Application of moving average filter in ECG denoising

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Abstract:
The Electrocardiogram (ECG) is widely used for diagnosis of heart diseases. Several methods have been developed for ECG enhancement. This work presents a denoising method for ECG signal. The moving average is successfully applied to denoise the ECG signal on the MIT-BIH databases. The results show that the method achieves good denoising performances in terms of signal to noise ratio and MSRE.

Keywords:
Electrocardiogram, moving average, Signal to noise ratio, mean square relative error.

Introduction

The ECG represents the electrical activity of the heart and already provides a lot of essential information to physicians for diagnosis of heart diseases. Fig. 1 shows a simple ECG model characterized by a number of waves P, QRS, T, U related to the heart activity. These waves are the result of contraction and expansion of the heart muscles. The P wave is due to the depolarization of atria whereas QRS complex reflects the rapid depolarization of right and left ventricles [2]. The T-wave represents the repolarisation (or recovery) of the ventricles. The QRS complex is a major wave in each ECG beat since the duration, the amplitude, and the morphology are used for cardiac arrhythmias, conduction abnormalities, ventricular hypertrophy, myocardial infarction, etc [1] [2].

While recording ECG in a clinical environment it is usually contaminated by power line interference, EMG (electromyogram) signal cause due to high frequency signal related to muscle activity. These recordings are critically often contaminated by cardiac artifact [3]. Baseline wander elimination (a low frequency signal caused mainly by the breathing action) is considered as a classical problem. It is considered as an artifact which produces artificial data when measuring the ECG parameters, especially the ST segment measures are strongly affected by this wandering. In most of the ECG recordings the respiration, electrode impedance change due to perspiration and increased body movements are the main causes of the baseline wandering, the electrode motion is usually represented by a sharp variation of the baseline.

This corrupted noise prevents considerably the accurate analysis of the ECG signal and useful information extraction [4]. Many researchers have worked on development of methods for reduction of baseline wander noise. Zahoor-uddin, presented Baseline Wandering Removal from Human Electrocardiogram Signal using Projection Pursuit Gradient Ascent Algorithm & showed the comparative study of the results of different algorithms like Kalman filter, cubic spline [5]. Manpreet Kaur et al in 2011 has compare the
Methodology

One of the most common tools for smoothing data is the MOVING AVERAGE filter, often used to try to capture important trends in repeated statistical surveys. The approach that is known as a type of Finite Impulse Response (FIR) filter is applied to a set of data points by creating an average of different subsets of the full data set[12]-[14]. The moving average is the most common filter in DSP, mainly because it is the easiest digital filter to understand and use. In spite of its simplicity, the moving average filter is optimal for a common task: reducing random noise while retaining a sharp step response. This makes it the premier filter for time domain encoded signals. However, the moving average is the worst filter for frequency domain encoded signals, with little ability to separate one band of frequencies from another. Relatives of the moving average filter include the Gaussian, Blackman, and multiple-pass moving average[13]. These have slightly better performance in the frequency domain, at the expense of increased computation time. A subset of fixed size obtained from sample values in a given signal by taking their average, the moving average is obtained. Then this subset is shifted forward an element in the given signal. First element in subset is deleted whereas adding a next element to the end of the subset of the given signal. The new subset has the same size as previous one and it is averaged again[14][15]. Same process is repeated over the entire signal. In this paper moving average is defined for samples as follows:

Suppose \( s_m = \{x_m,x_{m+1},\ldots,x_{N/(m+1)}\} \) is a subset of sample values in an ECG signal \( S = \{x_1,x_2,x_3,\ldots\} \) and the fixed size of the subset is \( N \). Then, a new series of \( \{A_1, A_2,\ldots,A_m\} \) is called the moving average of \( S \) which is obtained by the following calculation[14]:

\[
A_m = \frac{x_m + x_{m+1} + \cdots + x_{N/(m+1)}}{N} \quad (1)
\]

Algorithm

Step 1. Choose a proper size \( N \) of the subset \( s_i = \{x_{m_i}, x_{m_i+1},\ldots,x_{N/(m_i+1)}\} \) in a given signal \( S \).

