Noise Reduction Technique for Heart Rate Monitoring Devices

Q.H.Hii[1], Yusnita Rahayu[2], Reza Firsandaya Malik[3]
[1,2]*Department of Electrical & Electronics Engineering,Universiti Malaysia Pahang(Pekan Campus)*
26600 Pekan, Pahang, Malaysia
[1]qhui_0906@hotmail.com
[2]vannebula2001@yahoo.com
[3]*Computer Engineering Department,*
Faculty of Computer Science, Sriwijaya University.
[3]reza.firsandaya@gmail.com

Abstract— **Electrocardiogram (ECG) signal has been widely used to detect the heart rate of the human, and it is useful in cardiac pathology. ECG detects several heart diseases of the patients. Wearable technology comes to be conducted as work as the monitoring devices to get the ECG signal directly from the patients. However, the movement of the patients will cause noises which interfere the result of the ECG. To overcome this problem, the digital filter is proposed to be designed and used in getting an accurate ECG signal. The filtering ECG results give likely in analysing the heart disease.The structures and the coefficients of the digital filters are designed using Filter Design & Analysis (FDA) tool in MATLAB. The analysis of magnitude responseis done in two type of the digital filter - the infinite impulse response (IIR) and finite impulse response (FIR). This paper evaluatesthat the FIR digital filter is more stable and better to be used in removing noise from ECG signals.**

***Keywords*— Electrocardiogram; noise reduction technique; digital filter; Finite Impulse Response (FIR); Infinite Impulse Response (IIR)**

I. INTRODUCTION

There are more than six billion people alive today, and the number is expected to reach nine billion in another 30 to 40 years. This projected growth in population because of testament to medical and agricultural successes; it brings in declining birth rate and rate on aging population getting increase. As a result, it is expected that more elderly people than the young children for the first time in human history. The services and the quantities on hospital cannot stand for this booming population. The wearable technology provides the solution to sustain for people and get rid in solving these problems.

Wearable technology may provide an integral part of the solution for providing health care to a growing world population that will strained by a ballooning aging population. By providing a means to conduct telemedicine – the monitoring, recording, and the transmission of physiological signal from outside of the hospital – wearable technology solutions could ease the burden on health-care personal and use hospital space for emergent or responsive care [1].

The electrocardiogram will be focused in measuring by using the wearable technology. The ECG is a tool that used to record the electrical and muscular functions of the heart in exquisite detail. It is also a non-invasive test that records the electrical activity of heart over time and it is very useful in the investigation of heart disease, for example a cardiac arrhythmia. The electrodes which placed on the body's surface can be used to measure the signal generated by rhythmic contractions of the heart. The function of the pumping blood of heart performs though the circulatory in human body. But the every movement will lead the electrode give a noisy ECG. Filtering is important and required to be the step on getting a clean ECG signal. To achieve the requirement on cancellation the noise from the ECG signal, designing the filter is indeed.

In the figure1 below is a clean and normal ECG signal. The ECG signal waveforms consists of six continuous electromagnetic peaks which namely as P wave, QRS wave,T wave and U wave. First, the P wave gives the activation of the right and left atria. Depolarization of the right and left ventricles is reflected by the QRS complex. The T wave shows ventricular activation. The main function of the electrocardiogramis used to measure the rate and the rhythm of the heartbeat, as well as provide indirectly become an evidence of blood flow to heart muscle [2].

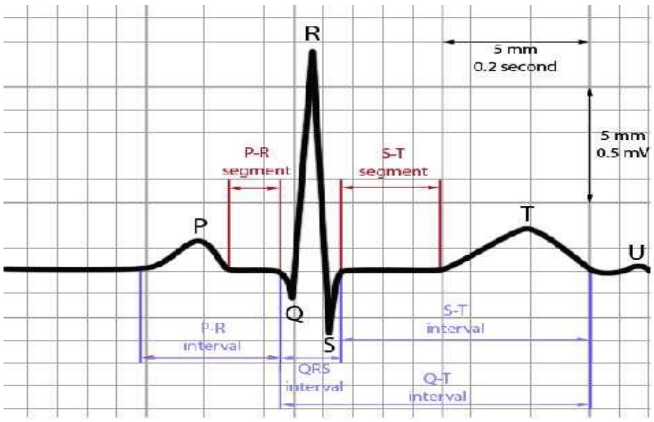

Fig.1 1v Normal ECG signal [2]

A. Various kinds of artifacts

The ECG signal will get to be corrupted due to different types of artifacts and interferences such as powerline interference, electrode contact noise, muscle contraction, baseline drift, instrumentation noise which is generated electronic and mechanical devices, electrosurgical noise as described as below [2-5]:

Baseline wander: The patients' movement and their respiration can cause the low frequency wander. The wander T peak which is higher than R peak will cause detected as R peak. The variation on amplitude is 15% of the peak to peak of the ECG amplitude.

