Integrative Technique for the Determination of QT Interval

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Abstract

The 2006 Physionet/Computers in Cardiology Challenge is motivated by the expected requirement of regulatory agencies for skilled readers to conduct QT duration studies of all drugs in clinical trials. However, clinically valid automatic methods would reduce the cost and time need to conduct such QT studies, which are crucial in determining potential proarrhythmic side effects, such as torsade de pointes, of non-antiarrhythmic drugs. The challenge dataset is the PTB Diagnostic ECG Database, which consists of 549 records from 294 subjects. This work proposes an integrative approach for the identification of the PQ junction and T-end of the QT interval. This novel approach uses the curvature of the Q-wave and the T-wave in order to identify an accurate iso-electric curve, between two consecutive peaks, that intersects the extremities of the features. The score for the challenge is 35.19 ms for this method compared to top score of 17.33 ms.

1. Introduction

Under many conditions the duration of the QT interval can indicate the risk of sudden death due to cardiac arrhythmias. Thus, it is essential to monitor any changes in the duration of the QT interval. This can be crucial for patients who are awaiting a heart transplant surgery [1]. Because of the importance of accurately measuring the QT interval, the 2006 Physionet Computer in Cardiology challenge focuses on monitoring the QT interval measurement using automatic detection algorithms. The objective of the automatic detection is to determine the Q-onset and the T-wave offset in order to measure the QT dispersion for the first good beat in Lead II. However, the QT measurement is subject to error due to the embedded noise cause by power line interference, muscle noise and baseline wandering [2]. Additionally, the baseline wandering effect is considered as a major cause for the faulty detection of the ECG features as well as the measurement of the duration of these features. This effect is due to movement of the patient [2].

McLaughlin et al. have dealt with the power line noise using a second order bandpass Butterworth filter with high and low cutoff frequencies of 0.5 and 40Hz, respectively [3]. This work considers the same filtering method in order to eliminate the high frequency noise. Moreover, the removal of the baseline wandering is performed using a moving average technique as suggested by [4].

McLaughlin et al. validated three techniques for the automatic measurement of the QT interval with comparison to manual measurement [2]-[3]. The first technique uses a variable 5% threshold of the T peak in order to determine the T-wave intercepts [4]. A similar technique was applied to the two point differentiation of the ECG signal [3]. Algra et al. presented an algorithm that estimates the T-end as the interception of the tangential from the T-peak and an iso-electric line [3].

We present a technique that improves on the method developed Zhang et al. by [5]. Where Zhang et al. utilizes the variation in the surface area of the T-wave in order to detect its end, their algorithm did not include a well defined criterion for the selection of the starting point of the algorithm. The work presented by Meij et al. [5] proposes a search algorithm to look for the encounter of the T-end. However, their algorithm did not propose an accurate start and end point for the iso-electric line used in the search algorithm. Our proposed algorithm uses an integration approach to determine an iso-electric curve that intersects the features of the signal at the onset and end of the QT interval. Our algorithm is divided into two steps. The first step is used to detect the peaks of each feature in the ECG signal. The second step uses the consecutively detected peaks as the start and end point of an integration process. The length of the integration window is progressively increased and the total area is recalculated, until the peak of the consecutive feature is reached. Finally, the intersection of the area curve with the ECG signal denotes the beginning or end of the current feature depending on the starting point of the integration. The proposed algorithm suggests an accurate way of determining the iso-electric curve that compensates for baseline wandering. The advantage of using the integrative curve is that it tracks along the concavity of the feature under consideration and the respective baseline. This ensures that the curve intersects at the extremity of the feature under consideration; rather than using an iso-electric line which might not yield a solution if the baseline wandering problem is not dealt with properly, since the iso-electric line would not intersect the T-end [4].

2. Data Set and preprocessing

The data set used in this study is the Physikalisch-Technische Bundesanstalt (PTB) Diagnostic ECG database [6]. The database consists of 549 records taken from 294 patients. Each record contains measurements taken from 15 leads, where the first 12 leads are the conventional leads and the last 3 are the Frank leads (X, Y, and Z). Each signal is digitized at 1kHz with 16 bit resolution over a range of 16.384 mV.

Power line noise is removed using a second order bandpass Butterworth filter with high and low cutoff frequencies of 0.5 and 40Hz. The signal is filtered twice, once forward and once backward to reduce phase distortion. Baseline wandering is removed using a moving average filter, where the window size for the moving average filter is 70% of the average R-R interval.

3. Methods

The proposed method uses the forward and backward integration of the ECG signal in order to identify the onset and offset of the QT interval. The purpose for the integration algorithms is to determine an iso-electric curve between the peaks of two consecutive ECG features depending on their concavity and convexity. The intersection of the iso-electric curve with the signal determines the onset and termination of the wave under consideration. This model is divided into three major parts. The first is labels peaks of the signal. The second performs a forward integration. The third performs a backward integration.

