Automatic Wave Onset and Offset Determination in ECG Signals: Validation with the CSE Database

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Abstract

This paper presents a method to automatically determine the characteristic points (onset and offset) of the P, QRS and T waves in the multi-lead ECG signals from the 15 standard leads. From these points significant clinical parameters are measured, in particular PR interval, PR segment, QRS interval, ST segment and QT interval. The method makes use of the differentiated low-pass filtered ECG signal and information about wave shape. The procedure begins applying a multi-lead QRS detector to recognize beat activity in each lead. After that, waves onset and offset are searched in each lead, and a selection is done to consider those limits from leads where the electrical activity of the heart has longer temporal projection. The method performance has been evaluated with the CSE multi-lead measurement database, comparing our method results with those from other programs and manual measurement. Our method improves the T wave end measures, since it results in much more agreement with the clinical experts that with other programs. Same evaluation has been done with the interval values (error mean and standard deviation), and the results are lower than the tolerances recommended by the CSE experts.

1 Introduction

The Electrocardiographic signal (ECG) is characterized by a recurrent wave sequence (P, Q, R, S, T) related with each beat. Time intervals defined from onset and offset of different waves are significant in electrocardiographic diagnosis. The most important intervals are the RR interval, PR interval, PR segment, QRS interval, ST segment and QT interval. Thus, P, QRS and T waves onset and offset must be determined. Some algorithms have been specifically proposed to estimate QRS onset and offset [1], others have been proposed to estimate QT interval limits [2] or to estimate onset of P and QRS waves and offset of P, QRS and T waves [3,4]. When signal is free of noise, the algorithm have an acceptable performance but it decreases when noise contamination appears. Specially, the T offset point measures present a significant disagreement between the program and the referee measurements because programs give earlier T offset than manual experts [4]. In this paper we present a general method to estimate the onset and offset of P, QRS and T waves in a multi-lead ECG record, that gets a good agreement

between program and manual referee results, even for the T offset point.

This method is based on the multi-lead generalization of a previously related procedure for single-lead measurement of the QT interval [2], and posteriorly used for single-lead onset and offset determination [5]. It makes use of the differentiated ECG signal and information about wave shape. The differentiation process avoids problems with baseline drift given that low frequencies are then attenuated. The system implements criteria to establish wave presence or absence in each lead according to the relative differentiated signal magnitude in the different waves. With the information about wave presence and the differentiated signal, the system estimates regular or inverted P wave, QRS complex pattern as composed of different Q, R, S, R' sequences, and T wave shape (regular, inverted, or bi-phasic) [6]. With the information about waves onset and offset in each lead, a procedure is applied to select the wave limits from those leads where the electrical activity has longer temporal projection.

The method has been applied on ECG records of the MIT-BIH database, and validated with the CSE multi-lead measurement database.

2 Methods

The procedure to determine significant points is composed of several steps: preprocessing, multi-lead QRS detection, fibrillation process rejection, waves location and wave onset and offset determination.

2.1 Preprocessing:

The first step consists of a filtering process for noise reduction and a non linear transformation to improve QRS detection [7]. The linear filtering uses a second order band-pass Lynn filter (0.8-18 Hz) to attenuate baseline drift and high frequency contamination. Once the band-pass filtered signal (ECGPB) is reached a low-pass differentiator is applied to get the information about changes in the signal slope. This differentiated signal is called ECGDER. The non linear transformation we use is the one described in [7].

2.2 Multi-lead QRS detection:

The multi-lead QRS detector used in this work is an adaptation of the single-lead one proposed by Pan and Tompkins [7] considering information of the signal slope. From the ith QRS complex positions of each j lead ($QRS_j(i)$), we only consider as QRS complexes in each lead, those whose positions do not

However, due to noise or errors, wrong detections could have occurred in the determination of some I_j, that may lead to an erroneous final I position. To prevent that, we apply the following procedure: We search the minimum time position (for onsets) or maximum time position (for offsets) I_j positions. If no more than two other leads have their I_j mark in the interval (*min*, *min* + δ) or (*max* - δ, *max*), the *min* or *max* I_j point is rejected as a possible noisy detection. The value of δ is selected according to the usual variability in manual estimations [6] and the empirical practice. Values for δ are 6, 6, 6, 10 and 12 ms for P on, P off, QRS on, QRS off and T off, respectively. After that we consider the wave onsets, offsets as the minimum, maximum of the remaining I_j positions.

