A Semi-Automatic QT Interval Measurement Based on Digital Filters

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Abstract

The QT interval of ECG signal, a representative duration of cardiac cell activation, has been evidenced to correlate with cardiac disease or drug. Therefore the accurate QT measurement is important for clinical diagnosis and prognosis. In this paper we developed and presented a semi-automatic QT interval measurement method to participate the 2006 computers in cardiology challenge. This method locates the major markers of ECG signals (the P, Q, R, S T waves) based on digital filtering and predefined conditions in waveform. First a proper lead was select to measure the QT interval by manually inspection. The proper lead was defined as in which there are obvious upward R and T waves after 0.4-50 Hz band-pass filtering to diminish the noise and baseline wandering. Then R waves were found as local maxima after applying thresholding techniques. After the approximated first deviation of the filtered ECG (dECG) was obtained by difference filter, the Q onsets were located as the second cross-zero point of dECG 2-120 ms upstream R waves and the ends of T waves were located as the intercept of the filtered ECG signal and the line passing through T peak and maximum slope point on T wave. A visualization interface to display the characteristic markers on the ECG waveform was used to inspect the primary results and thus a representative beat could be manually selected as a final result. This method involves tow-steps manually intervention to raise the accuracy of QT measurement. However, these tow-steps are not time-consumed and easy for users with minimum knowledge of interpreting ECG. Finally an automatic method was developed by using the mean of 12 leads as processed signal.

1. Introduction

The QT interval (from the Q wave onset to the T wave end) represents the duration of ventricular depolarization and subsequent repolarization. A delay in cardiac repolarization has clinical relevance to cardiac arrhythmias.[1,2]

Automated methods, in comparison with manual methods, offer advantages in terms of absolute repeatability of measurements, immunity from errors related to observer fatigue, lapses of attention, and transcription, as well as efficiency and cost considerations that permit either more extensive and rigorous testing for the same cost as manual methods, or more rapid testing at lower cost.[3,4]

There are four automated methods that have been around by McLaughlin et al.[5]: the Technique TH (threshold), DTH (differential threshold) Technique SI (slope intercept), Technique PSI (peak slope intercept). The mean of the QT interval determined by the four methods described above may vary of up to 62 ms, in particular, the results of Technique TH are highly undesirable.

In addition, filtering has proven to be more difficult than we ever anticipated, because the program has to be robust enough regardless of the quality of the recordings. With more processing power in today's computers, an order higher than two can be done with acceptable efficiency.[6]

The aim of the study is participate the Computers in Cardiology Challenge 2006 and do a delicate task of performing automated QT interval measurements with a high reproducibility, based on the 549 recordings of the PTB Diagnostic ECG Database.

2. Methods

The PTB Diagnostic ECG Database, which includes 549 records from 294 subjects (each subject is represented by one to five records). Each record includes 15 simultaneously measured signals: the conventional 12 leads (I, II, III, avr, avl, avf, v1, v2, v3, v4, v5, v6) together with the 3 Frank lead ECGs (vx, vy, vz). Each signal is digitized at 1000 samples per second, with 16 bit resolution over a range of ± 16.384 mV.

2.1. Filtering and R-peak finding

A forth order Butterworth IIR digital filter with a bandwidth of 0.4 Hz to 50 Hz was used to eliminate high frequency noise and baseline wandering. A lead was selected for further processing by manually inspection.

The R peak was identified as local maxima by squaring the signals and then sorting them into clusters by means of amplitude thresholding. In case that the T wave of the signal had an abnormally high peak, the program could be forced to find the peak in the anterior position by selecting manually. The procedure for R-wave finding was shown as figure 1.

