Challenge 2006: QT Interval Measurement

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Abstract

This years challenge addresses the question if it is possible to measure the QT interval by fully automated methods. For this task we implemented an algorithm which (1) performs beat detection, measures wave boundaries on a beat-to-beat basis and (2) selects a representative beat whose QT interval is used.

To get the positions of the wave boundaries, the algorithm searches for peaks in the 1st derivative of bandpass filtered ECG signals using thresholds which are adapted to the amplitudes in the segments of interest. When the peaks associated with the QRS complex and the T wave are found, the beginning of the QRS complex and the end of the T wave are assessed using the "Philips Diagnostic ECG Interval Measurement" method [1].

For the selection of the representative beat, a noise level for each single beat was calculated by determining the standard deviation of the ECG 30ms before the onset of the QRS complex and 30ms after the end to the T wave. The beat with the lowest noise level was selected as the representative beat and from this the QT interval was used.

This approach results in a score of 70.94ms.

1. Introduction

This years Physionet/Computers in Cardiology Challenge addresses the question if it is possible to measure the QT interval by fully automated methods. A description of the challenge can be found on the Physionet/Computers in Cardiology Challenge website (http://physionet.org/challenge/2006/) and in the paper by Moody et al. elsewhere in this volume [2].

We decided to participate in division 3 of the challenge, which meant that our implementation had to be fully automated and the source code had to be published using an open source license.

2. Methods

For the detection of the beats and the assessment of the wave boundaries, the filtered ECG signal and its first derivative is used. For QRS related measurements a FIR

bandpass filter with a pass band of 15Hz-60Hz is applied (this time series will be called *sig-qrs*), for the T-wave a FIR bandpass filter with a pass band of 0.05Hz-40Hz is applied (this time series will be called *sig-pt*). Both filters were designed with the Window method using a Hamming window and an order of forty one. To correct any temporal- and phase-delays produced by the filtering process, the forward/backward filtering approach was used [3].
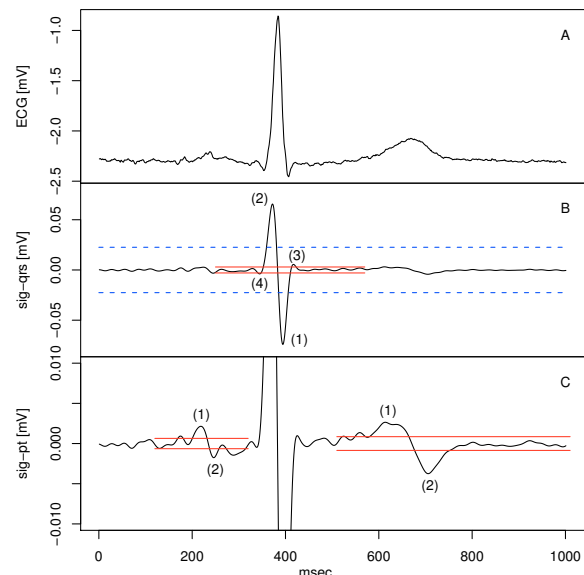

Figure 1. The upper panel shows the original ECG signal. The middle panel shows the first derivative of the filtered ECG signal (*sig-qrs*, bandpass 15Hz to 60Hz). The blue dashed lines are the thresholds used to detect the occurrence of a beat. The red lines are the thresholds used to assess the waves of the QRS complex. The numbers show the order in which the peaks are selected (the peak with the maximum absolute amplitude is (1)). The lower panel shows the first derivative of the filtered ECG signal (*sig-pt*, bandpass 0.05Hz to 40Hz). The red lines are the thresholds used to assess the morphologies for the P- (left of the QRS complex) and T-waves (right of the QRS complex).

First, the heartbeat is detected using a threshold of two times the root-mean-square of *sig-qrs* (figure 1, panel B,

blue thresholds (dashed line)). The threshold is calculated for each five second segment.

After a beat is detected, the wave boundaries and morphologies for the QRS complex are assessed in *sig-qrs*, for the P- and T-waves *sig-pt* is used. To get QRS complex related information, the segment 120ms before and 200ms after the position found with the first threshold is further analyzed. This segment will be called the segment of interest. The threshold used to get the components of the QRS complex (e.g. Q-wave, R-wave) is 7.5% of the maximum absolute amplitude in the segment of interest (figure 1, panel B, red thresholds). For the P-wave the segment of interest is between 230ms and 30ms before the QRS complex begins, the threshold is 10% of the maximum absolute amplitude in the analysed region (figure 1, panel C, red thresholds left of the QRS complex). For the T-wave, the begin of the segment of interest is 100ms after the end of the QRS complex. The length of the region depends on the heart rate and can be between 300ms and 500ms. The threshold used is also 10% of the maximum absolute amplitude (figure 1, panel C, red thresholds right of the QRS complex).