3 Results

The single-lead procedure has been applied to different records of the MIT-BIH database. In figure 3 are displayed the results on four different records: record 106 presents a RSR' pattern, record 108 present a QS pattern, record 114 presents a W pattern and record 111 present a R wave with two peaks. In all cases the wave limits are well determined, including wave shape determination. The base line (horizontal line in figure 3) is estimated as the average ECG signal value in the PR segment of each beat, excluding first and last 15 ms in this interval.
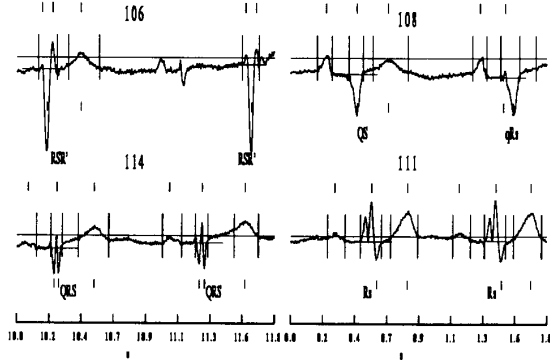

Figure 3: *Results on different ECG patterns.*

The multi-lead procedure has been applied to records of the CSE multi-lead measurements database. Figure 4 shows the results obtained on the MO1_063 record of this database. We may appreciate the improvement of multi-lead detection at the T offset point, that differs largely from leads V_2 and V_3 to the others leads like I or III.

4 Validation with the CSE database

The method to determine onset and offset has been validated with the CSE multi-lead measurement database [9]. The validation has been carried out in terms of the mean (μ) and standard deviation (σ) of the differences between: the mean referee estimates of CSE database (RE_{CSE}) or the mean program estimates of CSE database (PE_{CSE}), and our method estimates (ME) in each measured beat set. In table 1 we have these results together with the accepted tolerance for referee deviations (σ_{ref})

reported in [6]. The value $n°$ refers to the number of available measured beats reported at the CSE database for comparisons (one beat from each CSE multilead ECG records).
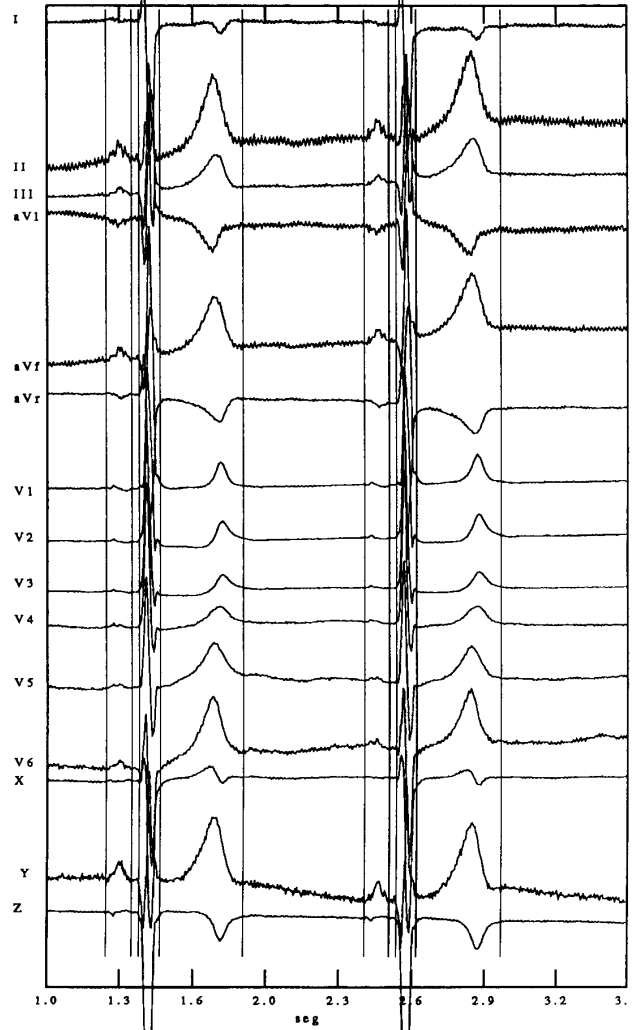