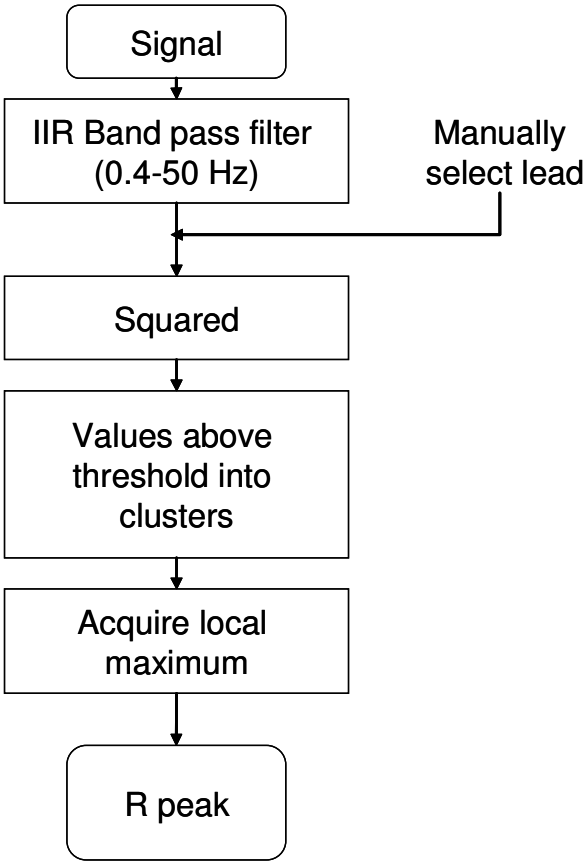

Figure 1. The procedure for finding R-wave peak including manually inspection and lead selection

2.2. Q onset and T end determination

The Q onset then was identified following R peak finding. After the approximated first deviation of the filtered ECG (dECG) was obtained by difference filter, the Q onsets were located as the second cross-zero point of dECG 2-120 ms upstream R waves. Because of the special nature of the filtered signals and slight difference between leads, the program had a second method of finding Q onset, by using the same method described above, but using lead II as the input signal, finally adjusting it by using methods described below. The user had to choose which Q onset was the more desirable one. Figure 2 showed the procedure for Q onset locating.

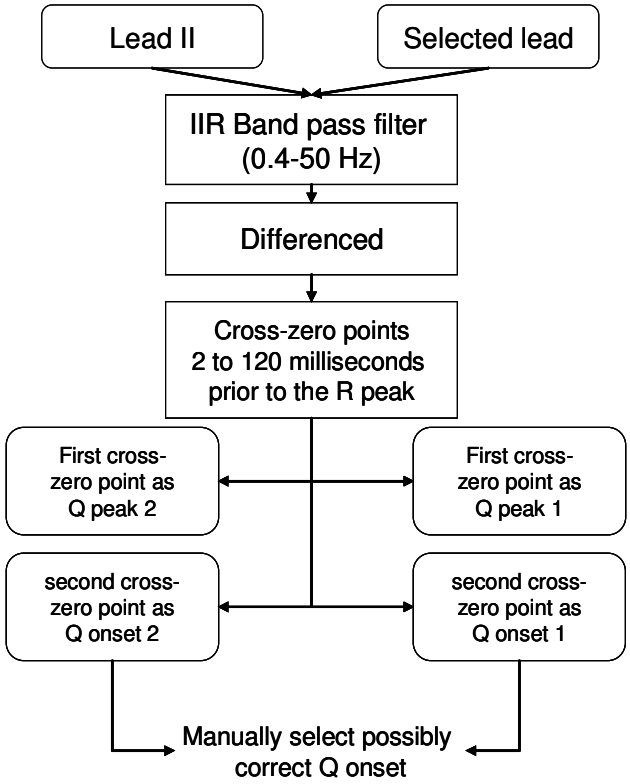

Figure 2. The procedure for finding Q wave and Q onset on lead II and manually selected lead.

Three methods were applied to locate the end of T wave (T end). First method (zero-slope method) located T end as the second cross-zero point of dECG 200-600 ms downstream R waves.

The second and third methods referring to previous works [5,7] uses the peak of T wave (T peak) and the slope of T wave as reference features. The T peak was designated as the cross-zero point with the highest amplitude 200 to 600 milliseconds posterior to the R peak. The maximal slope behind T peak was found and the point with maximal slope (MSP) was located. An isoelectric point was obtained by finding the next first deviation cross-zero point behind MSP. The second method (MS-ISO method) found the intercept of the line tangential to the MSP and the isoelectric line to recognize the time as T end location. The third method (MS-Tpeak method) found the intercept of the filtered ECG signal and the line passing through T peak and MSP to identify it as T end. Although all three methods have been implemented, we adopted the MS-Tpeak method to participate this challenge. The procedure for T end locating by MS-Tpeak method was shown in figure 3. The locations of T ends obtained by these three methods

were shown on figure 4 in result section. However this method is semi-automatic needing some manual processes.

