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Determination of Signal to Noise Ratio of Electrocardiograms Filtered by Band Pass and Savitzky-Golay Filters

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Abstract

Digital or electronic displays of biosignals like electrocardiograms (ECGs) require noise reduction for accurate representation. In this paper noise reduction of normal ECG has been done using two types of filtering. The first type is band pass filtering of ECG, the filter taken from Pan Tompkins' algorithm of QRS detection, and the second type is Savitzky-Golay filtering of ECG. The band pass filter consists of a low pass filter with subsequent high pass filter. Then signal to noise ratio (SNR) has been calculated for the two types, after filtering to compare which method is better for ECG filtering.

Keywords: Electrocardiograms; QRS detection; Savitzky-Golay filter; signal to noise ratio

1. Introduction

Electrocardiogram is a time domain representation of body surface potentials, obtained through placements of electrodes, originating from the heart. It is a very popular biosignal because of its distinct regions corresponding to signals from specific regions of the cardiac system as well as acquirement of this signal from the patient is completely devoid of side effects unlike other diagnostic methods like x-rays. Earlier ECGs were only recorded on strip charts but nowadays these are also shown on digital displays. Digital displays are advantageous because of its ease of storing data. However for digital displays the signal is to be made as much noise free as possible. The origin of noise in electrocardiograms can be from various sources like powerline noise of 50 Hz, noise due to motion artefacts, noise due to muscle artefacts etc.

In order to know about the different regions of the heart corresponding to the parts of the ECG signal, it is beneficial to know about the normal waveform. This wave consists of certain parts named as the P wave, PR interval, QRS complex, ST segment, T wave, QT interval and then the infrequent presence of U wave. The sino-atrial node or the SA node is positioned on the left atrium and this initiates the electrical signal causing atrial depolarisation.

Although the atrium is anatomically divided into two parts, electrically they function as one part. Atria have very little muscle and produce a wave of small amplitude called the P wave. The PR segment is the subsequent part after the P wave and occurs as the electrical impulse is conducted through the atrio-ventricular node or the AV node, bundle of His and Purkinje fibres. The PR interval can be defined as the time between the onset of atrial depolarisation and the onset of ventricular depolarisation. After the PR interval, QRS complex occurs. This complex is generated by the

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depolarisation wave which travels through the inter-ventricular septum via the bundle of His and bundle branches and reaches the ventricular myocardium via the Purkinje fibre network. The impulse first depolarises the left side of the septum, and then spreads towards the right. The left ventricle has larger muscle mass and thus its depolarisation dominates the ECG wave. The QRS complex ends at the J point and from here starts the ST segment. The ST segment which lies between the J point and the onset of the T wave, represents the period between the end of ventricular depolarisation and repolarisation. The T wave is the result of ventricular repolarisation. This wave in a normal ECG is asymmetrical as the first part of this wave is more gradual than the subsequent part. The QT interval is measured from the beginning of the QRS complex to the end of the T wave. Measurement of this interval is done by taking into account the heart rate as this interval elongates as heart rate decreases. The last part of the ECG is the U wave which is found just after the T wave ends. It is a small deflection and generally upright [1-2].

Noise reduction of ECGs have been done through various approaches including non linear filtering with thresholding, artificial intelligence using hidden Markov models, fuzzy neural network, time-recursive prediction techniques, and wavelet transforms. Cubic spline technique and other digital filters have been used for base line drift removal [3-7].

For this paper, electrocardiogram from a normal person has been used. The band pass filter from Pan Tompkins' algorithm of QRS detection has been used as this filter can attenuate low frequency characteristics of P and T wave and baseline drift and also attenuates the higher frequencies associated with electromyographic noise and powerline interference [8-9]. Savitzky-Golay filter has been used both for ECG noise reduction and compression in different papers [10-14]. Here it has been used because of its signal following capabilities by least squares approach [15]. To observe which approach is better for filtering of the electrocardiogram, signal to noise ratio (SNR) calculation is done [16-18].