Figure 4: *Multi-lead waves onset and offset determination at the MO1_063 record of the CSE database.*

From this table 1 we see that the proposed method is an unbiased estimate (μ < sampling period = 2 ms) with deviation comparable to that of manual experts and then, for the validation sample, a valid estimate. In case of T offset point, the ME shows much more agreement with the RE_{CSE} (1.8 ms mean difference) than for the PE_{CSE} (9.7 ms mean difference). These results lead us to consider this method more accurate for T offset than the mean program estimates.

We have also validated the method in terms of the signifi-

Table 1. Waves onset and offset validation results.

ME - PE$_{CSE}$					
	P$_{on}$	P$_{off}$	QRS$_{on}$	QRS$_{off}$	T$_{off}$
n°	111	111	121	121	121
μ (ms)	-0.072	0.505	-3.587	0.083	9.700
σ (ms)	5.695	8.310	4.193	7.705	16.467

ME - RE$_{CSE}$					
	P$_{on}$	P$_{off}$	QRS$_{on}$	QRS$_{off}$	T$_{off}$
n°	30	29	30	25	26
μ (ms)	1.000	-1.034	-2.067	-0.160	1.846
σ (ms)	7.926	5.144	7.437	7.893	10.552

Accepted tolerances for referee deviations [6]					
σ_{ref}	10.2	12.7	6.5	11.6	30.6

cant interval values: P duration (P-DUR), PR interval (PR-INT), QRS duration (QRS-DUR) and QT interval (QT-INT). The validation has been done in terms of the mean and standard deviation of the differences between: the intervals measured from the mean referee estimates of CSE database (RE$_{CSE}$) or the intervals measured from the mean program estimates of CSE database (PE$_{CSE}$), and the intervals measured from the method estimates (ME). In table 2 we have these results together with the interval tolerances (μ_{tol} and σ_{tol}) reported in [10]. The value n° refers to the number of available measured beats reported at the CSE database for comparisons.

Table 2. Interval validation results.

ME - PE$_{CSE}$			
	P-DUR	QRS-DUR	PR-INT	QT-INT
n°	111	121	111	121
μ(ms)	0.577	3.802	-3.423	13.133
σ(ms)	10.690	9.050	6.803	16.831

ME - RE$_{CSE}$			
	P-DUR	QRS-DUR	PR-INT	QT-INT
n°	25	23	25	23
μ(ms)	-0.400	3.217	-2.400	4.261
σ(ms)	7.095	9.812	8.679	10.274

Error limit tolerances for programs [10]			
μ_{tol}(ms)	10.0	3.5	4.5	7.0
σ_{tol}(ms)	12.0	8.0	8.0	13.5

From this table we see that the interval measures obtained with the proposed method have mean difference and standard deviation inside the expert tolerance limits.

5 Conclusions

The proposed method to determine wave limits in the ECG has been shown to be robust when noise or baseline drift are present.

It allows the determination of all intervals clinically interesting in ECG records with the accuracy of a human expert. Validation of this method shows higher agreement with the experts in the T offset determination than other programs referenced at the CSE database. The information about the waves shape obtained with this method is very useful for ECG classification and cardiac diagnosis. The interval values, wave amplitudes, patterns of P, QRS and T waves, and wave presence or absence, could be used as inputs to a system that allows automatic cardiac diagnosis from ECG analysis.

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