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Improving ECG Signal using Nuttall Window-Based FIR Filter

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ABSTRACT: The heartis an important organ of the body whichis capable of producing an electrical signal known as Electrocardiogram (ECG). This signal isvery vital in diagnoses of heartdiseases as itcanbeusedto ascertain the medical condition of the heart at any time. Unfortunately, other signals may be picked up during the process of recording the ECG with an electrocardiograph. Such signals may hinder the possibility of obtaining accurate ECG reading for a patient which may lead to wrong diagnosis. These unwanted signals also referred to as noise or artifact may include powerline noise, baseline wander and electromyogram (EMG). This paper demonstrates how a 0.1mV 50Hz powerline noise can be removed from a contaminated single cycle ECG signal using a Nuttall window-based Finite Impulse Response (FIR) filter. MATLAB simulation software was used both for generation of the single cycle ECG signal and implementation of the FIR filter model. The results obtained show that the FIR filter designed with Nuttall window successfully removed the powerline noise.

Keywords -ECG Signal, FIR filter, Noise reduction, Nuttall window, 50Hz powerline,

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I. INTRODUCTION

Electrocardiogram (ECG) is a very important biomedical signal that is originated from the electrical activity of the heart. ECG represents the physiological state of the heart. This electrical signal from the heart is recorded with an electronic machine called the Electrocardiograph. Great concerns arise about the rising cases of heart related diseases and deaths across the world including the most active folks (sports persons). A good ECG recorded from a patient presents vital information to the physician to analyze and determine the state of health of the heart of the subject and more importantly helps the physician to prescribe ways to manage the heart of the patient. This way of medical treatment may be ineffectual if the parameters of the ECG signal are compromised. When a biomedical signal is misrepresented, the patient stands the risk of getting a wrong treatment. The major problem with obtaining any electrical signal from humans is the problem of noise interference. This means that these human-originated electrical signals are recorded alongside with other signals which tend to corrupt the integrity of the desired signal. The common artifacts that affect ECG are powerline interference, baseline wander and electromyogram (EMG) [1]. Powerline interference is either 50Hz or 60Hz depending on the frequency of the local power supply authority. Baseline wander is signal generated due to respiratory activities and has frequency below 1.0Hz. EMG is generated by the movement of the body muscles. Most of these biomedical signals have their maximum frequencies around 100Hz [2]. Frequency range of ECG is within the bandwidth of 0.05 and 100Hz [3] while the amplitude of the signal is about 2mV. This work seeks to remove 50Hz powerline artifact from ECG using Nuttall window based FIR filter.

Some works have been done already on noise reduction from biological signals using various window-based FIR filters, adaptive filters and wavelet techniques. Mbachu and Offorin their paper [3] proposed the use of triangular window-based FIR filter for ECG signal enhancement. The authors tried to determine the effectiveness of triangular window-based FIR filter in filtering 50Hz powerline interference from ECG. The authors also compared their result with that obtained from an adaptive filter. They concluded that though the triangular window-based FIR filter was able to reduce the noise, the adaptive filter gave better performance. In [1] Kumar et al. compared the performance of FIR filters using five windows in removing baseline wander, powerline interference and EMG artifacts from ECG. The authors used the Rectangular, Hann, Blackman, Hamming and Kaiser Windows to model the FIR filter at filter orders of 300, 450 and 600. Finally, the authors concluded that the FIR filter modeled with Kaiser Window produced the best filtration result among other windows. Mbachu et al. in [4] proposed the use of rectangular window-based FIR filter in ECG noise attenuation. Furthermore, the authors modeled a cascade of low pass, high pass and stop band FIR filters using rectangular window to remove high frequency signals, baseline wander and powerline interference from ECG. They finally highlighted that the design has a distortion problem which they attributed to rectangular windows and suggested that such windows like the Kaiser, Hann and Hamming windows could overcome the distortion problem.

Hassan et alin [5] concurred with [1] after a comparison investigation on EEG artifacts attenuation using the same five windows namely Rectangular, Hann, Blackman, Hamming and Kaiser Windows. They affirmed that Kaiser (β12) yielded the best signal-to-noise ratio (SNR), main lobe and side lobe results. In their research, Dhankhar and Khalericombined both FIR adaptive filter and normalized least mean squares (NLMS) adaptive algorithm to perform eye blink artifact (EBA) removal from EEG[6]. This study tends to design and implement Finite Impulse Response (FIR) filter which is based on a Nuttall window to filter out 50Hz powerline noise from ECG signal. The design is implemented with a band stop filter procedure.

