A Principal Component Regression Approach For Estimating Ventricular Repolarization Duration Variability

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Abstract. Ventricular repolarization duration (VRD) is controlled by neural regulatory system same way as heart rate and, thus, also VRD varies in time. Traditionally, VRD variability is assessed by determining the time differences between successive R and T-waves. In this paper, a new algorithm for quantifying VRD variability is presented. The algorithm is based on principal component regression and it does not necessitate T-wave detection. The method is tested with real ECG measurements and the results are compared with traditional VRD estimation methods.

1 Introduction

Ventricular repolarization duration (VRD) can be measured from the ECG recording as the time interval between the onset of Q-wave and offset of T-wave, i.e. QT interval. VRD is controlled by neural regulatory system same way as heart rate (HR) and, thus, also QT interval duration varies in time. It has been argued that abnormal QT variability could be a marker for a group of severe cardiac diseases such as ventricular arrhythmias [1]. In addition, it has been argued that QT variability could yield such additional information which can not be observed from HR variability [2]. Due to the difficulty in fixing automatically the Q-wave onset in VRD determination, RT interval is typically used instead [3, 4]. The RT interval can be defined as the interval from R-wave maximum to either T-wave offset ($\mathrm{RT}_{\mathrm{end}}$) or T-wave maximum ($\mathrm{RT}_{\mathrm{apex}}$). The T-wave maximum is naturally easier to fix automatically [5, 6] and, in addition, the VRD dependency on HR has been shown to be concentrated in the early portion of QT (ending at the maximum of T-wave) [7]. Thus, $\mathrm{RT}_{\mathrm{apex}}$ is often preferred in VRD variability studies, although the variability of the T-wave downslope could yield important physiological information [8].

We have recently proposed a robust method for quantifying the variation in the RT interval [9]. The method is based on principal component regression (PCR) and it does not necessitate the detection of T-wave. In this paper the proposed method is further developed and tested with real ECG measurements. The results are compared with the traditional RT interval measures.

2 Methods

First, the R-waves of the ECG recording are detected and the T-wave epochs are extracted according to Fig 1. The time window used for T-wave epoch extraction was 0.1-0.4 seconds as for R-wave maximum. In PCR, each of these epochs is presented as a weighted sum of orthogonal basis vectors, where the basis vectors are obtained as the eigenvectors of the correlation matrix of the epochs. That is, the j'th T-wave epoch denoted with a length N column vector $z_j = (z_j(1), z_j(2), \ldots, z_j(N))^T$ is presented as a linear combination

$$z_j = H\theta_j + e_j \tag{1}$$

where $H = (v_1, v_2, \ldots, v_K)$ is a $N \times K$ matrix consisting of the first K eigenvectors, θ_j is a $K \times 1$ column vector of weights (i.e. principal components) related to j'th epoch, and e_j is error term. The eigenvectors are now orthonormal and, thus, the ordinary least squares solution for the PCs θ_j yields

$$\hat{\theta}_j = H^T z_j. \tag{2}$$

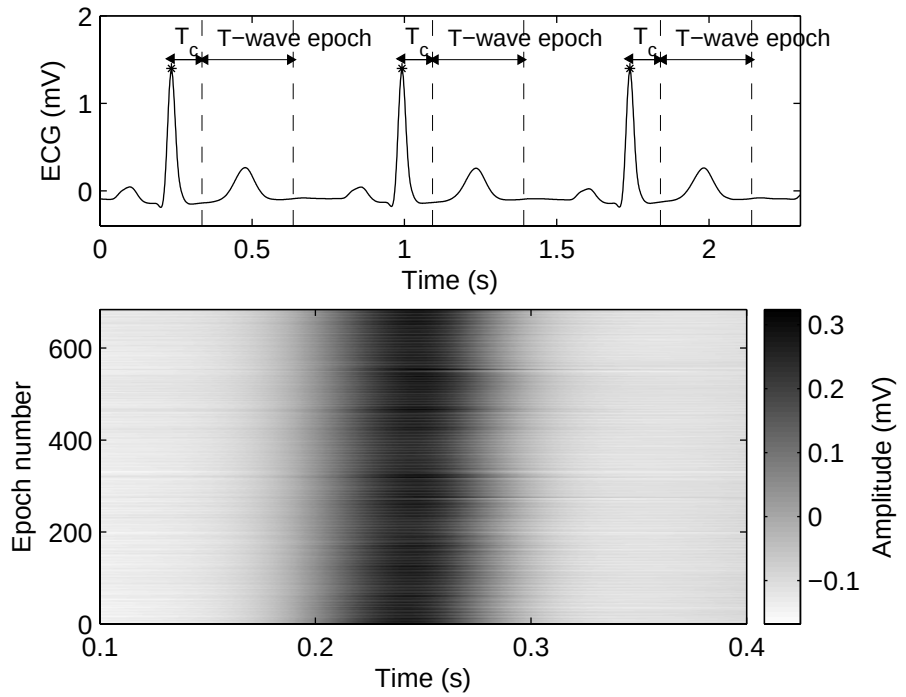

Fig. 1: Extraction of T-wave epochs from the ECG recording.