Electrode contact noise: The loss contact between the electrode and the skin generated that disconnects the measurement system from the subject. The result of movement and vibration would be the case on loosing the electrode is brought in or out of the contact of the skin in permanent or can be intermittent. The duration is in 1 sec only and the amplitude is maximum recorder output with the frequency 60Hz.

Powerline interference: Powerline interference contains 50/60Hz pickup and harmonics that can be modelled as sinusoids and combination of sinusoids. Its amplitude can rise up to 50% of peak to peak of the ECG amplitude.

Muscle contractions (EMG): This type of noise brings artifactualmilivolt-level potentials but it usually insignificant. The standard deviation is about 10% of the peak to peak ECG amplitude and the frequency content –dc to 10 KHz.

Motion artifact: Motion artifact happens in a transient baseline changes in the electrode-skin impedance with electrode motion. The ECG amplifier sees different source impedance which forms a voltage divider with the amplifier input impedance therefore the amplifier input voltage depends upon the source impedance which changes as the electrode position changes as the impedance changes. The duration is between 100 to 500ms and the amplitude is 500% percent of peak-to-peak of the ECG amplitude.

For correct extraction of the features of ECG signal, these significant noise signals that corrupt ECG signal have to be cancelled. Digital filter makes the noise reduction to produce the ECG signal measurement more accurate [2-5].

II. Literature Review

Different techniques and method on noise reduction have been proposed and supported by many researchers. Sonuet al presented the moving median filter with the help of artificial neutral network system and successfully denoised ECG signal [6]. Poornachandra suggested a wavelet-based denoising technique for the recovery of signal contaminated by white additive Gaussian noise and investigates the noise free reconstruction property of universal threshold [7]. There are several samples and efficient signs and errors nonlinearity-based adaptive filters, which are computationally superior having multiplier free weight update loops are used for cancellation of noise in electrocardiographic (ECG) signals by Muhammad [8]. Rahman et al proposed some samples and efficient sign based normalized adaptive filters, which are computationally superior having multiplier free weight update loops are used for cancelation of noise in electrocardiographic (ECG) signals [9]. Monisha et al used two types of filtering, the first type is bandpass filtering of ECG, the filter taken from Pan Tompkins' algorithm of QRS detection and the second type is Savitzky-Golay filtering of ECG in requirement noise reduction for accurate representation [10]. Sanyal et al used a time frequency transformation technique which is based on smooth wavelet tight frame with vanishing moments to eliminate baseline wander from ECG signal [11].LMS, NLMS,RLS and BPNN algorithm are utilized for the comparison noise cancellation and the analysis of ECG signal presented in paper [12].

Different digital filter is designed to achieve this cancellation of significant noise in ECG. Mbachu et al designed and implemented FIR filter with hamming window for reducing 50Hz powerline noise in ECG signal. Thus, the comparison on the effectiveness between the filter designed with hamming window and adaptive filter is carried out [13].Smita et al proposed two types of filter, band-pass filter and notch filter, in removal of noise like baseline wander and powerline interference from signal [14].

III. Methodology

In this paper, the data is collected from the PhysioNet [15]. It provides several types of physiologic signals such as ECG signal, thus the analysis is done by using the data from MIT-BIHdatabase provided by PhysioNet.The collected ECGs are from MIT-BIH Arrhythmia Database which is a set of over 4000 long term Holter recordings that were obtained by the Beth Israel Hospital Arrhythmia Laboratory between 1975 and 1979. Twenty-three recordings were chosen at random from a set of 4000 24-hour ambulatory ECG recordings collected from a mixed population of inpatients (about 60%) and outpatients (about 40%) at Boston's Beth Israel Hospital; the remaining 25 recordings were selected from the same set to include less common but clinically significant arrhythmias that would not be well-represented in a small random sample. The data is sampled with sampling frequency of 360 Hz per second per channel with 11-bit resolution over a 10 mV range. This directory contains the entire MIT-BIH Arrhythmia Database. About half (25 of 48 complete records, and reference annotation files for all 48 records). The database contains 23 records (numbered from 100 to 124 inclusive with some numbers missing) chosen at random from this set, and 25 records (numbered from 200 to 234 inclusive, with some numbers missing) selected from the same set to include a variety of rare but clinically important phenomena that would not be well represented by a small random sample of Holter recordings. Figure 2 shows an example of the ECG signal of the patient who hasarrhythmia disease [15].