II. NUTTALL WINDOW

The function of window in FIR filter modeling is to truncate the length of a desired impulse response of the filter function. By so doing, a finite impulse response for the filter is obtained. In other words, windowing process in FIR filter is used to obtain a finite-duration impulse response in FIR filter modeling. In this paper, Nuttall window is the truncating window. Equation (1) is the impulse response of the filter which can be represented as a product of desired impulse response and a definite-duration as represented in Equation (2). Equation (3) represents the Nuttall window function.

$$h[n] = \begin{cases} hd[n], & 0 \le n \le M \\ 0, & otherwise. \end{cases} \quad (1)$$

$$h[n] = hd[n]\, w[n] \quad (2)$$

$$w(n) = \alpha_0 - \alpha_1 \cos\left(\frac{2\pi n}{N-1}\right) + \alpha_2 \cos\left(\frac{4\pi n}{N-1}\right) - \alpha_3 \cos\left(\frac{6\pi n}{N-1}\right) \quad (3)$$

Where h[n] is impulse response, hd[n] is desired impulse response, M is the filter order and w[n] represents the truncating window function.In the Nuttall window function w(n), which is expressed in equation (3), $\alpha_0 = 0.355768$; $\alpha_1 = 0.487396$; $\alpha_2 = 0.144232$; $\alpha_3 = 0.012604$ and N = window length.

Fig 1 and Fig 2 depict MATLAB wintool-generated time domain and frequency domain respectively of a Nuttall window of a length of 401. Fig 3 and Fig 4 represent the impulse response and phase response of Nuttall window respectively. Fig 4 clearly shows the linearity of the Nuttall window which is a vital characteristic of a good window in FIR filter design. Hence, this also suggests stability for the filter.