Quantitatively the first eigenvector is the best mean square fit of a single waveform to the entire set of epochs. Thus, the first eigenvector is often similar to the mean of the epochs. The second eigenvector, on the other hand, covers mainly the variation in the T-wave times and is expected to resemble the derivative of the T-wave. The model parameters corresponding to second eigenvector (i.e. the second PCs) are thus expected to reflect the variability of the time difference between the R- and T-waves (RT interval).

3 Results

The proposed method was tested with an ECG recording measured from a healthy young male subject in relaxed conditions. The sampling rate of the ECG was 1000 Hz and the recording was band-pass filtered to enable unambiguous detection of traditional RT interval measures. Both $\mathrm{RT}_{\mathrm{apex}}$ and $\mathrm{RT}_{\mathrm{end}}$ measures were calculated. The $\mathrm{RT}_{\mathrm{end}}$ measure was determined by using the threshold technique where the threshold was set to 10 % of the T-wave maximum amplitude. The $\mathrm{RT}_{\mathrm{apex}}$ and $\mathrm{RT}_{\mathrm{end}}$ time series were then compared in frequency-domain with the second PCs by calculating the spectrum estimates with the Welch's periodogram method. The results are shown in Fig. 2.

4 Discussion

As can be seen from Fig. 2, the second PC captures authentically the frequency content of RT interval variability. Also the absolute RT interval values can be estimated from the PCs by evaluating the degree of time shift of the T-wave corresponding to specific PC values.

5 Conclusions

A robust method for extracting the RT interval variability has been developed. The method does not necessitate T-wave detection. Thus, the method is expected to give reliable results even in high signal-to-noise ratio conditions when traditional methods, based on the detection of T-wave maximum or offset, may fail.

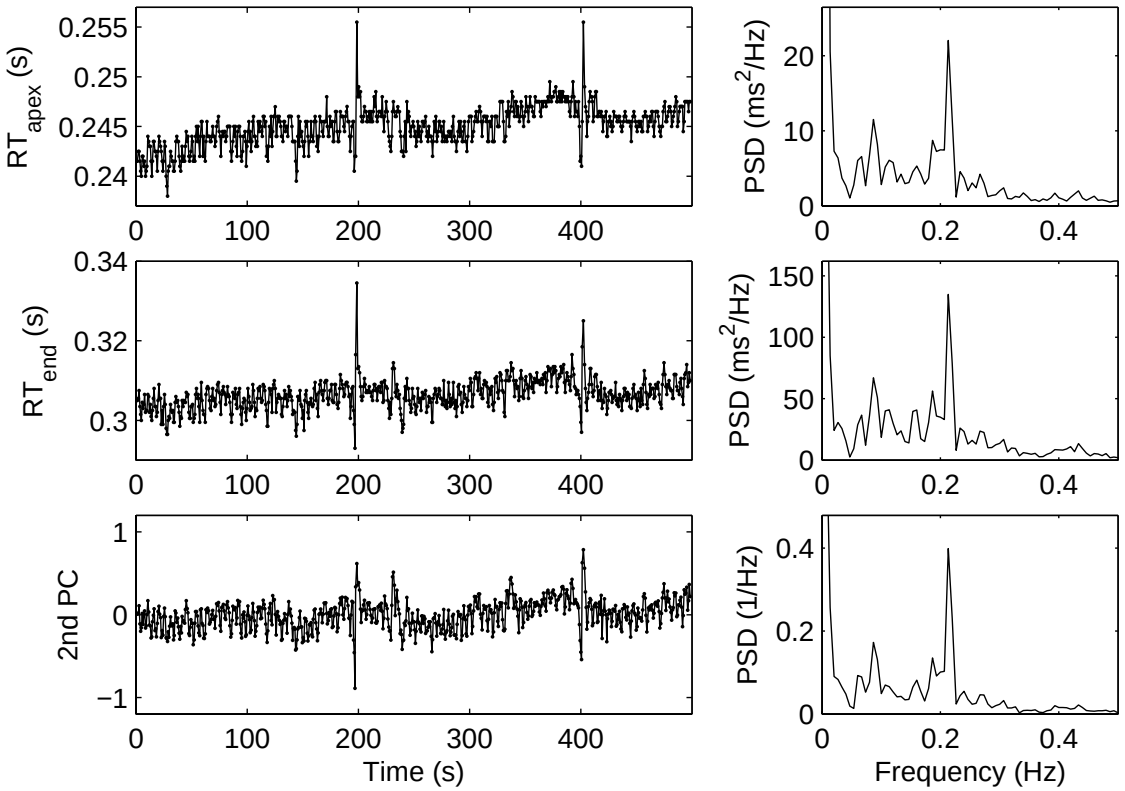

Fig. 2: $\mathrm{RT_{apex}}$, $\mathrm{RT_{end}}$, and second PCs (left column) and the corresponding power spectrum estimates (right column).

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