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Enhancing Ecg Signals Using Triangular Window Based Fir Digital Filtering Technique

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Abstract: - Electrocardiography generates signals referred to as Electrocardiographic signals or simply ECG which describes the electrical activities of the heart and is very vital in the clinical monitoring and diagnosis of the health conditions of the human heart. Naturally during acquisition, the ECG signals get distorted by different artifacts such as Baseline Wander, Muscle Contractions, Equipment Artifact, Powerline Interference etc., which must be removed otherwise incorrect information regarding the patient's heart condition will be conveyed. However, the most significant signal that corrupt the ECG is Powerline Interference. Hence, for correct extraction of the features of the ECG signal there is need to separate the wanted signal from noise caused by these signals that corrupt the ECG. Different types of digital filters can be used to achieve this. In this work, a Modified Triangular Window FIR filter was used for the removal of the 50Hz Powerline interference in the ECG. Using MATLAB The Signal Power before and after filtration using the modified window was determined and compared with that of triangular window and simulation results obtained.

Keywords: ECG Signals, Biomedical, Powerline interference, FIR filter, Triangular Window

I. INTRODUCTION

Electrocardiographic signals describe the electrical activity of the heart, and are universally employed in the diagnosis of cardiac pathologies.The ECG signal frequency ranges from 0.5Hz to 100Hz, and during acquisition, various artifacts contaminate the Electrocardiogram (ECG) recording, such as;

1. Power line interference
2. Electrode contact noise
3. Motion artifacts
4. Muscle contraction
5. Base line drift

When doctors use electrocardiography they can identify dangerous heart conditions, such as heartbeats that are not rhythmic, and treat the conditions appropriately [1]. However, if these conditions are not diagnosed early the individuals will mature into adulthood only to suffer sudden cardiac death as their first visible symptom [2]. For the meaningful and accurate detection, steps have to be taken to filter out or discard all these noise sources. Many tools, methods and algorithms from signal processing theory have been proposed, described and implemented [3]. Different window functions are used in Digital Signal Processing (DSP) for Finite Impulse Response (FIR) filter design.

In [4] Bhattacharya simulated the frequency responses of the four basic types of Finite Impulse Response (FIR) filters using a modified Taylor window function. Then he compared the

FIR filter responses with those using the Taylor window function, and improved frequency responses were observed in each case. Muralidhar et al in [5] used a new window which is a hybrid combination of hamming and Bartlett windows for the reduction of 60hz powerline interference. The authors applied a lower cutoff frequency of 59.5hz and a higher cutoff frequency of 60.5hz as the notch filter design specifications, and the method yielded better results than hamming and Bartlett individually. Ahmed in [6] demonstrated the magnitude and phase responses for different design techniques at particular cut off frequency and filter order. The design techniques presented were those of high pass FIR filters using Hanning, Bartlett and Kaiser Windows. It was shown that the degree of flatness varies with the length of the filter. Suman et al [7] optimised the adaptive noise canceller with Modified Memetic Algorithm (MMA) to remove power line interference in the ECG signals. The performance of these algorithms was analysed on the basis of parameters viz., improvement in signal to noise ratio, normalized correlation coefficient (NCC) and root mean square error (RMSE). The results showed that (MMA) outperforms both LMS and GA algorithms. In [8] Mbachu *et al* designed and implemented 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. They used matlab to generate the signals and observe results. The performance of the triangular window was compared with that of an adaptive noise canceller and results showed that the adaptive filter is far much better in ECG processing with respect to removing powerline interference and, good enough for correct clinical interpretations. Also Mbachu in [9] examined the effectiveness of six different types of window functions including the Height Adjustable Triangular (HAT) Window with the value of alpha as 0.02 in the design and development of digital FIR notch filters for reduction of powerline interference in ECG. From results, the Kaiser window was relatively most effective in reducing the 50Hz powerline interference.

