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Enhancing Electrocadiographic Signal Processing Using Sine-Windowed Filtering Technique

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Electrocardiographic (ECG) signal is a biomedical signal that is generated by the electrical activity of the heart, and it conveys lots of clinical information with respect to the health conditions of the heart of a patient. The result of desired ECG can be affected by biomedical and non-biomedical signals including 50Hz power line interference, technically referred to as artifacts. The correct interpretation of clinical information can be guaranteed when these artifacts are removed from the corrupt ECG. The technique for removing 50Hz power line interference artifact from human ECG was developed and implemented. The technique consists of sine window function for use in static filter coefficient. The corrupt signal was made to pass through Finite Impulse Response adaptive filter. Based on the developed window function, filter order of 100, sampling frequency of 1000Hz, pass band frequency of 40/60Hz and rejection frequency of 47.5/52.5Hz, processing of the electrocardiographic signal for the removal of 50Hz power line interference was extensively performed. The filter order, sampling frequency and pass band frequency were widely varied to determine their optimum values and they were ultimately determined to be 100, 900Hz and 40/60Hz respectively. From the modeled, analytical and simulated results, it has been proved that the noise in the corrupt signal power was lowered to -27.25dB at 50Hz which indicates a signal to noise ratio of -33.98dB. The inference is that the sine window technique provided an improved performance in electrocardiographic signal processing.

KEYWORDS*- Adaptive filter, Sine Window Function and Sine Window Filter*

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I. INTRODUCTION

Presently, there are numerous equipments that are used in monitoring and checking the health conditions of the human heart in other to discover any heart-related diseases. This heart related disease includes cardiac arrest or heart attack. An electrocardiogram is the study in medicine which deals with monitoring of small electrical changes on the skin of a patient body arising from the activities of the human heart. The signal generated during electrocardiogram is called electrocardiographic signal (ECG signal). There are some other signals that are generated by human body that are very useful in medical diagnosis. They include: the electrocardiographic (ECG) signal generated from electrical activities of the heart, the electromyography (EMG) signal generated from the electrical activity of the muscles, and the electroencephalographic (EEG) signal generated from electrical activity of the brain. The signal that is our major concern in this paper is the ECG signal. The ECG signal frequency lies between 0.5Hz and 100Hz (Mateo et al, 2007; Mahesh et al, 2008f). The EMG signal frequency can lie below or between 0.11 Hz and 20Hz depending on the body movement while the frequency of electroencephalographic (EEG) component that interfere with ECG signal during measurement is above ECG signal frequency, that is, above 100Hz (Raya and Sison, 2002).

An instrument for determining the health conditions of human hearts by measurement of the quality of ECG signal is called an electrograph. This signal gives vital information to doctors concerning a patient's cardiac conditions and general health. Digital filters are employed in processing of electrocardiographic signals for measurement. ECG signals, in their natural forms, present very small amplitude of about 1mV and frequency component below 100Hz. Due to these characteristics, recording ECG signal tends to be very sensitive to various interferences such as 50/60Hz power line, baseline wander, electromyogram and EEG. Baseline wander is a signal generated due to respiration and the frequency is below 1Hz (Ju-Won and Gun-Ki, 2005). Since the electromyography frequency depends on the movement rate and pressure, it can be reduced to the patient staying still and quiet so that the muscles are fully relaxed. With the static filter, the base line wander and EEG noises can effectively be filtered out with static coefficient filters because these lie outside the ECG frequency range.

However, Finite Impulse Response (FIR) static coefficient notch filters can be used to remove power line interference effectively during ECG measurement. FIR filters without window weighting tend to suffer from oscillations due to Gbbs Phenomenon (Sarkar, 2013). Several researchers have used rectangular window (Mahesh et al, 2008b, Mahesh et al, 2008e), Hamming window and Kaiser window (Van Alste and Schilder,1985; Chinchkhede et al, 2011). In this paper, our focus is on developing a sine window function which is a reliable technique in ECG signal acquisition and processing.