After selecting the segment of interest and the threshold, the single waves of the QRS complex and the P- and T-wave are assessed. For this task, the peaks (signals above the thresholds) are extracted from the signal. Only peaks with alternating orientations (positive/negative) are valid. The peak with the maximum absolute amplitude is selected as the starting point. From this peak, the peak to the left or to the right with the higher amplitude is selected. Then the next peaks are selected alternating the side (left/right). In figure 1, panel B the peak selection is shown for the QRS complex. The first peak is the one with maximum negative amplitude. The next one is left to the first one, the third is the first right to the start peak and the last one is left to the second one. The selection of peaks is stopped when either there are no more peaks or the distance between the peaks is too large, so the peak is not related to the current wave(s).

The current implementation allows for the QRS complex a maximum of four peaks and for the P- and T-wave a maximum of three peaks. Table 1 shows how the found peaks and their orientation are related to the morphologies of the QRS complex. Table 2 shows the mapping for the P- and T-wave.

The start and end positions of the first and last peak selected above are used as the intermediate start- and end-position of the QRS complexes and the P- and T-wave. Because these positions are dependent on the threshold, a threshold independent start and end position is assessed using the 'Philips Diagnostic ECG Interval Measurement' method.[1]. This method creates a slope line from the relevant peak of the wave to a point 100ms before/after the

Table 1. Mapping of the found peak sequence in the 1st derivative to QRS morphologies

Peak Sequence	Morphology
NPNP	QRS
PNPN	RSR'
PNP	RS
NPN	QR
PN	R
NP	S

N: negative peak, P: positive peak

Table 2. Mapping of the found peak sequence in the 1st derivative to P- and T-wave morphologies

Peak Sequence	Morphology
PN	positive wave
NP	negative wave
PNP	bi-phasic (positive - negative)
NPN	bi-phasic (negative - positive)

N: negative peak, P: positive peak

temporary inflection point and looks for the maximum difference between the slope line and the signal. Figure 2 shows an example how the measurement is performed to assess the end of the T-wave.
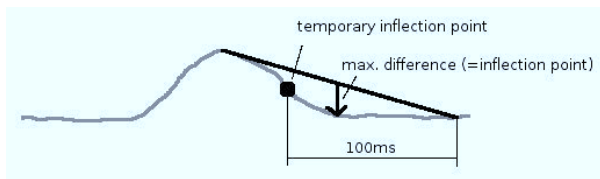

Figure 2. The figure shows how the end of the T-wave is assessed using the 'Philips Diagnostic ECG Interval Measurement' method. After selecting the peaks in the first derivative of the ECG signal, a temporary inflection point is available (it is the position where the signal falls below the threshold). From this point, the local maximum before the position is searched in the original ECG signal (i.e. the peak of the T-wave) and a line from this maximum to the position 100ms after the temporary inflection point is created. Then the differences between the line and the signal is calculated and the position where the difference has its maximum is the inflection point used.

The wave delineation is done on a beat-to-beat basis using a single lead. For the measurements done here, lead II is used as specified by the challenge instructions. After an ECG is processed, the morphologies of the QRS complex and the T-wave with the most occurrences is assessed. Then the wave boundary assessment is repeated, but this

time the thresholds are adjusted to force the algorithm to 'detect' the major morphology selected from the first run. For example when the QRS complex has a small Q-wave which is overlooked from time to time, the threshold is decreased in case no Q-wave was detected to be able to find smaller Q-waves. The change of the threshold is repeated until the wanted morphology is found or a meaningful measurement is not possible.

The second part of the challenge was to select a representative beat from which the QT interval is used. For this task, the noise level for each single beat is measured by calculating the standard deviation for a 30ms segment directly before the QRS complex and the standard deviation of a 30ms segment directly after the T-wave. Because these segments are isoelectric, the measured value should be independent of the electrical activity of the heart. The larger value of these two measures is used for further selections.

After all assessment of the wave boundaries and the noise level, the beat with the lowest noise level is used as the representative beat. The QT interval from this beat is then exported to the result file.

3.   Implementation

The algorithm for the beat detection, the wave boundary assessment and the noise level calculation are implemented as libRASCH [4] process plugin. The program controlling the beat detection (starting the first run, selecting the major morphologies and starting the re-assessment), selecting the representative beat and writing the results to a file (using the format requested in the challenge instructions) is written in Perl using the Perl API bindings of libRASCH.

The source of the beat detection is published under the LGPL, the Perl script is published under the Artistic License. Both are free and open source licenses.

The source code is part of the libRASCH distribution which can be downloaded at the libRASCH-project website at www.librasch.org. You will find the source code of the beat detection plugin in the directory LIBRASCH_ROOT/plugins/access/detect_ecg. The source code of the Perl script is in the file LIBRASCH_ROOT/scripts/get_qt_cinc_2006.pl.

4.   Results

The performance of the QT interval measurement was assessed with a score value; the lower the score the better the method is. You will find a description how the score is calculated in the paper by Moody et al. elsewhere in this volume [2].