II. THE WINDOW CONCEPT

The design of Digital Filters using window method involves obtaining the Desired Impulse Response or Unit Sample Response $h_d(n)$ from the Desired Frequency Response $H_d e^{jw}$ of the filter.

$$H_d(e^{jw}) = \sum_{n=\infty}^{\infty} h_d(n)\, e^{-jwn} \quad \ldots. \quad (1)$$

$$h_d(n) = \frac{1}{2\pi} \int_{-\pi}^{\pi} H_d(e^{jw}) e^{jwn} dw \quad \ldots \quad (2)$$

Naturally the Impulse Response of the filter $h_d(n)$ is of infinite duration which implies that the filter resulting from the Fourier series representation $H_d e^{jw}$ without application of any weighting factor on the series is unrealizable. To make the series finite and hence realizable (i.e having a Finite Impulse Response) the Fourier Series is truncated at point n = M for instance where M is a whole number representing the length of the unit sample response desired). This direct truncation of the series will actually make the filter finite but will lead to Gibbs Phenomenon which manifests itself as a fixed percentage overshoot and ripple before and after approximated discontinuities in the frequency response. A better approach is to use a finite weighting sequence called window, *w*(n), to modify the Fourier coefficients $H_d(n)$ in (1) i.e multiplying $h_d(n)$ by a window sequence $w(n)$. where $w(n)$ represents generalized window function. With Window application, the Unit Sample or Impulse Response of the FIR filter is then given as;

$$h(n) = h_d(n)\, w(n) \quad \ldots. (3)$$

$h(n)$ can also be called the designed FIR filter coefficients.

III. TRIANGULAR WINDOW BASED DIGITAL FILTERING TECHNIQUE

The design of FIR filter using windows follows a sequence as depicted by fig. 1

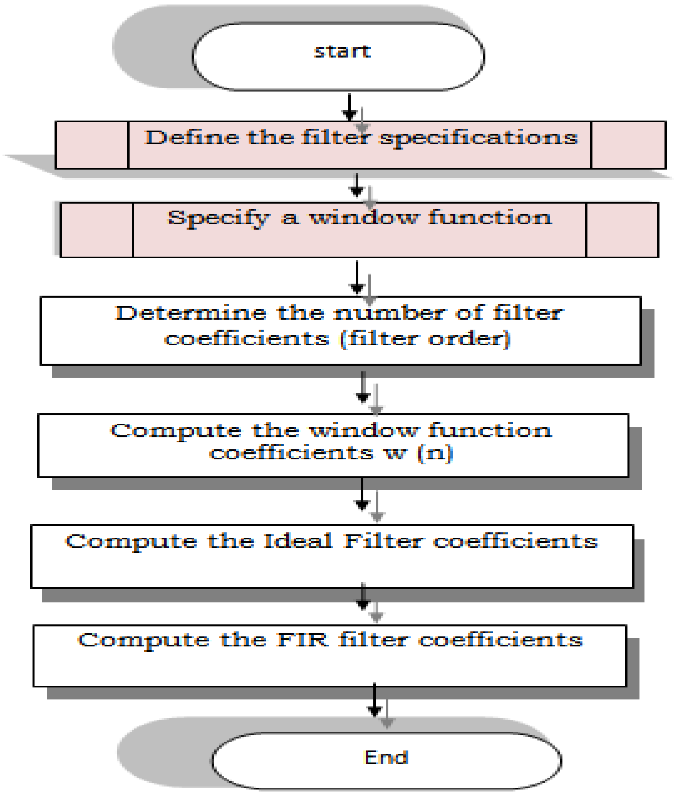

Fig. 1 Window Based FIR Filter Design Steps

In defining the filter specification the sampling frequency (f_s) is taken to be 1000Hz and the cut off frequencies (f_{c1} and f_{c2}) are 45Hz and 55Hz respectively, and the filter order is taken to be 100.
The Triangular window function for total number of samples, M = 100 plotted with Matlab is shown in fig. 2 and is described by the expression 2.4. The sample points (*n*) are indicated along *x-axis* and the corresponding amplitude levels along *y-axis* respectively.