II. RELATED WORKS

Many works have been reviewed based design and implementation of digital filter using so many windows. Some of the works could not completely remove artifacts from desired signal due to ineffectiveness of the filter. The followings were specifically reviewed based on ECG signal processing.

Mahesh et al (2008b) designed and implemented digital filters using rectangular window, with a view to applying them for noise reduction in ECG. The authors designed and implemented low pass filter, high pass filter and notch filter. The filter order used is 50 and sampling frequency is 1000Hz. Application of the filters to a corrupt ECG signal indicated filtering effects from the filters on the ECG signal. However, the disadvantage of this type of filter is the presence of ripples in the pass band due to Gibb's phenomenon. Mahesh et al (2006) used Kaiser Window instead of rectangular window to design low pass, high pass and notch filters to be used in cascade for ECG processing. The Kaiser window corrects the problem of Gibb's phenomenon that is associated with rectangular window and therefore offers better removal of noise in ECG and less modification of QRS complex. The sampling frequency is 1000Hz and the order of each filter is 100. Arshan and Roberts (2001) presented "A CMOS digitally programmable current steering semi-digital FIR reconstruction filter". They targeted a low-power, area efficient, single bit finite impulse response (FIR) reconstruction filter for delta-sigma applications based on current steering approach. The filter coefficients are made programmable with discrete values from -8 to 8, thus allowing for various filter responses on the same chip. The filter is implemented in a 0.25μm standard CMOS process and incorporates 2.09mm^2 of active area and a 2.5V supply. Three different filter functions are implemented to consist of a voice band low pass filter, an audio band low pass filter and a band pass filter. The audio band example achieves a dynamic range of 78dB for a signal bandwidth of 20 kHz and 65 dB over a 100 kHz bandwidth. Pranab et al (2008a) used what they described as window method to design and implement digital filters for audio signal processing. The window method is actually a Fourier series method that applies window to reduce Gibbs Phenomenon. The phenomenon is an error arising from truncation of the infinite Fourier series of the desired filter response to make it finite. In other words they designed and implemented finite impulse response digital filters. Rectangular window was used to design three different types of digital filters (low pass, high pass and band pass) while Matlab programming was used to implement them. In the low pass, the cut-off frequency is 3.4 KHz while the cut-off frequency for the high pass is 600Hz. In the band pass the pass band frequencies are 600Hz and 3.4 KHz. Pranab et al (2008b) implemented an finite impulse response filter using DSP blocks. They considered three digital filters (low pass, high pass and band pass) in which the high and low frequency components of real-time voice signals were removed. The filters were designed using Kaiser Window in one instance and triangular window in another instance. The performance evaluation of the filters resulting from the two designs was carried out in terms of the filtered outputs and the frequency response curves. Experimental results indicate that a maximum number of ripples appear in stop band for Kaiser Window, while minimum number of ripples appear in triangular window for different filters. Therefore, real-time FIR digital filters using triangular window gives optimal result to process the audio signals. It should be noted that both Kaiser Window and triangular window are parts of the process in the Fourier series method of design of digital filters. Mahesh et al (2005) investigated the application of elliptic filters for artifacts removal in ECG signal. In the work, instrumentation is built with the help of operational amplifier as instrumentation amplifier. The instrumentation amplifier provides amplified version of the ECG signal. For protection purpose the isolation amplifier has been used. The instrumentation amplifier and isolation amplifier form the analogue domain. The LPF, HPF and NOTCH filter are elliptic filters, which are designed digitally so they form the digital domain. The analogue part provides the unfiltered ECG signal. These elliptic filters exhibit equiripple behaviour in both the pass band and the stop band. Elliptic filters are optimal filters in that they achieve the minimum order N for given specification (or alternatively, achieve the sharpest transition band for the given order N).