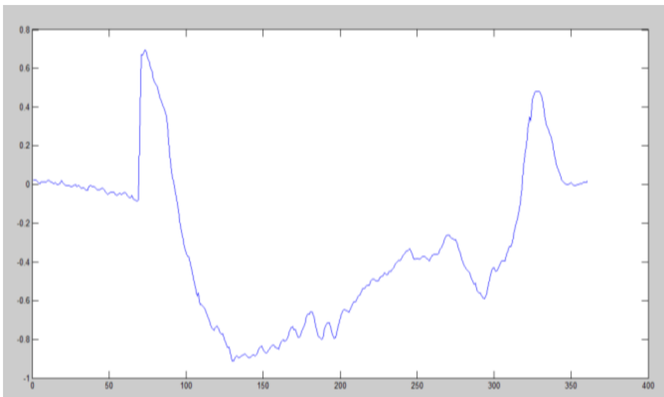

Fig. 2 The Arrhythmia disease ECG [15]

MATLAB is used to evaluate both digital filters performance on FIR and IIR, instead of their capability to eliminate the noise from ECG. Parameters in FDA tool are set up with sampling frequency 360 Hz and minimum order.

The effectiveness of the performance of the FIR digital filter is determined by the number of order used. High order will give stable response of filter for the system.

IV. Digital Filter for Noise Removal

A. Infinite Impulse Response filter (IIR)

By having an impulse response, IIR filters are outstanding by which does not become exactly zero past a certain point, but continuous indefinitely. This is in contrast to a finite impulse response (FIR) in which the impulse response h (t) does become exactly zero at times t > T for some finite T, thus being of finite duration. In practice, the impulse response even of IIR systems usually approaches zero and can be neglected past a certain point [16].

The IIR system function in the z-plane is [16]:

$$H(z) = \frac{\sum_{k=0}^{M} b_k z^{-k}}{\sum_{k=1}^{N} a_k z^{-k}} \qquad (1)$$

where a_k and b_k are the filter coefficients, M the number of zeros and N the number of poles. The function shows that the output of IIR depends on the input before it as AND output samples.

The problems which IIR brings are they do not have a linear-phase characteristics, so they should not be used when the applications where linearity is a big issue. The poles and zeros must stay in the unit circle to eliminate from the poor designed of the IIR [16].

B. Finite Impulse filter (FIR)

It has the impulse responsewhich is finite duration, since it settles to zero in finite time. FIR is in contrast to infinite impulse response (IIR) filters, which may have internal feedback and may continue to respond indefinitely (usually decaying). The impulse response of an Nth-order discrete-time FIR filter lasts exactly N + 1 samples (from first nonzero element through last nonzero element) before it then settles to zero [16].

V. Result and Discussion

To evaluate the performance of the filter means to select the coefficients such that the system has specific characteristics. The required characteristics are stated in filter specifications. Most of the time filter specifications refer to the frequency response of the filter. There are different methods to find the coefficients from frequency specifications:

A. Window Design Method:

The main idea behind the Window Design Method is to consider an ideal IIR filter and then apply a window function to it. This is - in time domain- a multiplication of the infinite impulse by the window function. These results in the frequency response of the IIR being convolved with the frequency response of the window function – thus the imperfections of the FIR filter (compared to the ideal IIRfilter) can be understood in terms of the frequency response of the window function [17].

B. Frequency Sampling Method:

This type of design method is using a filter with a frequency response exactly equal to the desired response at a particular set of frequencies [17]. In this paper, the frequency sampling is set to be 360 Hz.

