Automatic Multilead VCG Based Approach for QT Interval Measurement

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Abstract

The precision of QT interval measures depends on the correct location of QRS and T boundaries and also on the analysing lead. The usual automatic strategy to deal with multiple leads is to apply post-processing decision rules for selecting one of the single-lead (SL) measures. We proposed a multilead VCG strategy that locates the onset and the end of the QT interval, attending to an optimal transformed lead according to the spatial characteristics of the VCG. The performance was evaluated over the CSE database considering different VCG systems: corrected Frank system (lead set F), pseudo-orthogonal leads V5, aVF and V2 (M) and the X, Y and Z leads derived by Dower transformation (D). Multilead delineation over F achieved a better results than any single lead by itself or any other lead set, with an error dispersion similar to SL over 12 leads plus decision rules. The multilead approach is validated in the PTB database, in the Physionet/CinC Challenge 2006, with final scores of 27.04, 27.81 and 28.96, over F, M and D, respectively.

1. Introduction

The precision of QT interval measures depends on the correct location of both QRS onset and T wave end. Specially problematic is the delineation of flat boundaries as it is usually the case of T wave end. Furthermore, there are not universally accepted clear rules to locate waves' boundaries, what difficults the systematization of delineation. Automatic methodologies allow to avoid intra/inter-observer variability and therefore, developing accurate and robust methods for ECG automatic delineation is a topic of main interest.

Most automatic delineation systems described in the literature are based on a single ECG lead. The availability of multiple simultaneous ECG leads means that more information is accessible to the automatic systems, which can be used to increase the robustness of delineation. The different spatial orientation of each lead may cause different latencies on the electrical phenomena, making the QT dependent on the analysing lead. Thus considering different view points over the same electrical phenomena, that is different leads, can be crucial to determine the QT value.

When multiple leads are available, some authors proposed as multilead strategy the use of post-processing decision rules to select one of the single-lead measurements [1]. Those rules consist in ordering the SL annotations and selecting as the onset (end) of a wave the first (last) annotation whose k nearest neighbors lay within a δ ms interval. If no SL annotation satisfies the criteria, no mark is provided. Thus, rules can work quite well for choosing among a large set of SL annotations (for instance on a record acquired using the standard 12 lead system) but are not adequate to deal with just 2 or 3 leads.

We proposed a multilead VCG strategy that locates the onset and end of the QT interval, attending to an optimal transformed lead according to the spatial characteristics of VCG representation. A version regarding only T end location has been previously presented [2]. The delineation system constructs a transformed spatial lead obtained from 3 orthogonal leads which is optimized for delineation improvement. The single lead delineation strategy based on the Wavelet Transform (WT) [3] is then applied. The performance is evaluated on the CSE and the PTB databases considering different VCG lead systems: the corrected Frank system (lead set F), pseudo-orthogonal leads V5, aVF and V2 (M) and the X, Y and Z leads derived from the 12-lead using Dower transformation (D). Results were compared with the strategy of [3] over each of the 12 leads plus decision rules (SLR) to obtain the final marks [1]. The multilead delineation strategy was further compared with other methodologies by participating on the Physionet/CinC Challenge 2006 [4].

2. Methods

The multilead VCG delineation system proposed is an extension of the WT based single lead system [3] that has also participated in the Challenge [5]. The WT provides a description of the signal in the time-scale domain, allowing the representation of the temporal features at different resolutions, according to their frequency content. Thus, regarding the purpose of locating different waves with typical frequency characteristics, the WT is a suitable tool for ECG automatic delineation.

The theoretical basis for using a 3-lead system is the dipole hypothesis, stating that the electrical activity of the heart can be approximated by a time-variant electrical dipole (the electrical hear vector - EHV). According to this hypothesis, any hypothetical lead can be synthesized by an adequate projection of the EHV. Using the WT of the orthogonal leads at a scale $a = 2^m|_{m \in N}$ it is defined the loop $\mathbf{L}^m(k) = [W^X_{2^m}(k), W^Y_{2^m}(k), W^Z_{2^m}(k)]^T$. As a consequence of the prototype wavelet used [3], the WT 3D loop $\mathbf{L}^m(k)$, $k \in I$, is proportional to the smoothed ECG derivative and describes the EHV evolution in a time window I. Moreover, $\mathbf{U}$, the director of the best line fit to the points in $\mathbf{L}^m(k)$, is the main direction of EHV in I. A derived wavelet signal $D(k)$, corresponding to the ECG lead $E(k)$ along the axis defined by $\mathbf{U}$, can be constructed by projecting the loop points over the direction of $\mathbf{U}$. The projected WT signal on the optimal lead direction, chosen as the one closely parallel to the EHV on the wave's boundary neighborhood, is well suited for its delineation since it will present the higher projected derivative magnitude.

