

Baseline Wander Removal from ECG Signals Using Triangular Window Based FIR Digital Filtering Technique

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Abstract – Digital filters are widely deployed in the processing of Electrocardiographic signals which describe the electrical activities of the heart. Naturally during acquisition, the ECG signals get distorted by different artefacts such as Baseline Wander, Muscle Contractions, Equipment Artefact, Power line Interference e.t.c. This work focuses on the removal of baseline wander from ECG using an FIR filter.

Keywords: Digital filter, ECG Signals, Baseline wander, FIR filter, Triangular window

1. Introduction

Electrocardiogram (ECG) signals are a measure of the electrical activity of the heart. These electrical signals are collected using the electrodes. The amplitude and the timing of the various waves in ECG viz, P, Q, R, S and T (see fig.2) give the vital information about the heart's condition. A physician can detect a heart problem from this information and can suggest timely measures. But during the acquisition of ECG signal, it may get corrupted by different types of noises [1] making it difficult for the physician to give diagnosis. Baseline wander which is a low-frequency component present in the ECG system, results due to movement of the electrodes i.e voltages in the electrodes. It can also be due to respiration and body movement. Baseline wander can cause problems to analysis, especially when examining the low-frequency ST segment [2]. The typical frequency range of baseline wander is usually between 0.1hz and 0.3hz. Therefore in making the choice of the filter cut-off frequency, it is essential to find the lowest frequency component of the ECG spectrum such that the clinical information in the ECG signal remains undistorted while as much as possible the baseline wander is removed. Hence high pass filter with cut-off frequency of 0.5Hz can serve the purpose of filtering, having components with frequencies below 0.5 Hz filtered out [3].

Different approaches have been applied by researchers for reduction of Baseline wander noise.

[4] presented the implementation and evaluation of different methods to remove baseline wander noise. The parameters Power Spectral Density (PSD), Average Power & Signal to Noise Ratio (SNR) of signals were calculated to compare the performance of different filtering methods and Infinite Impulse

Response zero phase filtering was proved efficient for the removal of Baseline wander from ECG signal. In their work, [5] used a derivative based high pass filter to remove low frequency base line wander from recorded ECG signal. The performance of this algorithm was found to be satisfactory. Also [6] implemented a computer program to remove 0.5 Hz baseline wander noise from the ECG signal using multistage adaptive filter and from testing results, it was clear that multistage filter gives better results than single stage filter for all cases.

2. Electrical System of the Heart

The ECG is a signal, which records the electrical activity of heart versus time. Therefore, it is an important diagnostic tool for assessing heart function [7]. The ECG is acquired by placing electrodes on the skin of the patient. The ECG

signal provides the following information of a human heart:

- disturbances in heart rhythm and conduction
- abnormalities in the spread of electrical impulse across the heart
- information about a prior heart attack
- sign of coronary artery disease
- abnormal thickening of heart muscle
- indication of decreased oxygen delivery to the heart
- extent and location of myocardial ischemia
- changes in electrolyte concentrations
- effects of drugs on the heart

An electrical stimulus is generated by the sinus node (also called the sinoatrial node, or SA node), which is a small mass of specialized tissue located in the right atrium (right upper chamber) of the heart. The sinus node generates an electrical stimulus regularly (60-100 times per minute under normal conditions). This electrical stimulus travels down through the conduction pathways (similar to the way electricity flows through power lines from the power plant to your house) and causes the heart's lower chambers to contract and pump out blood. The right and left atria (the two upper chambers of the heart) are stimulated first and contract a short period of time before the right and left ventricles.

The electrical impulse travels from the sinus node to the atrio-ventricular node (also called AV node), where impulses are slowed down for a very short period, then continue down the conduction pathway to provide electrical stimulation to the right and left bundles.

Normally at rest, as the electrical impulse moves through the heart, the heart contracts about 60 to 140 times a minute, depending on a person's age. Each contraction of the ventricles represents one heart beat. The atria contract a fraction of a second before the ventricles so their blood empties into the ventricles before the ventricles contract.

Any dysfunction in the heart's electrical conduction system can make the heartbeat too fast, too slow, or at an uneven rate, thus, causing an arrhythmia.