III. ADAPTIVE FILTER

Adaptive filters are filters that can adjust their filter coefficients in line with the characteristics of the input signal. It can be used among other applications to process ECG signal, especially where the input noise has unstable frequency. Daniel et al (2005) proposed an adaptive notch filter to eliminate the interference introduced by power transmission lines in the recording of ECG signals within the gamma band (35 – 100Hz), based on an adaptive noise canceling scheme implementation with a variable step-size LMS algorithm. The proposed algorithm avoids the cumbersome trails and error process needed to choose an adequate value for the step-size parameter and will minimize the rejection bandwidth required to effectively eliminate the time varying interference while, at the same time, preserving optimal convergence, tracking and mis-adjustment conditions. Figure 1 shows the control diagram for the scheme.

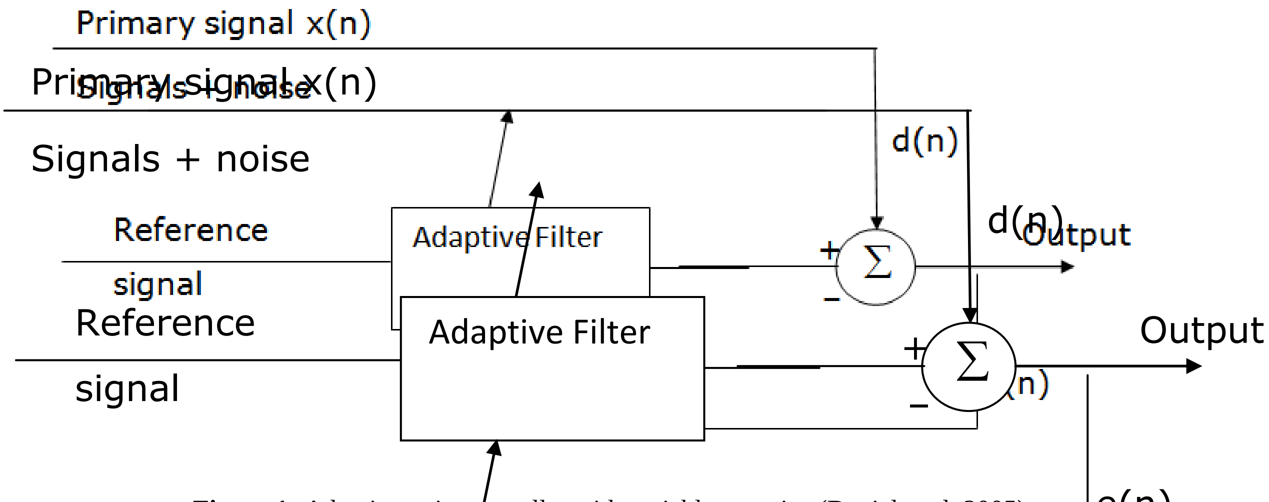

Figure 1: Adaptive noise canceller with variable step size (Daniel et al, 2005)

Recall that the equation that describes the adaptation of coefficients in an ANC based on the LMS algorithm with fixed step-size is given by

$$w(n+1) = w(n) + \mu e(n) r(n) \qquad (1)$$

where w(n) is the filter coefficients, e(n) is the error or output of the system, r(n) is the reference input, while μ is the step-size of the system. If it is desired to vary μ as a way of adapting w(n), the update algorithm for μ is given by

$$\mu(n+1) = \alpha\mu(n) + re^2(n) \qquad (2)$$

where α is a forgetting factor with values between $0 < \alpha < 1$ and $\gamma > 0$ is the step-size parameter for the update of μ. Substituting the variable step-size μ(n) in (1), the filter coefficient update equation becomes

$$w(n+1) = w(n) + \mu(n) e(n) r(n) \qquad (3)$$

The initial step size μ(0) is usually set to μ_{max} and this maximum value is chosen to ensure stability of the algorithm.

IV. METHODOLOGY

Several techniques can be adopted in filter design and implementation. The method to choose depends on the nature of response that is expected of the filter. Infinite impulse response (IIR) digital filter is chosen when impulse response of a filter is needed while Finite impulse response (FIR) is chosen when the frequency response of a filter is of utmost important. However, FIR adaptive filter was used in this work because of its self-adjusting ability. The filter varies its coefficients in line with the characteristics of the signal being filtered. Its transfer function takes the same form as of ordinary static filter. But its coefficients change during adaptation process until convergence is achieved. Its linearity property makes it more stable during filter design.