The strategy proposed for multilead delineation consists in a multi-step iterative search for a better spatial lead for delineation improvement, using WT VCG loops. It is adapted and applied separately for each boundary, as illustrated in Figures (1) and (2) for QRS onset and T end, respectively. A new derived lead $Dg_n(k)$ is constructed in each step g for each beat n, using a direction $\mathbf{U}g_n$ determined in an adequate time interval Ig_n and WT scale, according to the specific boundary characteristics. The window Ig_n is updated at each step, according to the obtained limits, to increase SNR and insure the steepest slopes in $Dg_n(k)$. Thus, $Dg_n(k)$ is well suited for QT boundaries detection and its delineation is then performed using the threshold based criteria of the single lead delineator [3].

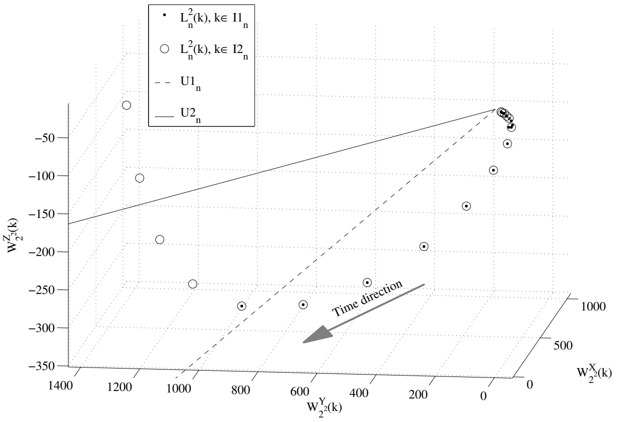
3. Performance evaluation

The multilead delineation system was evaluated considering three different VCG lead systems: the corrected Frank system (lead set F), pseudo-orthogonal leads V5, aVF and V2 (M) and the X, Y and Z leads derived from the 12-lead using Dower transformation (D). The leads for lead set M were chosen by their resemblance with the Frank leads. Nevertheless, this subset does not take into account the human torso's geometry. To include the needed corrections one should consider the lead set D.

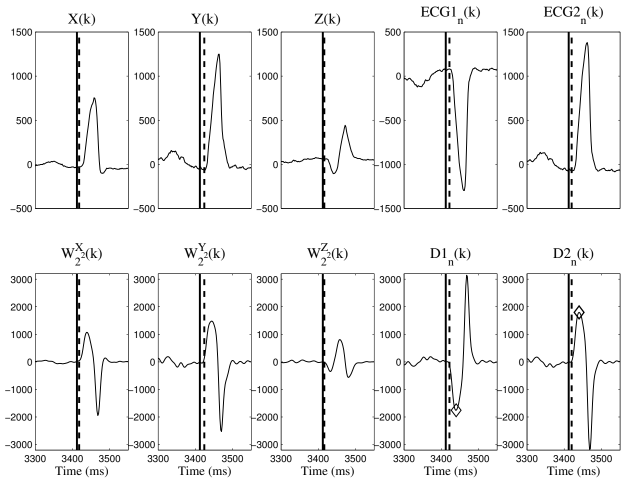
The **CSE database** [6] includes files of 10 sec with a total of 15 leads (12 standard and 3 orthogonal Frank leads), at 500 Hz sampling rate. It provides *median referee* annotations (after outlier rejection) from 5 cardiologists for a limited number of 42 beats. Taking the error (ε) as the automatically detected boundary minus the respective *referee mark*, its mean (m_ε) and standard deviation (s_ε) were evaluated across files. Extreme cases were excluded from the analysis. A file was considered as an extreme case if the corresponding error value ε_i does not satisfy

$$m_\varepsilon - 3s_\varepsilon \leq \varepsilon_i \leq m_\varepsilon + 3s_\varepsilon. \tag{1}$$

The values of the mean and standard deviation were actualized after the exclusion of such files, and the process was repeated until all files satisfy equation (1).