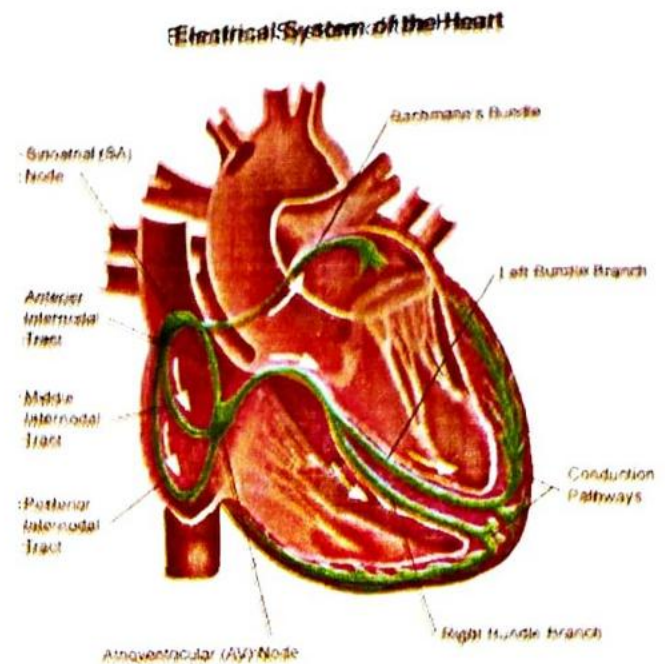


Figure 1: Conduction path of electrical potential for heart beat

ECG waveform of a normal individual consists of the P wave, QRS complex, ST segment, T wave and U wave. The labels of fig. 2.2 are commonly used in medical ECG terminology.

P wave: The first wave in ECG is called the P wave which is generated due to electrical activity of atria. That is, the depolarization of atria results the P Wave in the ECG.

QRS complex: The most important complex in the electrocardiogram is the QRS which shows electrical activities of ventricles.

T wave: The T wave represents re-polarization of ventricles.

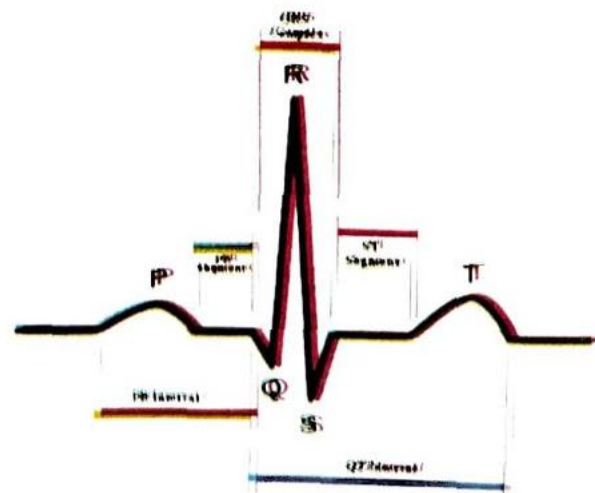


Figure 2: ECG waveform

3. Finite Impulse Response (FIR) Filtering

The digital filters are divided into two basic types, Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters, which are known as non-recursive and recursive filters. FIR filter was chosen since it is simple and stable. The choice between the filter type (recursive and non recursive) is done due to the computational property and the storage required for the implementation.

The simplest method of FIR filter design is called the window method. A window is an array $w[n]$ consisting of coefficients that meet proposed filter requirements. The design of the FIR filter using the window method requires specifying which window functions is used. All frequencies below the cutoff frequency (f_c) are passed with unity amplitude while all higher frequencies are blocked. By taking the in-verse Fourier Transform of this ideal frequency response, the ideal filter kernel (impulse response) is obtained.

The FIR filters are stable and having linear phase characteristics. FIR filters are having a transfer function of a polynomial in z -plane and is an all-zero filter that means the zeros in the z -plane determine the frequency response magnitude characteristic.

FIR filters are particularly useful for applications where exact linear phase response is required. The FIR filter is generally implemented in a non-recursive way which guarantees a stable filter. FIR filter using different windows are preferred due to ease of design and simplicity of programming.