2. Methods

For noise cancellation of the ECG, the filters that have been used are the band pass filter of the QRS detection algorithm by Pan and Tompkins [9] and Savitzky-Golay filter [15].

Noise reduction using the band pass filter consisting of a low pass filter cascaded by a high pass filter has been obtained for the electrocardiogram in the first method of filtering. The purpose of low pass filter is to suppress high frequency noise [9]. Filter design using digital filters having integer coefficients allows real time processing speeds [9]. As floating point processing is not required so speed is high. The second order low pass filter has the transfer function as shown in eq. (1) [9].

$$H(z) = (1 - z^{-6})^2 / (1 - z^{-1})^2 \quad (1)$$

The cut- off frequency of the filter is 11 Hz, delay is 5 samples and the gain is 36. The difference equation of the filter is as shown in eq. (2) [9].

$$y(nT) = 2y(nT - T) - y(nT - 2T) + x(nT) - 2x(nT - 6T) + x(nT - 12T) \quad (2)$$

The high pass filter is implemented by subtracting a first order low pass filter from an all pass filter with delay. The transfer function of the high pass filter is shown in eq. (3) [9].

$$Hhp(z) = P(z)/X(z) = z^{-16} - Hlp(z)/32 \quad (3)$$

It is finally obtained as shown in eq. (4) [9].

$$Hhp(z) = (-z^{32} + 32z^{16} - 32z^{15} + 1) / (32z^{32} - 32z^{31}) \quad (4)$$

The difference equation of the band pass filter is as shown in eq. (5) [9].

$$p(nT) = x(nT - 16T) - 0.03125\,[y(nT - T) + x(nT) - x(nT - 32T)] \quad (5)$$

The low cut off frequency of the filter is about 5 Hz and delay is 80 msec. Gain is unity [9].

In the second method of filtering of electrocardiograms, processing has been done using Savitzky-Golay filter which is a 17 point sixth order filter [14]. Savitzky-Golay filters are also known as digital smoothing polynomial filters or least-squares smoothing filters are typically used to "smooth out" a noisy signal whose frequency span (without noise) is large. They perform much better than standard averaging FIR filters, which tend to filter out a significant portion of the signal's high frequency content along with the noise. Although Savitzky-Golay filters are more effective in preserving the high frequency components of the signal, they are less successful than standard averaging FIR filters in rejecting the noise. These filters are optimal in the sense that they minimize the least-squares error in fitting a polynomial to frames of noisy data [14].

All programmings have been done on MATLAB programming platform. Filtering of the normal electrocardiogram has been done using the band pass filter in the first method and by Savitzky-Golay filter in the second method. The difference in the noise content of the output signals has been observed and signal to noise ratio (SNR) has been calculated after filtering in the two methods.

3. Results and Discussions

The raw ECG data for the normal electrocardiogram is shown in Fig. 1 and this signal is passed through the band pass filter. The band pass filtered ECG and the noise eliminated from the ECG after band pass filtering, are shown in Fig. 2 (a) and Fig. 2 (b) respectively.

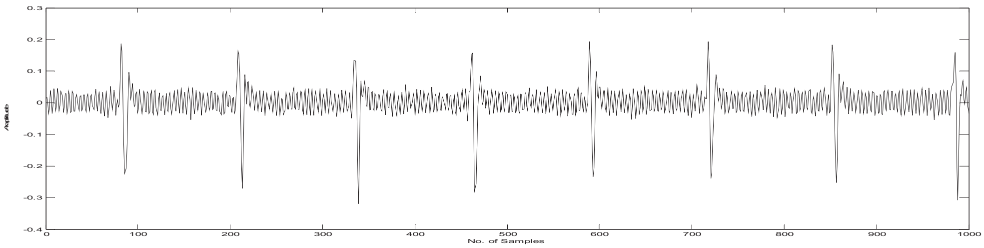

Fig. 1 Raw data of normal ECG

The signal shown in Fig 1 is filtered by Savitzky-Golay filter and the resulting signal is shown in Fig. 3 (a). Noise eliminated by this filter is shown in Fig. 3 (b). Noise reduction in case of Savitzky-Golay filter is much better as compared to band pass filter applied on the signal as there is appreciable increase in SNR in the second method. The SNR calculations are shown in Table 1.

