Automatic QRS-complex peak detector based on moving average and thresholding

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Abstract. In this article, we present QRS-complex peak detection using moving average and thresholding process. In the QRS-complex detection, electrocardiogram (ECG) signal is detrended to remove the baseline shift of the signal. Detrended ECG signal is passed through band pass filter that consist of low pass and high pass filter to remove various noises that present in the signal. The output of ECG signal from filtering process is differentiatied to provide the slope of QRS-complex. To make all ECG data point positive, derived ECG signal is processed by squaring process. The final process to detect QRS-complex is passing the ECG signal to moving average and thresholding process. We use ECG data that taken directly from patient with AD8232. The signal that is obtained from AD8232 is processed in Arduino UNO. Processed signal is sent to Android Smartphone and recorded in this device. The accuracy, positive predictive, and sensitivity of QRS-complex detection are 98.28%, 99.01%, and 99.26%, respectively.

1. Introduction
Electrocardiogram (ECG) represents the heart’s electrical activity that can be measured by placing some electrodes on the body surface of the patient. ECG signal gives information of how the heart can perform its function electrophysiologically. Some diagnoses of the heart diseases commonly use ECG signals. ECG signals is also used in monitoring the effects of a heart medication, for example drug induced QT prolongation [1]. Other than that, ECG is used for detecting hypoglycemia [2].

One of the most prominent waveforms in the ECG is QRS complex. The QRS complex represents the depolarization of the left and right ventricles. The heart’s ventricles have a large muscle mass compared to the atria, it makes the amplitude of the QRS complex is larger than the other waveform. The QRS detection is required to find the other waves and segment in ECG signal. So, QRS Complex detection is important. The QRS detection is hard and complicated task, it’s due to various kinds of noise, for example, artifacts due to movement, breath and perspiration of the patient, and power-line interference [3].

The main structure of common detection algorithm of QRS complex consists of two stage [4]. The first stage is preprocessing that comprises nonlinear and linear filtering that aims at emphasizing the QRS complex and suppressing noise and artifact in the ECG signal. And the followed stage is decision making to decide the QRS complex location. Many algorithms have been proposed and used in the literature. QRS complex detection based on quadratic filter [5], adaptive filter [6], S-Transform and
Shannon energy [7], envelop filter and K-means [8], sparse derivative [9], and max-min difference [10] have been developed and used. In this article, we present QRS-complex peak detection using moving average and thresholding process with low computational load and easy to implement.

2. Numerical Methods

This paper presents QRS-complex peak detection using moving average and thresholding process. This section will describe how the data is collected and the proposed method to detect QRS-complex.

2.1. Data collection

We design an ECG monitoring system to record the ECG signal from patient. This system consists of an ECG module to record cardiac activity of the heart. This module consists of three electrodes which is placed in the patient’s particular body surface. This module can amplify the small bio potential with amplification of 1100 times [11]. Besides that, the module can filter the noise of the ECG signal [12]. The ECG signal that is obtained from ECG module is processed to microcontroller and sent to Android via Bluetooth module. Furthermore, the ECG signal is saved in Android device. Figure 1 shows the system’s block diagram.

![Figure 1. Block diagram of ECG monitoring system](image)

A two-minutes ECG records from 10 patient is obtained. The patient consisted of 9 men and 1 woman with age between 20-60 years old. ECG signals is sampled at 250 Hz with sampling interval 4 ms. We calculate and simulate the ECG signals using a open source, powerful mathematics and oriented syntax with visualization tools, and built-in plotting program, GNU Octave.

2.2. QRS complex detection

We proposed a method to detect QRS complex using moving average and thresholding. This algorithm is based Pan-Tompkins with lower computational load and easier to implement [13,14]. In summary, this method consists of baseline-wander removing, lowpass filtering, highpass filtering, derivative process, squaring, moving average filtering, and thresholding process, then finally decision making to determine the location of QRS complex. The whole process of the QRS complex detection method is described as follow,

2.2.1 Baseline-wander removing

Baseline of ECG signal can make the inspection of the signal difficult and even mask some significant feature. So, baseline wander is important task in the QRS complex detection [3]. We use fast wavelet transform to remove the baseline-wander.

ECG with different frequency element is resolved to different scale space, then wavelet coefficients of each scale is handled to preserve the wavelet coefficient of original ECG and remove the wavelet coefficients of noise. Large-scale information contains the contour signal and this information can be acquired by lowpass filter, and highpass filter can acquire the small-scale information contains noise and mutation. Pure signal which baseline is removed is acquired by reconstructing ECG signal using inverse wavelet transform [15].

2.2.2 Lowpass and highpass filtering

The noise of the ECG signal from muscle noise, power-line interference, and T-wave interference can be reduced by lowpass and highpass filter [16]. Suppose the signal with removed baseline-wander is \( x \), then the output of lowpass filter, \( l \) is

\[
l(n) = 2x(n-1) - l(n-2) + x(n) - 2x(n-6) + x(n-12)
\]
and the output of highpass filter, \(H_t\) is
\[
h(n) = 32l(n-16) - [h(n - 1) + l(n) - l(n-32)]
\]
where \(n\) is the \(n\)th sample.

### 2.2.3 Derivative and squaring process

The derivative process, \(d\), provides the slope of the QRS complex. Derivative process is described in equation (3). The output signal of derivative process is squared point by point to make all data positive by equation (4).

\[
d(n) = \frac{1}{8}[-h(n - 2) - 2h(n - 1) + 2h(n + 1) + h(n + 2)]
\]

\[
s(n) = d(n)^2
\]

where \(s\) is the output of the squaring process.