4. Baseline Wander Filtering Using Triangular Window Based FIR Filter

The triangular window based FIR filter is simply a triangular window modified to yield better results. The modified triangular window is given as:

$$w(n) = \begin{cases} a - (2 - 2a)n/(M - 1), & 0 \leq n \leq \frac{M-1}{2} \\ 2 - [a - (2 - 2a)n/(M - 1)], & \frac{M-1}{2} \leq n \leq M - 1 \end{cases} \dots$$

(6)

In this work the value of alpha (α) is 0.06 and in defining further the filter specification, the sampling frequency (f_s) is taken to be 1000Hz and the cut off frequency (f_c) is 0.5Hz and the filter order is taken to be 100.

ECG signal corrupt with Baseline wander is modeled by addition of the equations described below:

$$X1 = \sin(2\pi \times 0.1t) \quad (1)$$

$$X2 = \sin(2\pi \times 0.2t) \quad (2)$$

$$X3 = \text{sawtooth}(2\pi \times 0.05t, 0.5) \quad (3)$$

$$X4 = 3.5 \times \text{ecg}(3000) \quad (4)$$

To create a random effect, (5) is also added.

$$X5 = 0.1 \times \text{randn}(\text{size}(t)) \quad (5)$$

Therefore, the input to the filter is a combination of all the signals expressed by equations (1) to (5).

5. Results

The Fig. 3 depicts the normal ECG trace.

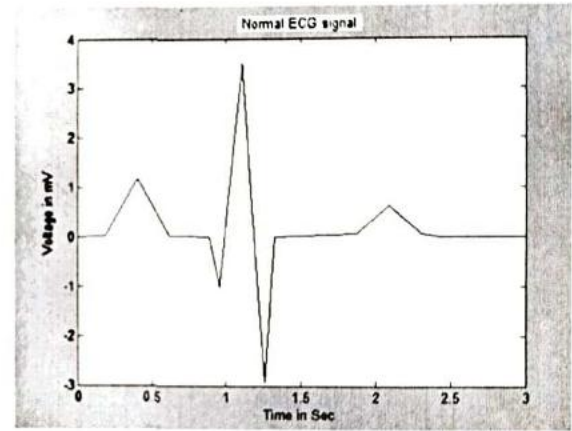


Figure 3: Normal ECG Signal

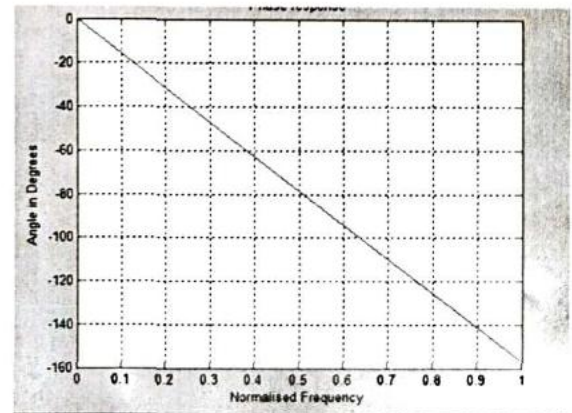


Figure 4: Phase Response of the FIR filter

Fig. 4 depicts the phase response of the FIR filter, which is linear – a characteristic of FIR filters. A filter with linear phase is desirable in order to avoid phase distortion that can alter various temporal relationships in the cardiac cycle.

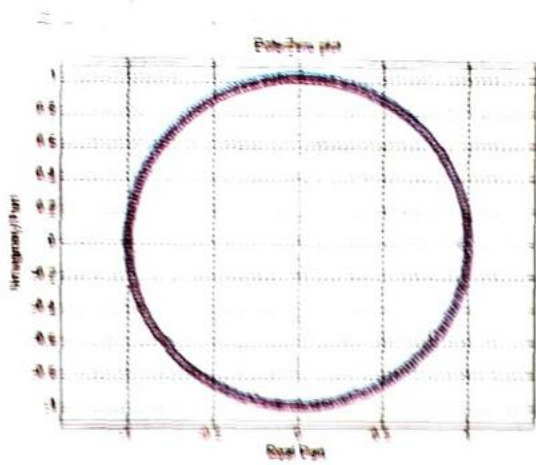


Figure 5: Pole-Zero Plot of the FIR Filter

A pole-zero plot is a graphical representation of a rational transfer function in the complex plane which helps to convey certain properties of the system such as stability. 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.