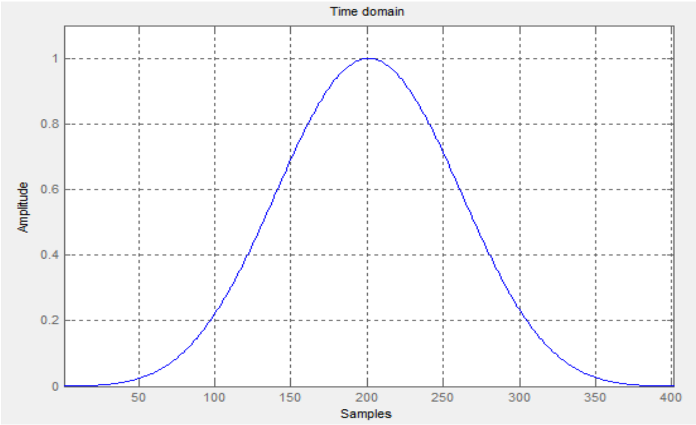

Fig 1.401-Length Time domain of Nuttall window

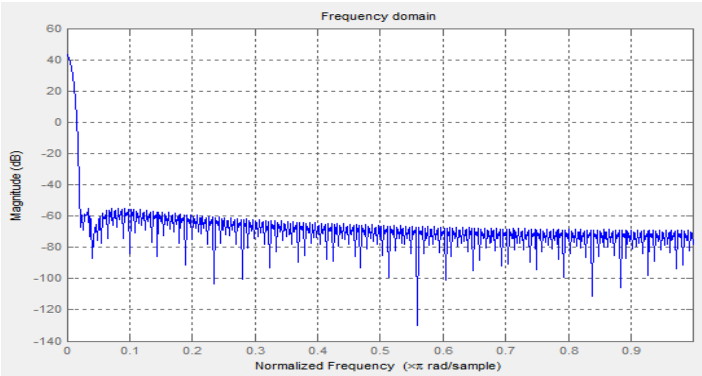

Fig 2. Frequency domain of Nuttall window

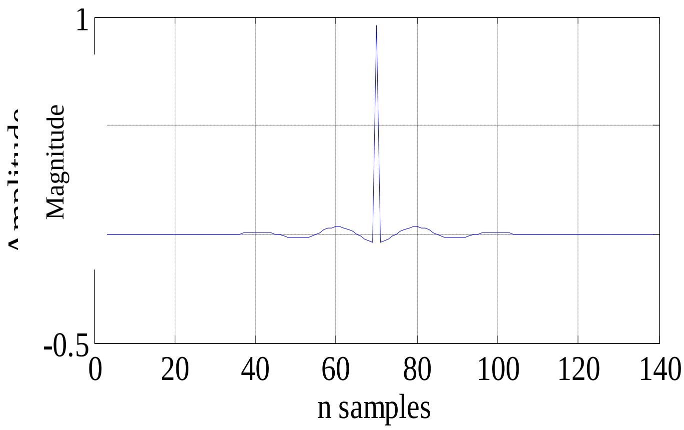

Fig 3. Impulse response of Nuttall window

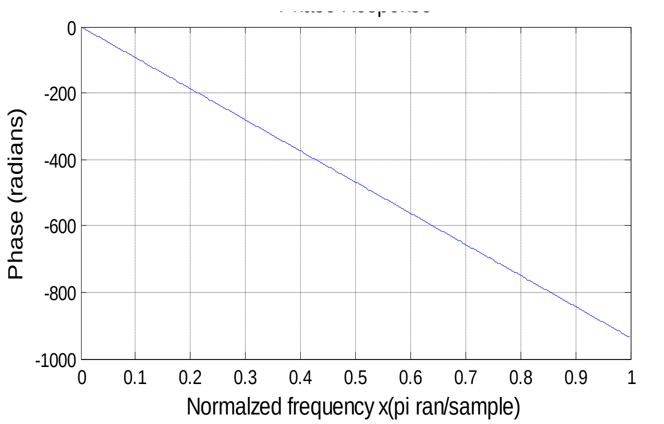

Fig 4. Phase response of Nuttall window

III. FILTER DESIGN

The design of a band stop FIR filter for reduction of 50Hz powerline noise from a 1-cycle ECG signal is shown. FIR Nuttall window-based filter is modeled and simulated with MATLAB application. The following filter parameters were used; sampling frequency f_s = 1000Hz, lower cut-off frequency f_1 = 45Hz and upper cut-off frequency f_2 = 55Hz, filter order 401. Fig 5 depicts the magnitude of FIR filter designed with Nuttall window.

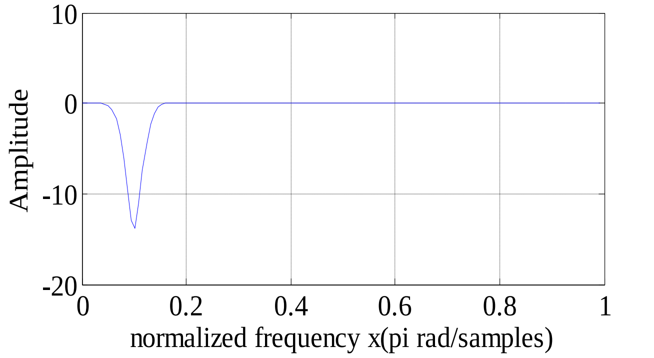

Fig 5 Magnitude response of FIR Nuttall window-based filter

IV. ANALYSES AND RESULT

50Hz sine wave of 0.1mV is generated in MATLAB environment to serve as 50Hz powerline artifact (Fig 6). This is used to corrupt a one-cycle ECG signal also generated in MATLAB environment (Fig 7) to obtain a contaminated ECG as shown in Fig 8. The FIR Nuttall window-based filter is shown to have successfully reduced the powerline interference earlier introduced into the ECG signal. The filtered ECG is shown in Fig 9.