3.1 Peak detection

The apexes of the Q, R, S features are identified using a peak and slope detection approach [12]. The R peak assumed to have a larger slope than that of Q and S peaks. Additionally, it is assumed that the Q-peak occurs prior to the S wave.

Next, the T and P peaks are identified between the S-peak of the current beat and the Q-peak the next beat by applying two thresholds. The first threshold, L_1, is initialized as follows:

$$L_1 = 2 * \max\left(abs\left(ECG\right)\right) \qquad (1)$$

The second threshold, L_2, is determined as follows:

$$L_2 = -L_1 \qquad (2)$$

The thresholds are updated until the first intersection with the ECG signal. The characterization of the T- and P-peaks depends on the position of the intersection points. The peaks, detected previously, lying between the intersected ranges of each feature is considered the T- and P- apexes. After the peak detection approaches, the peaks for each beat are labeled accordingly. This labeling is discussed in the following section.

3.2 Peak labeling

The labeling follows from the feature detection approaches presented above. At first, each of the Q, R, S peaks are labeled. Next, the labeling index for the T-peak is the same as that of the QRS complex, while that of the P peak is considered for the following QRS complex.

3.3 Integration algorithm

The integration algorithm is a novel approach proposed for the identification of the QT interval. This approach is used to identify the QRS onset and T wave end. The algorithm is divided in two techniques. The first is the forward integration, used to identify the Q-onset. The second is the backward integration, used for the identification of T-end.

3.3.1 Forward integration

The forward integration is used to determine an iso-electric curve in order to identify the T-end. The method depends on extending the integration area starting from the T-wave peak and ending at the next P-wave peak. This method allows the resulting curve to encounter the change in the movement of the ECG signal as shown in Figure 1. The resulting signal intercepts the end of the T wave. The formulation of the integral is given as the Simpson integration method as follows:

$$A_k = \frac{1}{6}\left(x_{k+1} - x_{k-1}\right)\left[f\left(x_{k-1}\right) + 4f\left(x_k\right) + f\left(x_{k+1}\right)\right] \qquad (3)$$

The integration is done starting from the T-peak up to a desired window size p. This results in B_p as follows.

$$B_p = \sum_{i=1}^{p} A_i \qquad (4)$$

The window size p is then increased and B_p is computed. This process is repeated until the intersection of the iso-electric curve, B_p and the ECG signal is determined. This intersection is noted as the T-wave end.

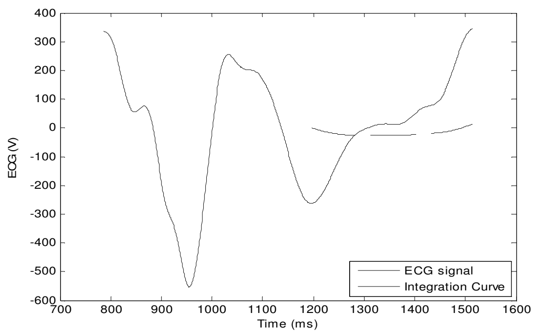

Figure 1 Forward Integration curve intersected with ECG signal

3.3.2 Backward integration

The backward integration is used to determine an iso-electric curve in order to identify the Q onset. The beginning of the integration window is chosen to start from Q_n to P_n. Similar to the forward integration process the first intersection of the integration curve with the ECG signal is considered to be the Q-onset. However, since the curvature of the Q feature is small relative to that of the T-wave, it is essential to normalize the integration curve and the considered ECG interval in order to track the relative change in the Q curve. The ECG signal is normalized according to the R peak under consideration, while that of the integration curve is normalized according to its maximum value. The first intersection of the integration curve with the ECG signal from the Q side is considered to be the QT interval. This leads to the detection of the Q-onset accurately as shown in Figure 2.

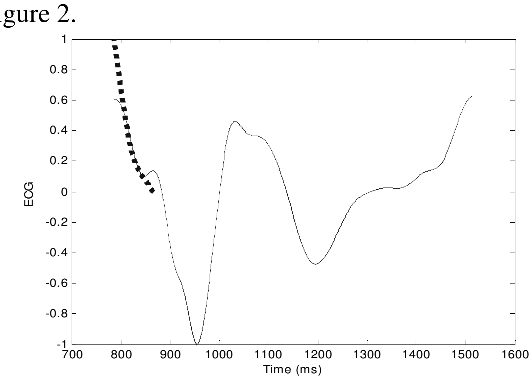

Figure 2 Backward Integration curve intersected with ECG signal

3.4 Manual measurement

The manual measurement of the QT interval for the first available beat of Lead II of the signal is performed using Wave [7]. The signal was processed at 125 mm/sec with amplitude of 10 mm/mV. The annotations were made according to the procedure discussed by Wagner et al. in [9].