### 2.2.4 Moving average

Moving average, \(m\), operates by averaging a number of points \(N\) from the input signal to get each point in the output signal [17]. Moving average is implemented with following equation,

\[
m(n) = \frac{1}{N}[s(n - (N - 1)) + s(n - (N - 2)) + \ldots + s(n)]
\]

### 2.2.5 Thresholding and decision making

Thresholding process aims to obtain the searching region limit of QRS complex peak in the ECG signal [11]. The value of threshold \(T\) is obtained by multiplying average of \(m\), maximum of \(m\) and \(\beta\), where \(\beta\) is constant \(0 < \beta < 1\). The left limit and right limit of searching region signal \(\gamma\) to find QRS complex peak is obtained by converting the output of moving average into 0 or 1 where,

\[
\gamma = 1 \text{ if } m > T, \text{ and } \gamma = 0 \text{ if } m < T
\]

\(\gamma\) is searching region signal. Then, the left limit \(\lambda\) is obtained if \(\gamma(n+1) - \gamma(n) = 1\) and the right limit \(\Lambda\) is obtained if \(\gamma(n+1) - \gamma(n) = -1\). Maximum value of ECG signal from each \(\lambda\) to \(\Lambda\) represent the QRS complex peak. The thresholding and decision making are shown in Figure 3 (g).

### 2.3. Performance of QRS complex peak detection method

The performance of QRS complex detection method is calculated based on three parameters. The parameters are described by the following equation [18],

\[
\text{Acc} = \left(1 - \frac{F_p + F_n}{\text{Total beat}}\right) \times 100\%
\]

\[
\text{Se} = \left(\frac{T_p}{T_p + F_n}\right) \times 100\%
\]

\[
+P = \left(\frac{T_p}{T_p + F_p}\right) \times 100\%
\]

where Acc is accuracy, \(+P\) is positive predictive, \(Se\) is sensitivity, undetected QRS complex peak is denoted as \(F_n\), \(F_p\) is number of false detections, and \(T_p\) is the number of QRS complexes which is detected correctly.

### 3. Result and Discussion

The proposed method is tested using the ECG data that is obtained directly from the patient using ECG module. We use single lead ECG module that consists of three electrodes and designed to extract, amplify with 1100 times amplification, and filter the presence of noisy condition in the small biopotential signal, such as those created by remote electrode placement or movement of the patient’s body [11]. The design of the module allows for an embedded microcontroller to acquire the output signal easily.

The ECG signal that is obtained from ECG module is sent to Android for recording. The ECG signal is sent via Bluetooth module with baud rate 115200. Android displays ECG signal and save it into text
Furthermore, the QRS complex peak detection is conducted in personal computer using Octave. We record ECG signal with 2 minutes in duration for 10 patient that consists of 9 men and 1 woman. To avoid the presence of the artifact due to motion, patient is asked to relax and silent while recording the data.

We proposed QRS peak detection method that consist of baseline-wander removing, lowpass filtering, highpass filtering, derivative process, squaring, moving average filtering, and thresholding process, then finally decision making to determine the location of QRS complex. Removing baseline wander is important task in the QRS complex detection, Zhang et.al use Mallat based wavelet for ECG denoising and baseline removing [15]. To remove the baseline-wander of the ECG signal we used fast wavelet transform. Then, the ECG signal is passed through highpass filter with cutoff frequency 5 Hz and lowpass filter with frequency with cutoff frequency 11 Hz to remove noises in the ECG. The filtered signal is passed through derivative process and squaring process to emphasize the QRS complex. Furthermore, we pass the ECG signal to moving average, thresholding, and QRS complex peak determination. The entire process of QRS complex detection is shown in Figure 2. Figure 3 shows detected peak of the ECG signal.

**Figure 2.** QRS complex peak detection process (a) ECG signal, (b) ECG signal with baseline removed, (c) lowpass filter, (d) highpass filter, (e) derivative filtering, (f) squaring process, (g) moving average process and thresholding process
Figure 3. QRS complex peak detection result

The performance of QRS complex peak detection is evaluated using three parameters. They are accuracy, sensitivity, and positive predictive. The accuracy is ability of the method to differentiate the QRS complex and not QRS complex peak correctly. The sensitivity is ability of the method to determine the QRS complex correctly. Positive predictive is ability of the method to determine the real QRS complex correctly. Table 1 shows the accuracy, positive predictive, and sensitivity of each patient. The overall accuracy, positive predictive, and sensitivity of QRS-complex detection are 98.28%, 99.01%, and 99.26%, respectively.

4. Conclusion

We present QRS-complex peak detection using moving average and thresholding process. In the QRS-complex detection, electrocardiogram (ECG) signal is detrended to remove the baseline shift of the signal. Detrended ECG signal is passed through band pass filter that consist of low pass and high pass filter to remove various noises that present in the signal. The output of ECG signal from filtering process is differentiated to provide the slope of QRS-complex and squared to make all ECG data point positive. The final process to detect QRS-complex is passing the ECG signal to moving average and thresholding process. The proposed method is tested using the ECG data that is obtained directly from the patient using ECG module. The accuracy, positive predictive, and sensitivity of QRS-complex detection are 98.28%, 99.01%, and 99.26%, respectively.
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