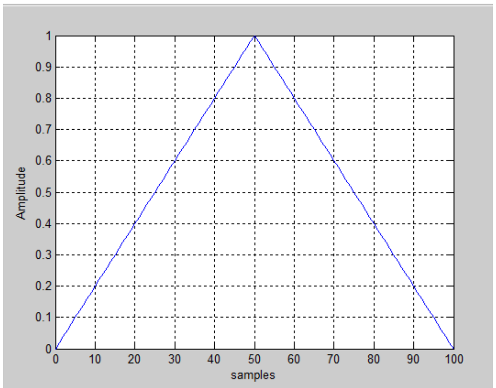

Fig. 2 The Triangular Window

$$w(n) = \begin{cases} \frac{2n}{(M-1)}, & 0 \le n \le \frac{M-1}{2} \\ 2 - \frac{2n}{(M-1)}, & \frac{M-1}{2} \le n \le M-1 \end{cases} \quad \dots (4)$$

The Triangular window based FIR digital filter is therefore a filter obtained from the modification of the Triangular window function and is given as:

$$w(n) = \begin{cases} \alpha + (2-2\alpha)n/(M-1), & 0 \le n \le \frac{M-1}{2} \\ 2 - [\alpha + (2-2\alpha)n/(M-1)], & \frac{M-1}{2} \le n \le M-1 \end{cases} \quad \dots\dots (5)$$

To modify the triangular window, the amplitude in fig. 2 ie *W(n)* is pulled up to alpha (α) at the rising and falling sides of the triangle, where alpha varies from 0 to 1. In this work, alpha is taken to be 0.06.
With the modified Triangular window function given in equation (5) and input signals defined as

x_1 = 0.1*sin (2*pi*50*(k-1)/fs) …. (6)

x = 3.5*ecg (3000) …… (7)

the impulse response of the FIR filter is improved and better results obtained.

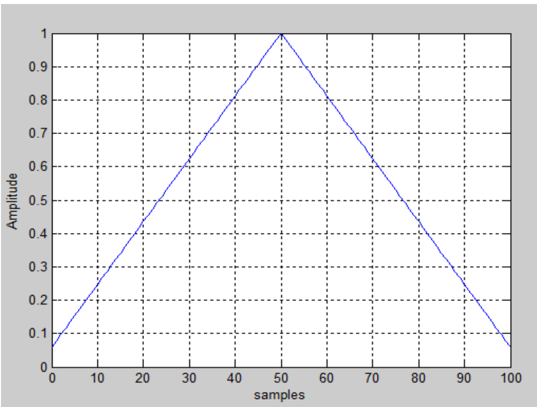

Fig. 3 The Modified Triangular Window

The Desired Unit Sample or Impulse Response for bandstop FIR filter also called the Desired Filter coefficients is given as;

$$h_d(n) = \begin{cases} \frac{\sin(wc1(n-M))}{\pi(n-M)} - \frac{\sin(wc2(n-M))}{\pi(n-M)}; & n \ne M \\ 1 - \frac{wc2 - wc1}{\pi} & n = M \end{cases} \quad \dots (8)$$

The steps for modeling of the modified system are described in the flowchart as shown in fig. 4.