V. PROPOSED FILTERING SYSTEM

The block diagram of the proposed system is presented in figure 2. It consists of a static FIR digital lowpass and high pass filters that remove noise signals outside the ECG signal frequencies (Pranab et al, 2008a; Kumar, 2008; Mahrokh & Mottaghi-Kashtiban, 2009). That is, the encephalographic noise signal which lies above 100Hz and the baseline wander noise signal which lies below 0.5Hz. It also consists of a notch filter that removes the 50Hz powerline noise.

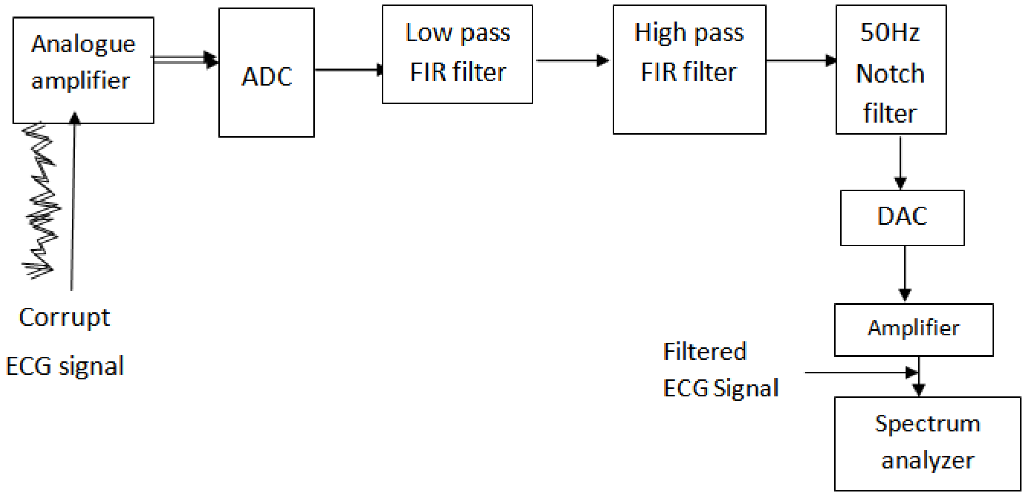

Figure 2: Block Diagram of the Proposed Filter

VI. DESIGN AND IMPLEMENTATION OF THE PROPOSED FIR SINE-WINDOWED NOTCH FILTER

Ten steps are involved in this design and implementation as follows; mathematical modeling of the sine window function, calculation of the order of the filter based on selected sampling frequency and attenuation values, obtaining responses of the filter based on the calculated order and cut-off frequencies, determining the optimum order of the filter, determining the optimum sampling Frequency of the Filter, determining the optimum passband frequencies, structural realization of the filter, generation of results, calculation of signal to noise ratio of the filter, and finally comparative analysis of the proposed window and other windows in use for the processing of ECG signal. But in this paper, mathematical modeling of the sine window function will be discussed in details.

3.3.1 Mathematical Modeling of a Sine Window function

A typical unit sine window function is represented in figure 3.

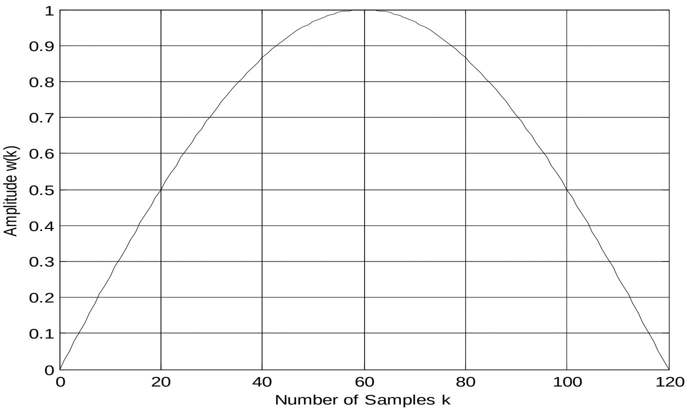

Figure 3: Sine Window Function

Let the width of the function from zero to the end along the horizontal axis be L. Usually L is the order of the filter. Let the angle covered by the function as it moves from zero to the end, that is to L along the horizontal axis be ɵ. At L the function covers 180^0. Therefore,