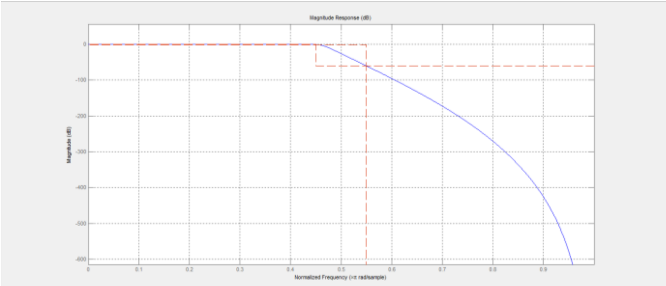

Fig. 3 IIR magnitude response with minimum order

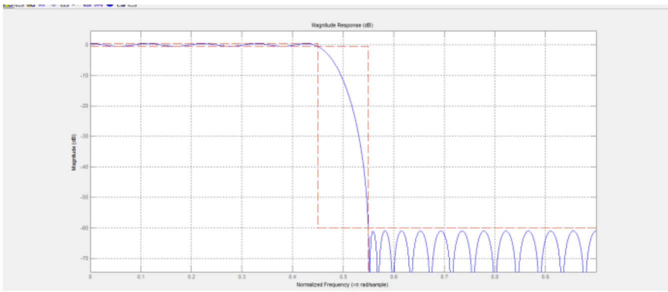

Fig. 4 FIR magnitude response with minimum order

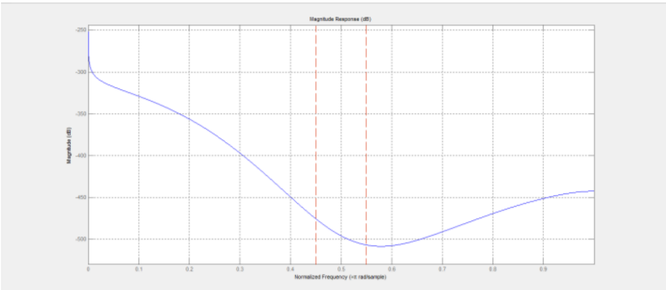

Fig. 5 IIR magnitude response with maximum 50 order

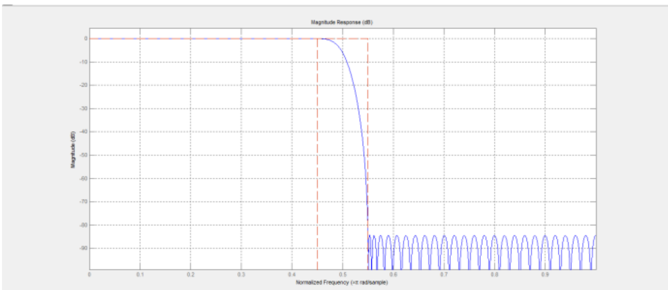

Fig. 6 FIR magnitude response with 100 order

As shown in Fig3, Fig 4, Fig 5 and Fig 6, each of the graphs have their own result for IIR and FIR filter in term of magnitude response. Fig 3 and Fig 4 shows that the minimum order for the IIR and FIR filter. From the graph, this shows that the range of the FIR filter is wider than IIR. For the Fig 5, the maximum order for the IIR is shown and it cannot stand for the filter order which is more than 50. But at the same time, the FIR can support more than 50 orders which is until 100 which is twice of the IIR's order as shown in Fig 6.

Based on the analysis above, FIR filters can be easier to design in order to fulfill a particular frequency response requirement. Furthermore, FIR filters can be easily made to be linear phase a property that is not easily met using IIR filters and then only as an approximation. Another issue regarding digital IIR filters is the potential for limit cycle behaviour when ideal, due to the feedback system in conjunction with quantization [18].

Comparison on FIR over the filter IIR. The FIR filters have the following advantages over the IIR [3, 19].

a. FIR always stable and its feedback is not involved
b. FIR has the exact linear phase while IIR can be only be used in the applications where the linear characteristics arenot concerned.
c. It brings effectiveness realizable in hardware.
d. The response of the FIR is finite.

VI. Conclusion

From the graph above, it shows that the finite impulse response (FIR) filter gives the magnitude response which has a better limited number of terms than the infinite impulse response (IIR). FIR will be chosen and used to be designed on the noise reduction issues in the wearable technology monitoring devices. The investigation will be done further on the designing on FIR digital filter and be implemented with the wearable technology.

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