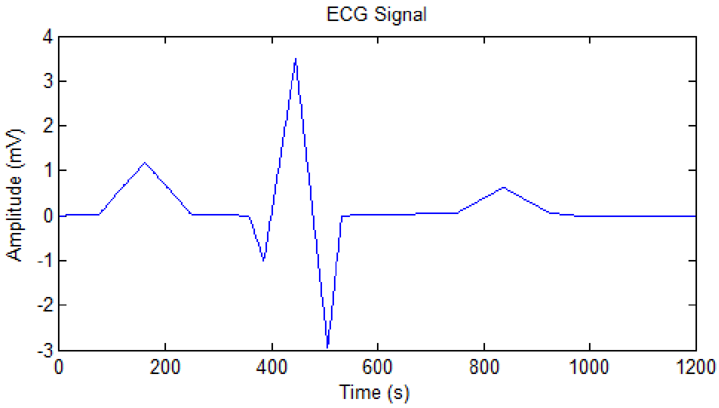

Fig 6.MATLAB generated 1-cycle ECG signal

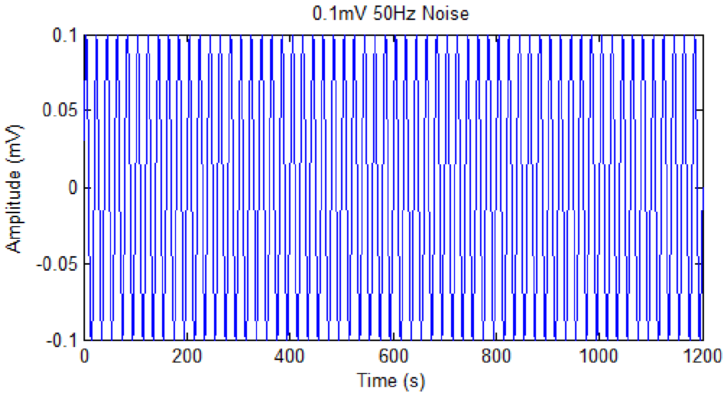

Fig 7.0.1mV 50Hz Powerline Noise

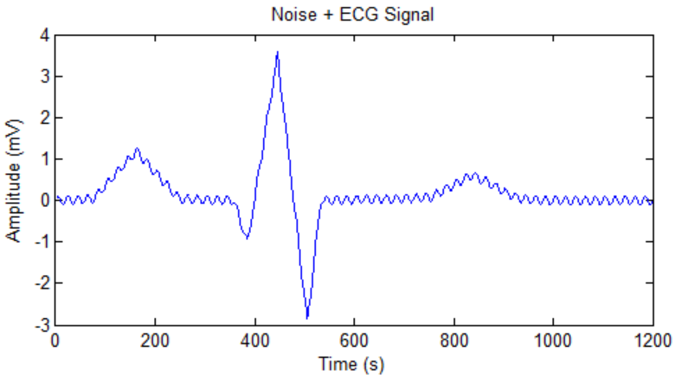

Fig 8. Corrupted ECG signal

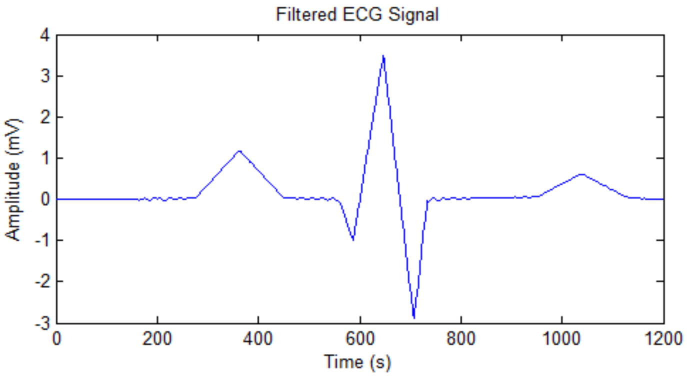

Fig 9. Filtered ECG signal

The evidence of noise reduction ability of FIR filter designed with Nuttall window can further be demonstrated with frequency spectrum diagrams as shown in Figs 10 to 13. Frequency response of ECG Signal is represented in Fig 10. It can be seen in Fig 10 that at about 0.1 normalized frequencyvalue, the power spectral density of ECG is 8.94dB. 50Hz powerline interference of 0.1mV with a power spectral density of 35.56dB is added to the ECG. This results to the power spectral density shown in Fig 12. This is the power density of the contaminated ECG. It can be seen in Fig 12 that power spectral density at normalized frequency value of 0.1 has become 35.21dB. After the filtration process with the Nuttall window-based FIR filter, the power density is reduced to 8.70dB. This is shown in Fig 13. Fig 11 represents Frequency response of 50Hz powerline signal.