The score of the measurements using the method described before is 70.94ms. Figure 3 shows on the x-axis the QT intervals found as the gold standard in the challenge and on the y-axis the QT intervals found with our

approach. One can see that our method has a tendency to assess QT intervals which are too long.
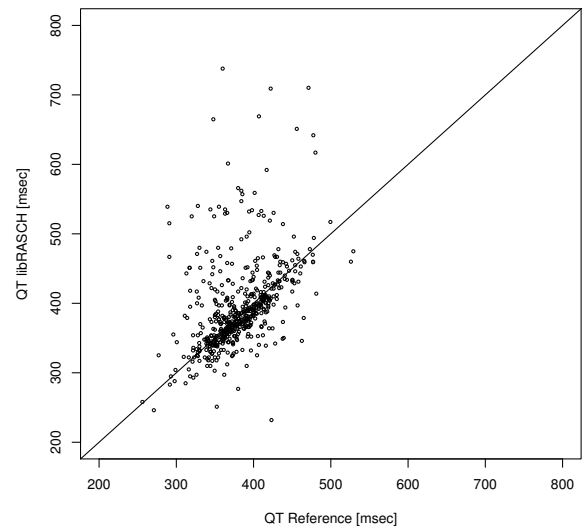

Figure 3.   Comparison of the QT intervals found as the gold standard during the Challenge (x-axis) with the QT intervals assessed using our approach (y-axis).

Figures 4 and 5 show examples of wrongly measured QT intervals. In figure 4 (recording s0057lre) the measured QT interval is 608ms, the reference value is 367ms. The reason for the wrong QT interval is because the amplitude of the T-wave is very low and there is some noise which masks the real end of the T-wave. One can see that in this example the best leads to measure the QT interval are V2 and/or V3. In all other leads the amplitude of the T-wave is low.
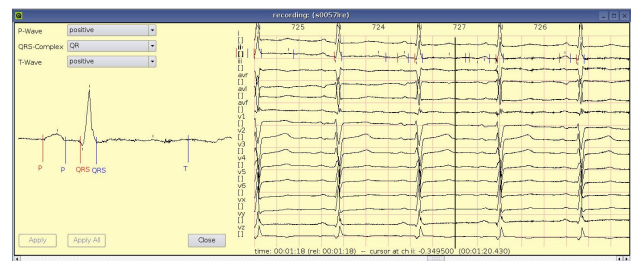

Figure 4.   Example (recording s0553_re) of a QT assessment which is longer than the reference value. The amplitude of the T-wave is low and the noise masks the real end of the T-wave.

Figure 5 (recording s0553_re) shows an example where the measured QT interval is shorter than the reference value. The found QT interval is 356ms, the reference value

is 437.5ms. In this example the T-wave is bi-phasic and the second part of the T-wave is overlooked.
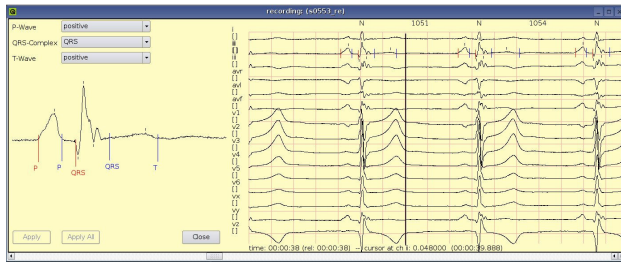

Figure 5. Example (recording s0057lre) of a QT assessment which is shorter than the reference value. The T-wave is bi-phasic, the second part is overlooked because the amplitude of the second part is too low.

5. Discussion and conclusions

The score of our approach is 70.94ms. The best fully automated methods reached a score of 16.34ms for division 2 and 17.33ms for division 3 (open source).

In our opinion, the main reason for the poor performance of our approach is that we looked only in one lead and did not use the information of the other leads. In both examples shown above, the amplitude of the T-wave in lead II was very low, in other leads the amplitude was much higher. One possibility could be that the end of the T-wave is measured in all leads and when the inter-lead difference is too high, this beat will be excluded from further analysis.

Another deficit of our approach is the lack of plausibility checks. One simple plausibility check could be that only QT intervals between 250ms and 500ms are allowed (this approach was used by another participant of the challenge), all beats with a QT interval outside this range are excluded.

References

[1] Lindauer JM, Gregg RE. Evaluation of philips diagnostic ecg interval measurements. In the Abstractbook Computers in Cardiology 2005. Los Alamitos: IEEE Computer Society Press; 2005.

[2] Moody GB, Koch H, Steinhoff U. The physionet/computers in cardiology challenge 2006: Qt interval measurement. In Computers in Cardiology 2005. Los Alamitos: IEEE Computer Society Press; 2006.

[3] Stearns SD. Digitale Verarbeitung analoger Signale. R. Oldenbourg Verlag Mnchen Wien: Oldenbourg, 1991.

[4] Website of the libRASCH project. URL http://www.librasch.org.

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