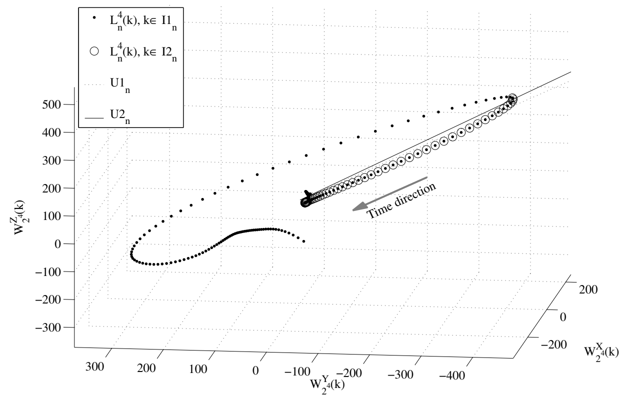


(a)WT VCG loops used for multilead QRS onset location: $\mathbf{U1}_n$ (dashed line) is the best line fit to the loop in $I1_n$ (dots) and $\mathbf{U2}_n$ (solid line) is the best line fit to the loop in $I2_n$ (circles).

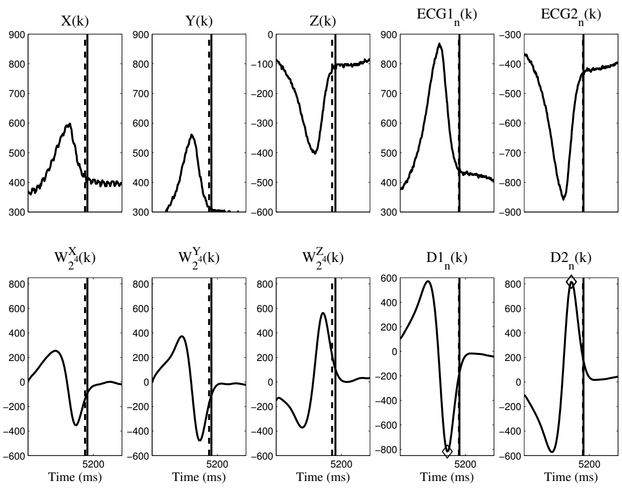


(b)ECG in orthogonal leads ($X(k)$, $Y(k)$, $Z(k)$), the correspondent WT signals ($W^X_{2^2}(k)$, $W^Y_{2^2}(k)$, $W^Z_{2^2}(k)$) and the new derived signals $D1_n(k)$ and $Dg_n(k)$ following the directions of vectors $\mathbf{U1}_n$ and $\mathbf{U}g_n$. Vertical dashed line stands for the QRS onset mark found in the respective lead; solid line stands for manual based QRS onset mark.

Figure 1. Multilead delineation of the QRS onset: **Step 1** (initial) and **Step g=2** (final step)



(a)WT VCG loops used for multilead T end location:: $\mathbf{U1}_n$ (dashed line) is the best line fit to the loop in $I1_n$ (dots) and $\mathbf{U2}_n$ (solid line) is the best line fit to the loop in $I2_n$ (circles).



(b)ECG in orthogonal leads ($X(k)$, $Y(k)$, $Z(k)$), the correspondent WT signals ($W_{2^2}^{X}(k)$, $W_{2^2}^{Y}(k)$, $W_{2^2}^{Z}(k)$) and the new derived signals $D1_n(k)$ and $Dg_n(k)$ following the directions of vectors $\mathbf{U1}_n$ and $\mathbf{U}g_n$ ($k \in t1_n$). Vertical dashed line stands for the T end mark found in the respective lead; solid line stands for manual based reference mark.

Figure 2. Multilead delineation of the T end: **Step 1** (initial) and **Step g=2** (final step)

In Figure 3 are presented the values $m_\varepsilon \pm s_\varepsilon$ found in CSE database files for each boundary and after excluding the extreme cases (# files considered in each case) considering: multilead delineation over each lead set, SL using [3] over each available lead or using post-processing rules ($k = 3$ and $\delta = 12$ ms) over the 12 SL marks (SLR). In Table 1, together with the multilead delineation errors, is presented the resulting error on the QT length measure. For the sake of comparison, only files that were no extreme in all approaches were considered (22 files).

The best performance is achieved by multilead delineation over lead set F, presenting less error bias and dispersion than over the other lead sets, and than SL over any lead by itself. The error dispersion of multilead over lead set F was similar to the obtained by SLR, in spite of a much higher bias. Multilead delineation over lead sets M or D perform worse that SL over lead X, but similar to the best of all the other SL results. They present higher bias and dispersion than lead set F or SLR, with lead set performing slightly better than M, on QT length.