ɵ x L=180

ɵ=180/L. The general sine window function is therefore given as w(k)=sin ɵ

w(k)=sin(180k/L), 0≤k≤L (4)

where L is the order of the filter. Since the number of samples M begins from 0 to L, then the number of samples M is given as

M=L+1 (5)

In filters the number of samples M corresponds to the number of filter taps for use.

VII. RESULT AND ANALYSIS

Filtration with the Proposed Sine window Filter

A clean ECG signal is generated using matlab function and it is shown in figure 4. A 50Hz powerline noise is also generated and it is depicted as figure 5. The clean ECG signal is corrupt with the powerline noise signal and the corrupt signal is presented as figure 6. The corrupt ECG signal is applied to the proposed filter and the output is presented in figure 7. The periodogram of the corrupt ECG signal is shown in figure 8 while the periodogram of the filtered ECG signal is shown in figure 9.

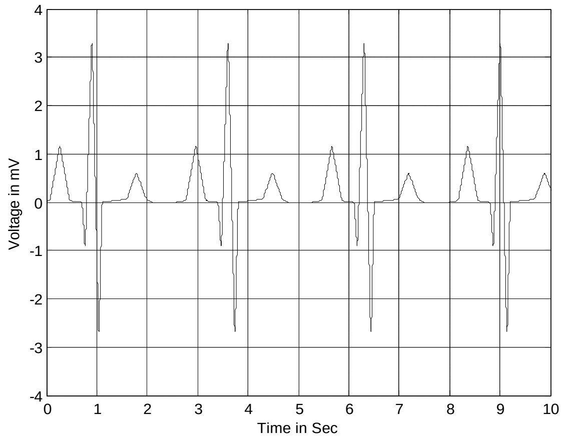

Figure 4: Clean Noise Free ECG Signal

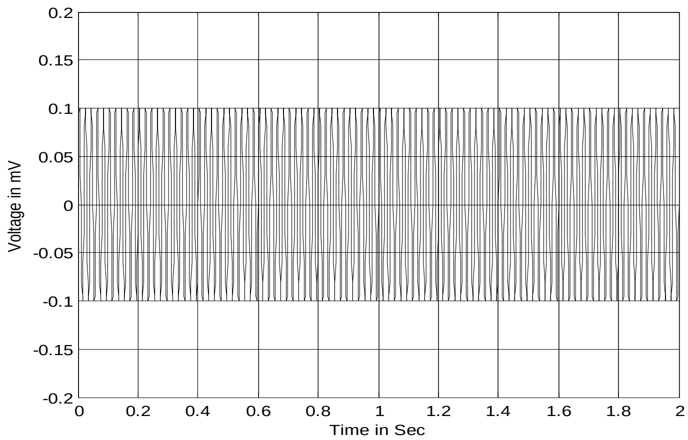

Figure 5: 50Hz Power line Noise

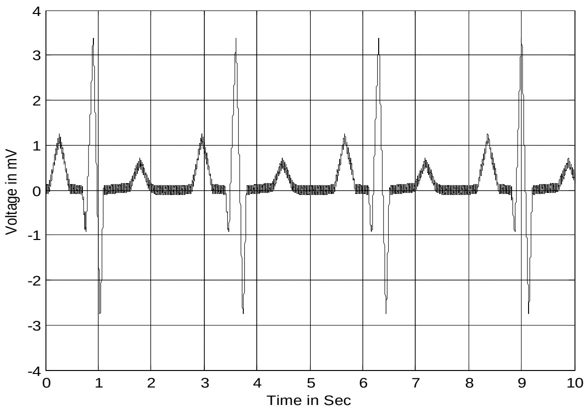

Figure 6: ECG Signal Corrupt with 50Hz Powerline Noise

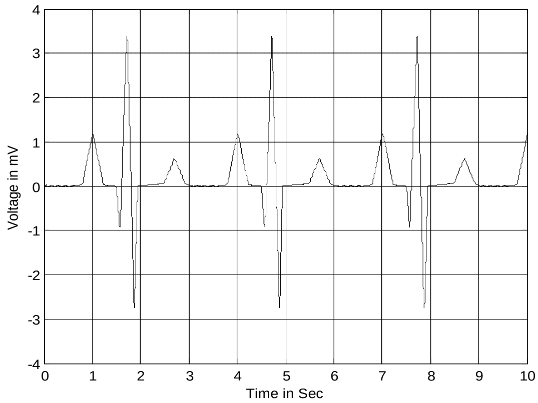

Figure 7: Filtered ECG Signal

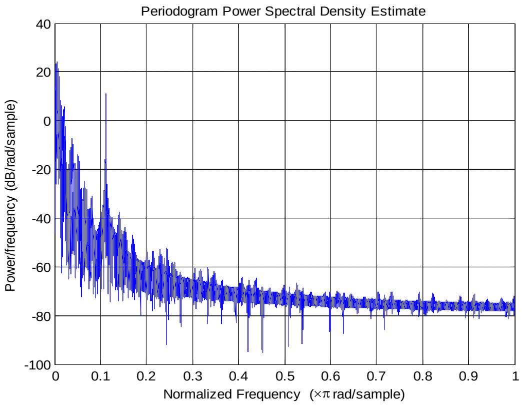

Figure 8 : Power Spectral Density of the Corrupt ECG Signal

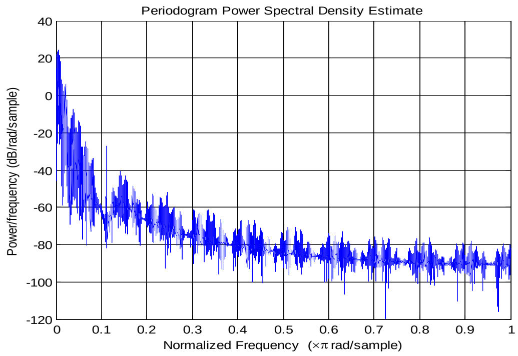

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Figure 9: Power Spectral Density of the Filtered ECG Signal