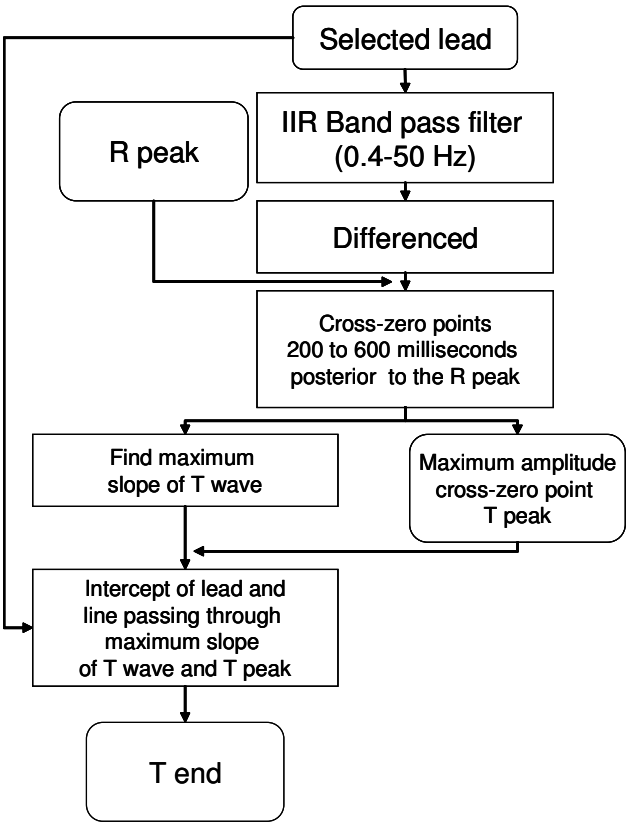

Figure 3. Determination of T end by intercept of ECG signal and line passing through T peak with maximum slope of T wave.

2.3. Automatic method involving 12 leads

The proposed semi-automatic method had a manual procedure for the selection of a proper lead to process. Hence we developed another automatic method using 12 leads data instead of manual selection of leads. The first process involved screens the twelve leads for inverted leads, and inverting them to let them with positive R waves. The second process was to calculate the mean and median of 12 lead ECGs including uninverted leads and the inverted leads which had been processed upon. The final signal was put through the procedures of finding R peak, Q onset, and T end by methods described previously.

3. Results

The criteria for manually lead selection was straight forward, lead II was always top on our priority, only when the peaks had inadequate amplitude, or the number of peaks abnormal. When lead II was unusable, other leads we selected for their recognizable PQRS complex, independent P and Q waves (P and Q waves not merged), and sufficient amplitude of the T wave.

Finally, of all the 482 sets of data we performed, lead II accounted for 320 sets, lead I was the second most favorable, accounting for 80 sets. We got a final score 46.96 ms based on the scoring rule of this challenge. Figure 4 demonstrated the characteristic points on ECG located by our proposed method. Three T ends obtained by three methods were indicted with different markers. Generally zero-slope method produced a longer QT interval, on the other hand, MS-ISO method produced a shorter result.