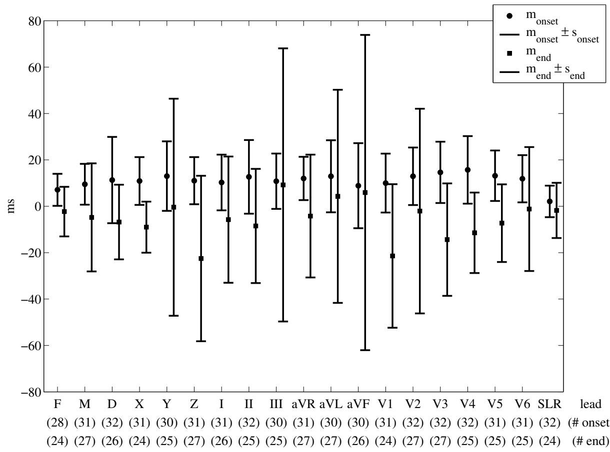


Figure 3. Multilead delineation over each VCG system versus SL over each of the 15 leads available in the CSE database and SLR. Extreme cases excluded separately for each approach and boundary (# files considered in each case)

The multilead approach proposed was also validated in the **PTB database** PTB database, in the context of the Physionet/CinC Challenge 2006 [4]. This database consists in a set of 549 files of more than 30 sec, with 15 leads (the 12 standard and the 3 orthogonal Frank leads), at 1000 Hz sampling rate. No reference annotations were initially provided, but a dataset of manually annotated QRS onset and T wave end marks on this files was recently published [7]. Also, the median of the entries submitted to the Challenge in Division 1 (manual or semiautomatic) were provided by the end of it. The details about Challenge goals and rules are described else here in this volume [5]. Briefly the participants were asked to, according to lead II, choose on each file the first representative, non ectopic and not noisy beat and locate the QRS onset set and T wave end.

lead set	QT onset	QT end	QT length
F	6.5 ± 6.4	-1.8 ± 11.0	-8.3 ± 12.7
M	6.9 ± 6.5	-7.7 ± 19.5	-14.6 ± 20.4
D	6.1 ± 14.3	-6.3 ± 12.1	-12.6 ± 19.5
SLR	0.2 ± 4.5	-0.4 ± 11.3	-0.5 ± 13.4

Table 1. Performance of multilead delineation over the VCG systems (F, M or D) on CSE database versus single lead with post-processing rules (SLR): $m \pm s$, ms Extreme cases in one approach excluded from all approaches.

	reference [4]	reference [7]	
			common beats
#	532	532	188
F	-10.4 ± 24.8	-12.9 ± 25.8	-11.3 ± 18.3
M	-7.1 ± 27.6	-9.5 ± 28.3	-7.6 ± 23.6
D	-10.0 ± 25.8	-12.4 ± 26.7	-8.6 ± 26.4
SLR	-22.5 ± 25.5	-24.9 ± 26.4	-22.5 ± 22.0

Table 2. QT length errors (ms) considering multilead delineation over the VCG systems (F, M or D) on PTB database: reference marks obtained as median manual marks of the challenge or median manual marks of [7].

The requirement of using lead II has no meaning in a multilead based approach. Instead we considered the three VCG systems and submit them as different approaches in Division 2 of the Challenge. The first beat for which the system was able to locate both QRS onset and T end, defining and following a normal RR interval is annotated. Results on lead set F constitute the official entry with a final score of 27.04. Other two non-official entries corresponding lead sets M and D were also submitted, with final scores of 27.81 and 28.96, respectively.

The errors in the QT length measures on the selected beats were also calculated taking as reference the median marks submitted in Division 1 of the challenge [4] and the manual marks of [7]. Results are presented in Table 2. The files for which no normal, following a normal, beat, with no important noise contamination was found in one of the approaches (F, M, D or SLR) were excluded from all approaches. Multilead over lead sets F and D present lower error bias and similar dispersion compared to SLR, while lead set M has lower bias but higher dispersion.

As only the selected beats are annotated, there is no guarantee than the same beat is being considered by the automatic approaches and reference. In the last column of Table 2 are the results considering only the cases for which the same beat was annotated (common beats), considering the reference in [7], for which beat information exists. For the median manual marks of the challenge no information is available about the chosen beat. Considering exactly the same beats the higher performance of the multilead using lead set F becomes quite notorious.

4. Conclusions

The automatic delineation system proposed allows to deal with multiple leads and takes advantage of their availability. Multilead delineation over recorded Frank leads presents better performance than single lead delineation of any lead by itself. Thus, it has advantages over any possible choice of a particular lead. This approach clearly outperforms single lead over 12 leads plus decision rules in the PTB database, both in error bias and dispersion. One should note that the reference marks are with respect to lead II only and thus some of the bias can be due to the lead used. The higher error bias found in the CSE database should be further explored and corrected, possibly by changing the threshold based criteria. Multilead delineation over leads derived using Dower matrix performs worse than over Frank leads, but still with acceptable results. Multilead delineation over lead set D is then an alternative in the case of unavailability of recorded Frank leads.

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