Comparing figure 6 and figure 7, that is the corrupt and filtered ECG signals respectively it can be seen clearly that the filter substantially removed the powerline noise in the corrupt ECG signal. From figure 8, the noise level in the corrupt ECG at 50Hz is 11.26 dB whereas from figure 9 the noise level was brought down to -27.25dB which shows that the proposed filter significantly removed the 50Hz powerline noise in the corrupt ECG signal.

VIII. CONCLUSION

The sine window FIR filter was designed and implemented in removing 50Hz powerline noise artifact from ECG signal. The linearity property of the filter was exploited because it helped to process complex signals such as ECG signal. From the information gathered about magnitude response, it shows that the filter was stable as there was no oscillation and it was able to remove 50HZ powerline fro ECG signal. Based on the developed window function, filter order of 100, sampling frequency of 1000Hz, passband frequency of 40/60Hz and rejection frequency of 47.5/52.5Hz, the processing of the ECG signal for the removal 50Hz powerline interference was performed. The result shows that the noise in the courrupt signal was lowered to -27.25dB at 50Hz which indicates a signal to noise ration of -33.40dB.

IX. RECOMMENDATION FOR FURTHER STUDIES

The proposed filter should be applied in filtering and processing other signals such as electroencephalographic signal, baseline wander, electromyographic, electrooculargraphic and even audio signals.

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