Step 2. Calculate the average of every \( N \) sample values to obtain the moving average.

Step 3. Maintain the same length, create series of \( \{A_1, A_2,\ldots,A_m\} \) of signal \( S \).

The testing criteria for denoising method performance in this paper consist of Signal to Noise Ratio (SNR) and Mean Square Relative Error (MSRE).

Basically signal to noise ratio (SNR) is an engineering term for the power ratio between a signal and noise. It is expressed in terms of the logarithmic decibel scale:

\[
\text{SNR}_{dB} = 10\log_{10}\left(\frac{A_{signal}}{A_{noise}}\right)^2 + 20\log_{10}\left(\frac{A_{signal}}{A_{noise}}\right) \quad (2)
\]

Where, \( A_{signal} \): Root mean square amplitude of the signal.

\( A_{noise} \): Root mean square amplitude of the noise.

Suppose that \( Y \) is a response variable and \( Y' \) is a predictor of \( Y \) that is a function of a single predictor variable \( X \). In ordinary predictions, we obtain \( Y' \) by estimating the conditional mean of a response given predictor value, \( E(Y' | X) \), because it minimizes the expected squared loss, \( E[(Y - Y')^2 / X] \), which is Mean Squared Error (MSE). However, when \( Y > 0 \), it will often be that the ratio of prediction error to the response level, \((Y - Y')/ Y\), is of prime interest: the expected squared relative loss,

\[
\text{MSRE}=E\left[\left\{(Y - Y')/ Y\right\}^2/X\right] \quad (3)
\]

Which is Mean Squared Relative Error (MSRE), is to be minimized [16].

Result and discussions

An ECG signal is not linear, rather more curvaceous consisting of waves of various shapes. Many author uses SNR as an objective method to analyze the performance of ECG denoising methods. Such as IIR and FIR zero phase filtering gives 12.708 and 11.679 SNR value[6]. Similarly wavelet and polynomial fitting is used for noise removal purpose provide 11.689 and 11.16 SNR value which is greater than moving average 10.989 SNR value[6]. Hamming Low Pass filter and LMS adaptive filter gives better SNR value (i.e. 21.6521, 22.5268) than Moving average gives 12.4004 SNR value[6]. Similarly wavelet and polynomial fitting is used for noise removal purpose provide 11.689 and 11.16 SNR value which is greater than moving average 10.989 SNR value[6].

As shown in fig 2 noisy signal is rough in nature. After denoising signal from moving average method produce

Smooth ECG signal. Signal to Noise ratio and MRSE being calculated against a subset of the MITBIH ANSI/AAMI Database. The optimal numerical experimental results for the subset of this standard database are summarized in Table 1.

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Table 1. SNR and MSRE Calculation of Denoised signal.

<table>
<thead>
<tr>
<th>Database</th>
<th>SNR(dB)</th>
<th>MSRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>aami3am</td>
<td>42.5410</td>
<td>0.0375</td>
</tr>
<tr>
<td>aami3bm</td>
<td>42.5495</td>
<td>0.0375</td>
</tr>
<tr>
<td>aami3cm</td>
<td>42.4939</td>
<td>0.0375</td>
</tr>
<tr>
<td>aami3dm</td>
<td>42.5085</td>
<td>0.0375</td>
</tr>
<tr>
<td>aami4a_dm</td>
<td>42.5622</td>
<td>0.0374</td>
</tr>
<tr>
<td>aami4a_hm</td>
<td>42.5916</td>
<td>0.0373</td>
</tr>
<tr>
<td>aami4am</td>
<td>42.5717</td>
<td>0.0373</td>
</tr>
<tr>
<td>aami4b_dm</td>
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<tr>
<td>aami4b_dm</td>
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<td>0.0373</td>
</tr>
</tbody>
</table>

Conclusion

In this paper, moving averaging-based filtration is presented. The novel method to provide better filtration gives better SNR and MRSE value. According to the various papers studied during research, it can be concluded that filtering through moving average permits relatively fewer calculations and better SNR, in comparison with most existing method.

References


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Figure 2: Noisy signal from MIT-BIH ANSI/ AAMI EC13 and denoised ECG signal.