Implementation of Digital Filters for ECG analysis

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Abstract-Heart rate variability (HRV) is defined as oscillation in the interval between consecutive heartbeats as well as the oscillations between consecutive instantaneous heart rates. HRV is a measure of cardiac autonomic modulation, as potentially useful predictive and prognostic tool in medicine. In a continuous Electrocardiogram (ECG) record, each QRS complex is detected, and the normal-to-normal (NN) intervals (that is, all intervals between adjacent QRS complexes resulting from sinus node depolarization) or the instantaneous heart rate is determined. For accurate HRV analysis of ECG data, it is vital that ECG signal be free from noise caused by external interferences. High quality digital filters are required to preprocess the ECG signal to eliminate the noise. In this project we will implement four digital filters, namely, low pass filter, high pass filter, notch filter and narrow band filters and demonstrate their use in HRV analysis.

Keywords-Digital Filters, ECG signal, HRV Analysis

1. INTRODUCTION

Filters: A program that accepts a certain type of data as input transforms it in some manner and then outputs the transformed data. Filters are analog circuits which perform signal processing functions specifically to remove unwanted frequency components from the signal to enhance wanted ones or both. Filters can be of two types: Analog or Digital.

1.1 Why digital filters?

Many input signals can be filtered by one digital filter without replacing the hardware. Digital filters have characteristics like linear phase response. Such characteristic is not possible to obtain in case of analog filters. The performance of digital filter does not vary with environmental parameters. But the environmental parameters like temperature, humidity etc, change the values of components in case of analog filters so it is required to calibrate analog filters periodically. In case of digital filters; since the filtering is done with the digital computer, both filtered and unfiltered data can be saved for further use. Unlike analog filters the digital filters are portable. The digital filters are highly flexible. Digital filters can be used at very low frequencies, for example in biomedical application. In case of analog filters maintenance is frequently required but not for digital filters. There are two types of digital filters: IIR and FIR filters

1.2 Why IIR filters?

FIR uses standard windows whereas IIR does not need to. Designing IIR filters has fewer constraints and therefore is flexible for designing and implementation. In FIR a new window will have to be designed which will not be required in IIR filters .Thus we choose IIR digital filters to suppress noise from the input ECG data for HRV analysis.

2. DESIGN AND IMPLEMENTATION OF FILTERS

Filters to be implemented in this system include Low-pass, High-pass, Band-pass (Narrow-band) and Band-stop (Notch) filters. These Filters will be using the coefficients of Butterworth and Chebyshev filters

2.1 Butterworth Filters

The Butterworth filter [6] is a type of filter for signal processing designed to have a flat frequency response in the passband. It does not have any ripples in the passband and even in the stopband .They have a more linear phase response in the pass-band than Chebyshev Type I/Type II Filters. The gain $G(\omega)$ of an *n*-order Butterworth low pass filter is given in terms of the transfer function *H(s)* as

$$G^2(\omega) = |H(j\omega)|^2 = \frac{G_0{}^2}{1 + \left(\frac{\omega}{\omega_c}\right)^{2n}}$$

Where n = order of filter, ω_c = cutoff frequency (approximately the -3dB frequency), Go is the DC gain (gain at zero frequency)

2.2 Chebyshev Filter

Chebyshev filter are the filters having a steeper transition and more passband ripple (typeI) or stopband ripple (typeII) than Butterworth filters. Chebyshev filters , with ripples in the passband ,have the property to minimize the error between the idealized and the actual filter characteristic over the range of the filter. It is of two types Type 1 and type 2.

2.2.1 Type1 Chebyshev Filter

These are the most common Chebyshev filters. They show equiripple behavior. The gain (or amplitude) response as a function of angular frequency ω of the *n*th-order low-pass filter is

$$G_n(\omega) = |H_n(j\omega)| = \frac{1}{\sqrt{1 + \varepsilon^2 T_n^2\left(\frac{\omega}{\omega_0}\right)}}$$

Where ε is the ripple factor, ω_0 is the cutoff frequency and T_n is a Chebyshev polynomial of the nth order.

2.2.2 Type 2 Chebyshev Filter

Also known as inverse Chebyshev, this type is less common because it does not roll off as fast as type I, and requires more components. It has no ripple in the passband, but does have equiripple in the stopband. The gain is:

$$G_n(\omega, \omega_0) = \frac{1}{\sqrt{1 - \frac{1}{\varepsilon^2 T_n^2(\omega_0/\omega)}}}.$$

2.3 Implementation Process

The input data is stored in an excel file in a tabular form with x co-ordinate and y co-ordinate values. The x value corresponds to Time offset and y value to ECG data which will be retrieved from this file and will be input to the filter.