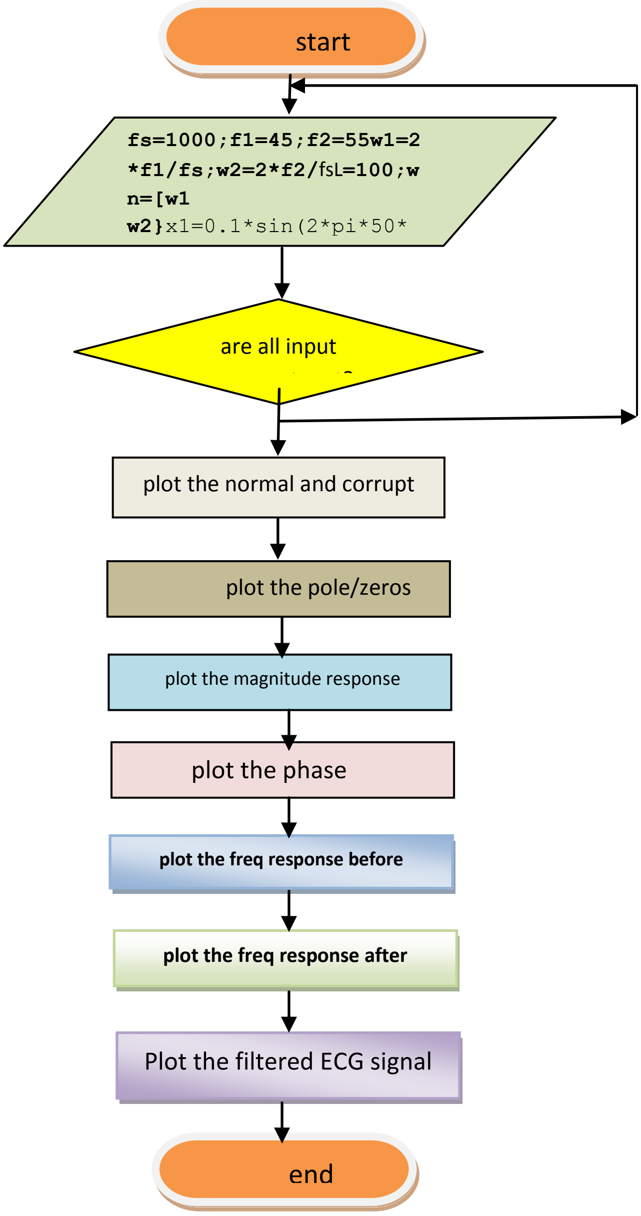

Fig. 4 Flowchart of the Procedures for Modeling the Modified System

IV. RESULTS

A corrupt ECG signal generated by Matlab is shown in fig. 5, obtained by superimposing a 50hz noise source equation (7) on a clean ECG signal equation (6). The corrupt signal is then passed through the modified window FIR filter, and other results obtained.

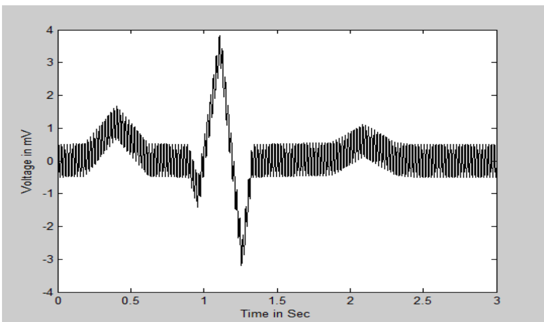

Fig. 5 Corrupt ECG Signal

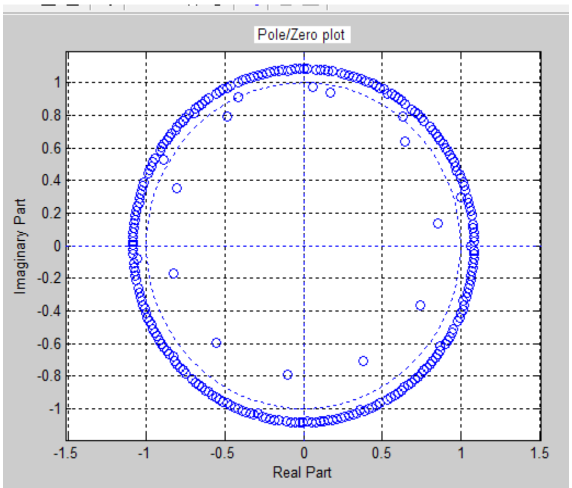

Fig. 6 Pole/Zero Plot of the FIR Filter

The poles and Zeros and are equivalent ways of describing the coefficients of a linear system and they have a direct influence on the dynamic properties of the system. The pole-zero plot depicted in fig. 6 shows that there is symmetry in pole-zero across the imaginary axis and that the system is stable.

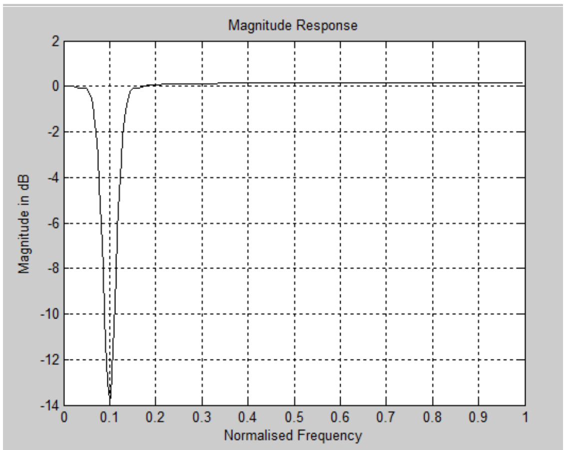

Fig. 7 Magnitude Response of the FIR Filter

The magnitude response depicted in fig. 7 shows closeness to the ideal situation.

