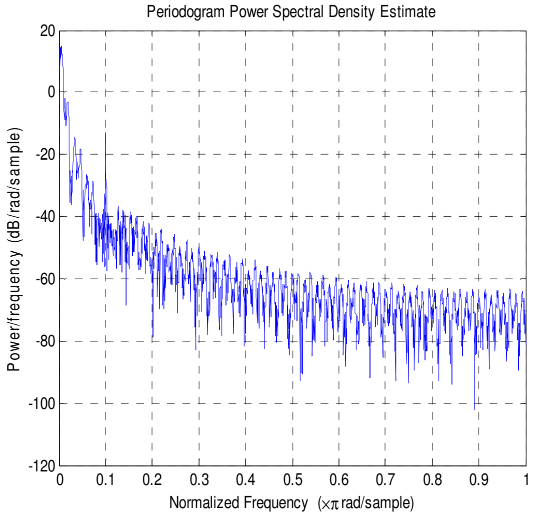

Fig.10: Periodogram of the filtered ECG Signal

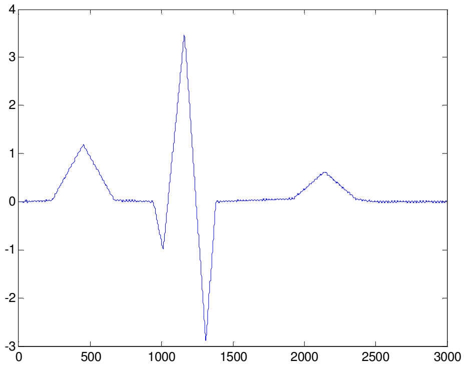

Fig. 9: Filtered ECG Signal

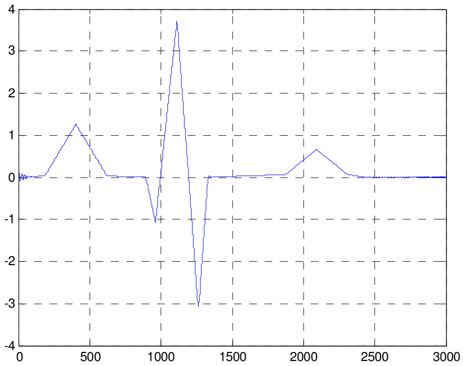

Fig. 11: Adaptively Filtered ECG Signal

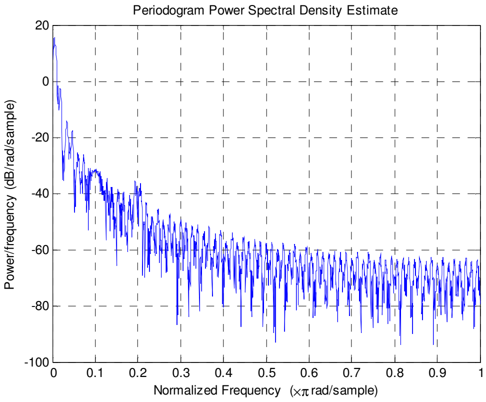

Fig. 12: Periodogram of Adaptively Filtered ECG Signal

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’,hamming(L+1)); % creates the object of the notch filter weighted with
          %  hamming 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 samples 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 impulse response shows that the filter is stable. The ripples in the magnitude response decay quickly and this is because the filter is stable, otherwise the oscillation is either sustained or decays slowly. The phase response is linear which implies that it will not distort the ECG signal. 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 hamming-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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