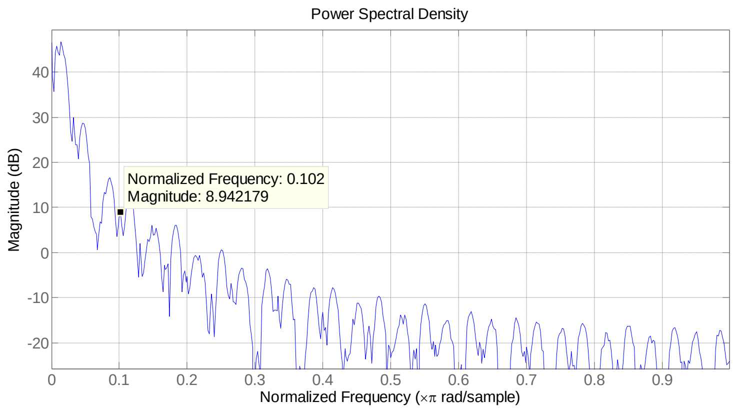

Fig 10. Frequency response of ECG Signal

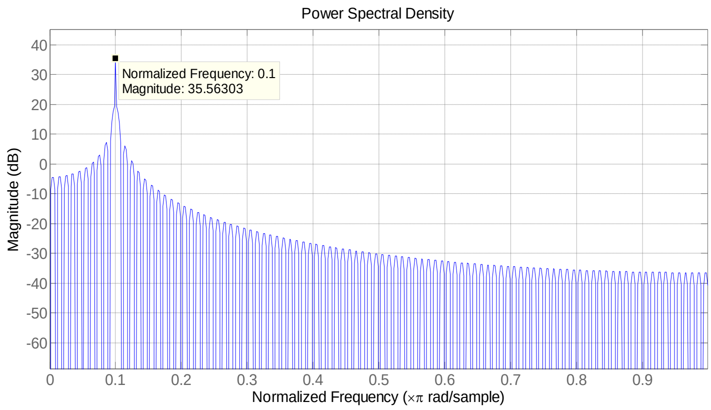

Fig 11. Frequency response of 0.1mV 50Hz Noise

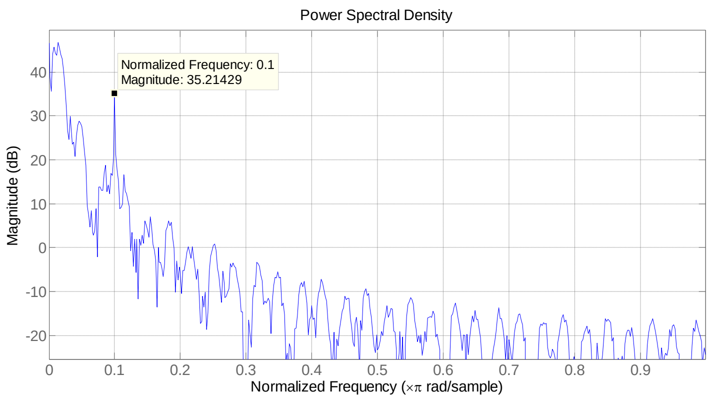

Fig 12. Frequency response of contaminated ECG

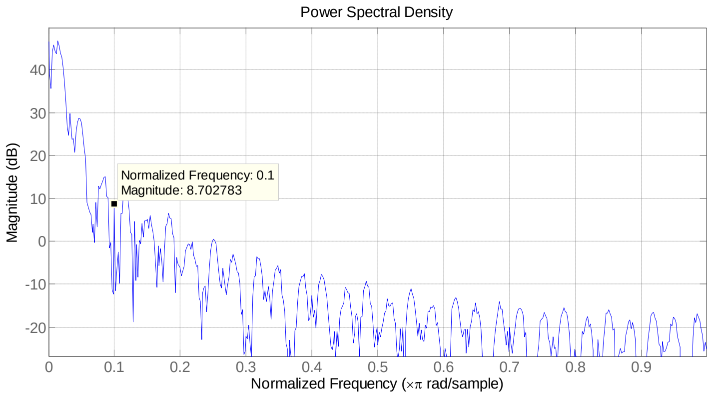

Fig13. Frequency response of filtered ECG signal

V. CONCLUSION

The results obtained show that FIR filter modeled with Nuttall window reduced the powerline noise. Hence the window is effective in the design of filter devices. Thus Nuttall window can be added to the list of windows used in modeling FIR filters. The stability and linearity of the FIR filter modeled with the window were validated as illustrated in Fig 4.

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