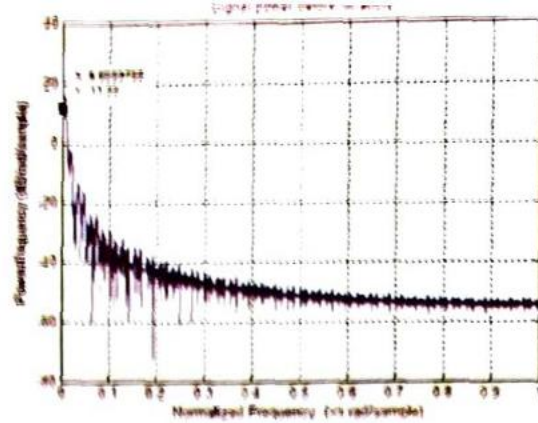


Figure 8: Frequency Response before filtration

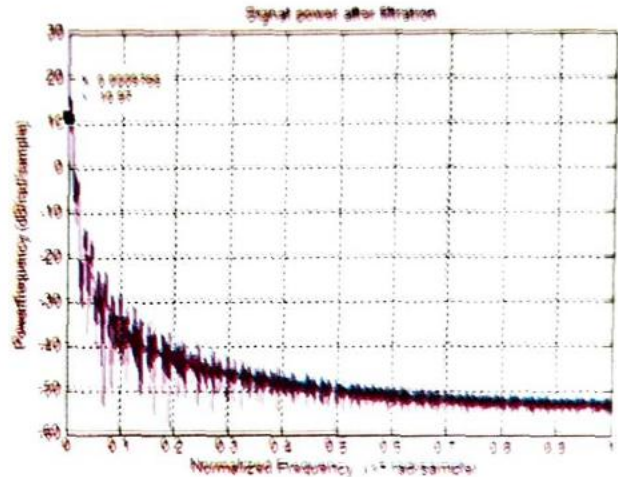


Figure 9: Frequency Response after filtration

6. Conclusion

From the results of Figs. 6 and 7, it was shown that the ECG waveform has been modified using the Triangular window based FIR high pass filter. Observe that the filtered ECG signal starts from zero point as in the normal signal of Fig. 3. Further, a comparison of the values of the signal power of Figs. 8 and 9 shows a reduction from 11.33dB to 10.97dB reveals that baseline wander noise was removed. Therefore, the modified triangular window based FIR high pass filter can be applied in the removal of baseline wander noise from the ECG trace.

7. References

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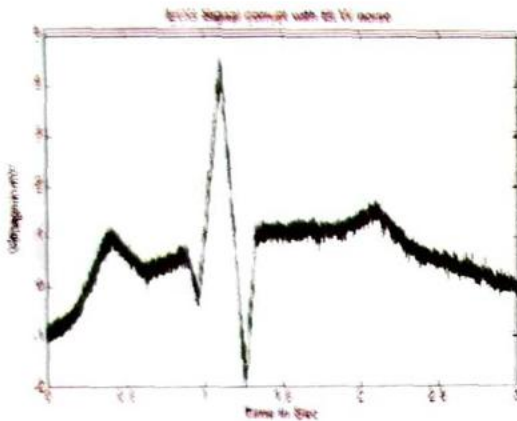


Fig 6. ECG signal corrupt with Baseline wander noise

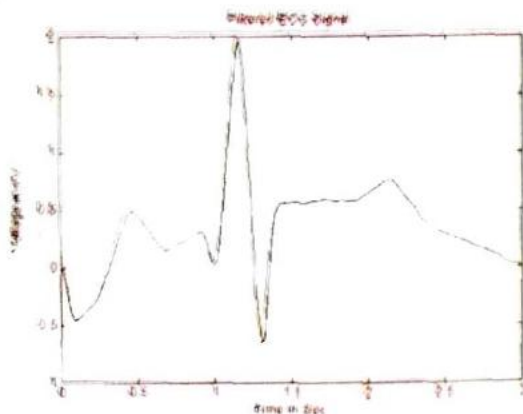


Figure 7: Filtered ECG Signal

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