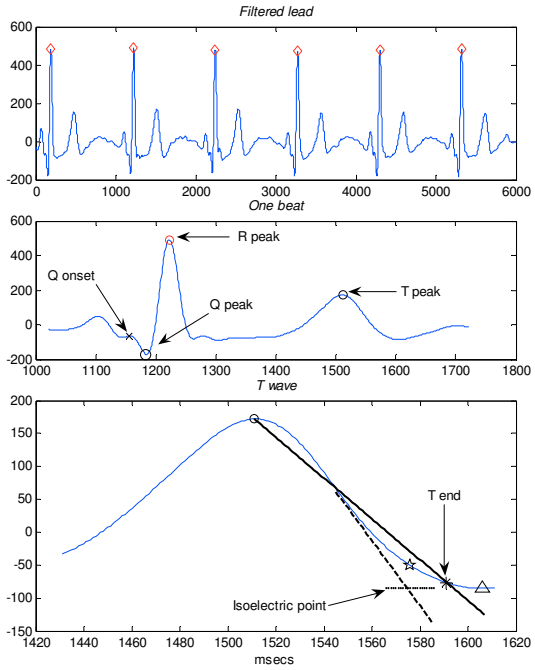

Figure 4. A typical demonstration for the found feature points on ECG using our proposed method. Three T ends were marked in the bottom figure: star marker for MS-ISO method, triangle marker for zero-slope method and * marker for MS-Tpeak method.

We attempted to use the mean or median of 12 leads as a new signal for automatic QT interval measurement without lead selection. However, applying to the PTB Diagnostic ECG Database the mean or median signal doesn't always provide robust results. We observed a strange phenomenon, compared to lead II half the time the 12 lead mean would provide good results, and when

the mean failed, the median would not fail to provide desirable results. Figure 5 showed the result of this method applied to a record with a good lead II. The result from median of 12 lead was comparable with that using single lead.

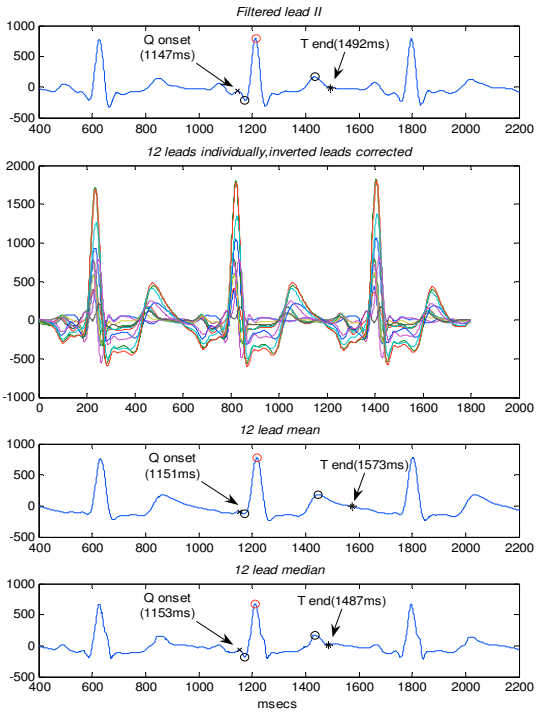

Figure 5. The Q onset and T end were obtained from the mean and median of 12 lead. The second figure showed 12 individual lead after rectification.

4. Discussion and conclusions

The lead II is supposed to be the most appropriate lead to diagnose. But sometimes lead II was heavy noise loaded, baseline wandering or without good shapes of T waves. This is why we gave the user the privilege to choose the most suitable one. Almost in all cases, even if the quality in lead II were too small to measure, other leads provided appropriate ones. This method involves manually interventions to raise the accuracy of QT measurement. However, these procedures are not time-consumed and easy for users with minimum knowledge of interpreting ECG.

In figure 5 which depicts all the twelve leads, it is possible that the second lead or the lead that most represents the correct ECG signal is not the mean or the median, only when at least half of the twelve leads have nearly exact results will this theorem come true.

If the isoelectric point remained steady, minimum noise whatsoever, and no baseline wandering occurred, identifying T end as the next cross-zero point from T peak would be very correct indeed. However using the PTB Diagnostic ECG Database such an ideal doesn't happen. In order to evade the uncertainness of the isoelectric point our program identified T end as the intercept of the filtered signal and the line passing through T peak and the point of the maximum slope of the T wave and thus yield better results.

Moreover, because the filtering process makes the signal shift a few milliseconds from the original, we devised a method to redeem such errors. The program used the R peak in the original signal as reference point for error adjustment, the value between the two R peaks was added to all corresponding points. This makes the position more scientifically correct.

In conclusion, QT interval measurement is a complicated task our proposed method combining minimum manual intervention can obtained reliable results.

Acknowledgements

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