4. Results

The approach was applied to a sample data taken from the PTB database available at Physionet Databank. At first the peaks were determined using slope detection and threshold peak detection. The intersection of the integration curve starting from the Q-peak toward the P-peak is chosen to be the Q-onset, while that beginning from the T-wave toward the next P-wave is chosen to be the T-wave end. The dataset consists of 549 records; however, the suggested algorithm used for peak detection was able to detect 548 records consisting of 99.7% of the total number of records. The reference measurement of the PhysioNet/CinC Challenge 2006 is the median. The scoring mechanism is the averaging of the RMS difference between the result under consideration and the reference measurement for all records. The score for the PhysioNet/CinC Challenge 2006 is 35.19 for the proposed integrative approach. It is to be noted that the lowest the score, the better and that the best score is 17.33. This integrative approach is compared with an algorithm proposed by Laguna et al [10]. This algorithm is implemented and supplied by the Physionet Toolkit software database as ECGPUWAVE. The results are also compared to manual measurement using WAVE, a tool designed specifically for viewing and annotating ECG signals. Table 1 shows the mean and standard deviation of the QT intervals for all the patients. The means are in the range of QT intervals which is usually 0.41 ms for female subjects and 0.39 for male subjects.

Algorithm	Mean	STD
Integration	397.70 ms	37.02 ms
Manual	375.29 ms	50.95 ms
ECGPUWAVE	386.24 ms	18.00 ms

Table 1 comparison between QT measurement techniques.

Additionally, the accuracy of the integrative approach is measured with respect to the difference between each record with both the manual measurement and the ECGPUWAVE method. The mean and standard deviation of the difference between all the determined measurements for each technique are shown in Figure 3. QTd1 represents the difference between the integrative approach and ECGPUWAVE, QTd2 represents the difference between the integrative approach and the manual measurement, and QTd3 represents the difference between the manual and the ECGPUWAVE algorithm.

Another comparison test for the duration of the QT interval is to study the QT dispersion with respect to the RR interval of the signal. This test was proposed by Hnatkova et al. in [11]. Figure 4 shows the relation between the QT interval measurements performed by the integrative approach with respect to their RR intervals.

Figure 3 shows that the integrative approach is able to accurately cluster the measured QT duration with respect to the RR interval of each beat.

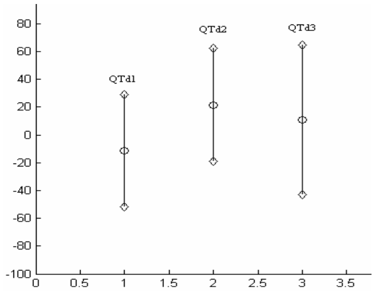

Figure 3 Comparison between QT different of the measurement techniques

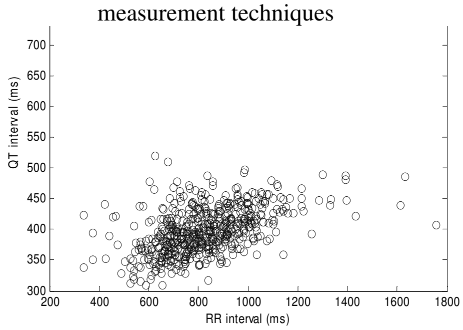

Figure 4 RR vs. QT interval

5. Discussion and conclusions

The integration algorithm proposes a novel approach for determining the threshold which is used for the detections of the onset and offset of the ECG features. This work was motivated by the 2006 Computer in Cardiology challenge. This challenge is based on the hypothesis that non-antiarrhythmic drugs might cause the elongation of the QT duration and could lead to sudden death. And while the manual annotation of the QT interval is time consuming and is subject to error due to fatigue, an automatic measurement approach is required to monitor patients under such drugs. Previous work used a straight line as a threshold for the detection, while this method suggests a curve which follows any changes in the features' baseline. This is because the baseline wandering is considered as one of the major challenges when trying to detect the end of the T-wave. This algorithm suggests how the integral is used to follow the curve as well as the baseline wandering. The results in the QT measurements show that the integrative approach is close to that of the manual detection and other automatic technique. The validation is considered to be acceptable with respect to the other automatic technique and the manual method since there is controversy even between different cardiologists [11]. Some of the results of the measurement of the QT interval were above the normal QT intervals. For some measurements it is because of the patient condition, in others, the curvature of the T-wave or Q-wave are not as concave as possible to accurately measure the iso-electric curve.

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