Table1.Input Data

	A	B	C	D
1	TimeOffset	ECGValue		
2	2501	-9		
3	2502	-9		
4	2503	-9		
5	2504	-9		
6	2505	-9		
7	2506	-9		
8	2507	-9		
9	2508	-9		
10	2509	-9		
11	2510	-9		
12	2511	-9		
13	2512	-9		
14	2513	-10		
15	2514	-10		
16	2515	-10		

The ECG data when plotted through MATLAB[8] tool looks like the Figure 1 .Thousand samples per second are taken.The Figure 2 shows 3-second data where each individual PQRST wave is made up of Thousand samples.
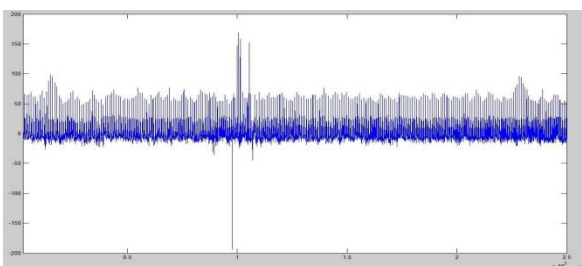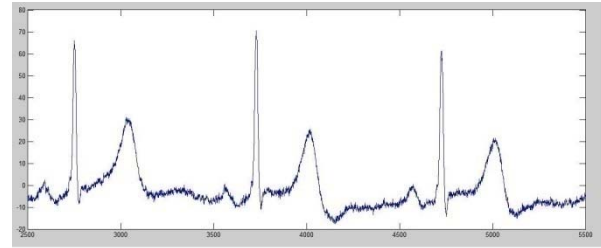

Fig.1 Unfiltered ECG data

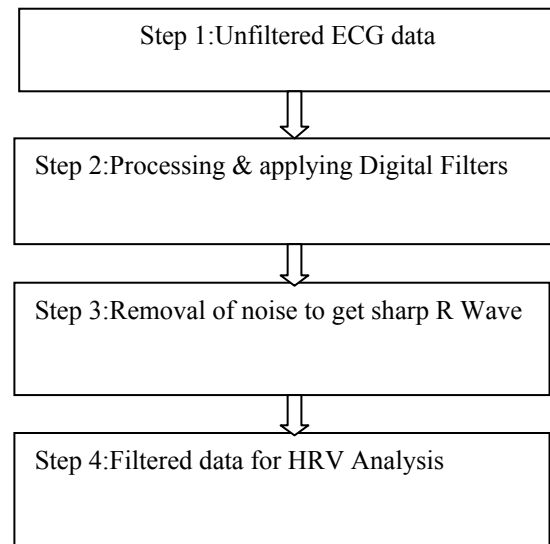Fig.2 Three second snapshot of unfiltered data

Fig.3.Implementation Process

The procedure for the design and implementation of digital filters is illustrated with the flowchart shown in Figure 3. and as outlined below.

1).ECG data is retrieved from an Excel file represented by ECG Values with their Time offsets.

2).Butterworth and Chebyshev filter algorithms are applied on the data which are designed in the C# language.

3).According to the Noise detected Low-pass, High-Pass ,Band-pass and Band-stop Filters are applied.

4)Filtered data is stored again into an excel file. This will be further used for HRV analysis.
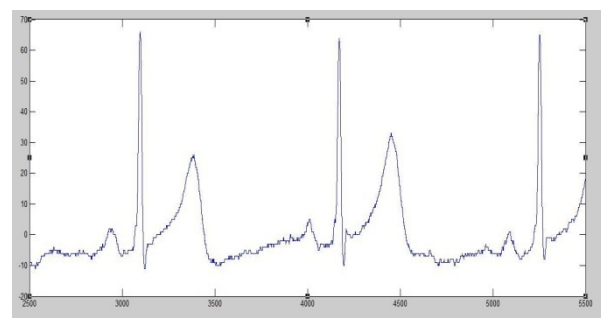
The filtered data when plotted look like the Figure 4.

Fig.4 Filtered ECG Data

3. CONCLUSIONS

The filtration extent depends on the order of the filter i.e. higher the order higher the filtration. When Applied the digital filters of order 2 we found that maximum noise was suppressed .This filtered data is useful for ECG analysis.

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