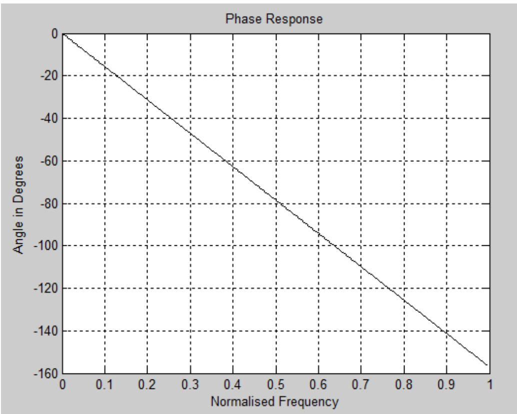

Fig. 8 Unwrapped Phase Response of the FIR Filter

Fig. 8 depicts the Unwrapped Phase Response of the FIR Filter. Unlike Bode plots that are mostly shown as wrapped phase responses, the unwrapped plot sees the angle as continuous values of same polarity so as to indicate when the phase is linear through a perfect straight line, or not linear by showing a distorted straight line in one or two or more segments of the line. The Lack of phase/delay distortion as with the case of linear filters, can be a critical advantage of FIR filters.

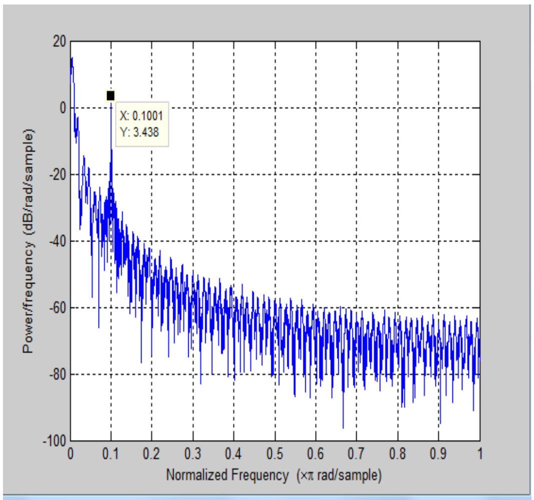

Fig. 9 Frequency Response (before filtration) of the FIR Filter

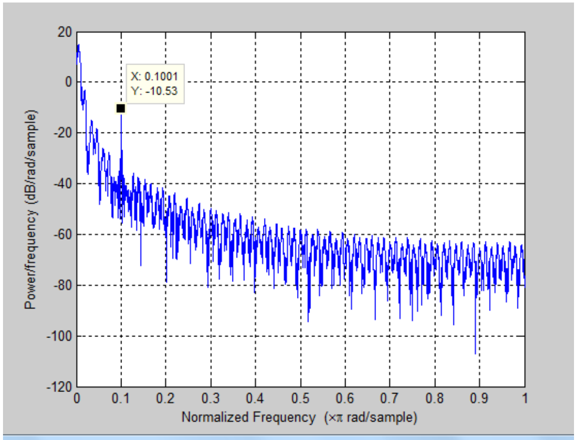

Fig. 10 Frequency Response (after filtration) of the FIR Filter

V. SUMMARY AND CONCLUSION

The removal or filtering of noise in ECG signal has remained a classical problem and more worrisome is the fact that Powerline interference is a constituent part of the ECG waveform. From results, the magnitude response of fig 7 indicates that the filter is very stable, and therefore the coefficients of the filter cannot upset the filter stability. A condition of steady state output is therefore guaranteed. The phase response of fig 8 shows that the filter is of linear phase which is desirable in processing complex signals like ECG signals. This ensures that multiple frequency signals do not suffer differential phase shifts, and as well the filter does not make the required intelligent signal tow a wrong position which leads to erroneous clinical diagnosis of the patient. From fig. 9, the power of the ECG signal corrupt with 50Hz powerline interference before filtration is (3.438dB) and from fig. 10, the power of the corrupt ECG signal at 50hz after filtration is (-10.53dB). This implies that the fitter removes the Powerline Interference in the noisy ECG signal. The conclusion from the results therefore is that Power Line Interference has been successfully and efficiently removed by the Modified Triangular Window Based FIR filter.

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