Table 1. SNR Calculations

SNR Calculations (in dB) using Band pass filter	SNR Calculations (in dB) using Savitzky-Golay filter
-0.0055	0.7490

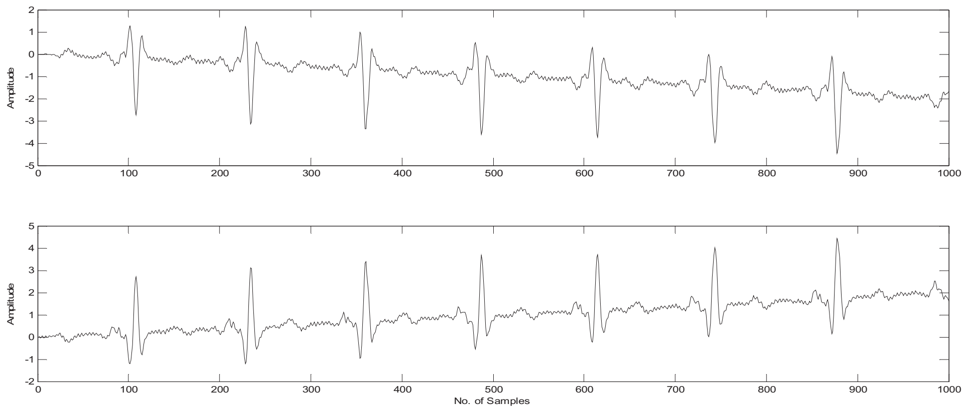

Fig. 2 (a) Band pass filtered ECG; (b) Noise eliminated by band pass filter from ECG

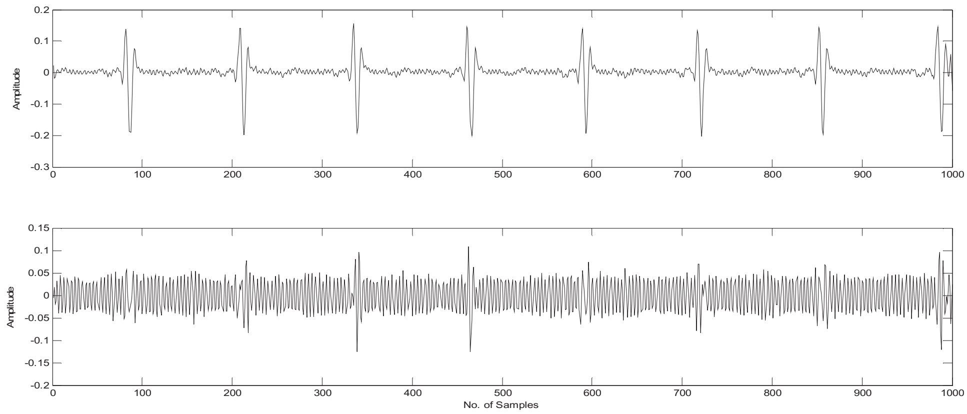

Fig. 3 (a) Savitzky-Golay filtered ECG; (b) Noise eliminated by Savitzky-Golay filter from ECG

4. Conclusion

From the results of this paper, it can be concluded that the method of using Savitzky-Golay filter can be an effective way of noise reduction in electrocardiograms as the signal to noise ratio (SNR) of filtered ECG by this filter is higher than the SNR of the filtered ECG using band pass filter of Pan Tompkins' algorithm of QRS detection.

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