PRINCIPAL COMPONENT REGRESSION APPROACH FOR QT VARIABILITY ESTIMATION

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Abstract

QT interval within an electrocardiogram (ECG) presents a measure for ventricular repolarization duration. In this paper, a new algorithm for quantifying the variation in the QT interval is presented. The algorithm is based on principal component regression and it does not necessitate the detection of T wave.

Introduction

- QT interval is controlled by neural regulatory system same way as heart rate (HR) and there is variation in the duration of the QT intervals same way than the HR varies during time [1, 2].
- Abnormal variation in the repolarization duration could be a marker for a group of severe cardiac diseases such as ventricular arrhythmias [3].
- QT variability could yield such additional information which can not be observed from HR variability [4].
- We have developed a robust method for quantifying the variation in the QT interval. The method is based on Principal Component Regression (PCR) and it does not necessitate the detection of T wave. The variation of the QT interval is seen to modify the shape of the eigenvectors of the autocorrelation matrix of an ensemble of data. It is further shown how these eigenvectors can be used in the estimation of each individual QT interval duration.

Methods

In the principal component regression, the vector containing the measured signal is presented as a weighted sum of orthogonal basis vectors.

- The ECG measurement is first divided into epochs such that each epoch includes one QRS complex and the following T wave. The epochs are fixed according to the fiducial points of the QRS complexes. Let us denote the t'th such ECG epoch with a length N column vector

$$z_t = (z_t(1), z_t(2), \ldots, z_t(N))^T .$$

- As an observation model we use the so-called additive noise model

$$z_t = s_t + e_t$$

  where s_t is the noiseless ECG signal corresponding to t'th epoch and e_t is additive measurement noise.
- If we have M such epochs, the response signals s_t will span a vector space $\mathcal{S}$, which will be at most of min$\{M, N\}$ dimensions. In the case that the ECG epochs are rather similar, the dimension of the vector space $\mathcal{S}$ will be $K \le \min\{M, N\}$ and epochs can be well approximated with some lower dimensional subspace of $\mathcal{S}$. Thus, each epoch can be expressed as linear combination

$$z_t = H_{\mathcal{S}}\theta_t + e_t$$

  where $H_{\mathcal{S}} = (\psi_1, \psi_2, \ldots, \psi_K)$ is a $N \times K$ matrix of basis vectors which span the K dimensional subspace of $\mathcal{S}$ and $\theta_t \in \mathbb{R}^K$ is a column vector of weights related to t'th epoch.
- The critical point in the use of the above model is the selection of basis vectors ψ_k. In PCR the basis vectors are selected to be the eigenvectors v_k of either the data covariance or correlation matrix [5, 6]. Here, the correlation matrix is utilized.
- The eigenvectors of the correlation matrix are orthonormal and, therefore, the ordinary least squares solution for the parameters θ becomes

$$\hat{\theta}_t^{\mathrm{PC}} = (H_{\mathcal{S}}^T H_{\mathcal{S}})^{-1} H_{\mathcal{S}}^T z_t = H_{\mathcal{S}}^T z_t .$$

- Quantitatively the first basis vector is the best mean square fit of a single waveform to the entire set of epochs. Thus, the first eigenvector is similar to the mean of the epochs and the corresponding parameter estimates or principal components (PCs) $\hat{\theta}_t(1)$ reveal the contribution of the first eigenvector to each epoch ($t = 1, \ldots, M$).
- The second and third eigenvectors, on the other hand, cover the time variations in the QRS complex and T wave times. Thus, either the second or third eigenvector is expected to resemble the derivative of the T wave and the corresponding PCs to reflect the variability of the time difference between the QRS complex and the T wave. These PCs are taken as estimates of QT variability.

Results

- The proposed method was tested with a high-speed ECG recording (sampling frequency 20 kHz, band-pass filter 1–30 Hz) measured from a healthy young male in relaxed conditions.
- The RT intervals were extracted for each consecutive beat as the time difference between the T and R wave maximums. The obtained values are here considered as the "true" RT intervals and the whole interval series is presented on Fig. 1.

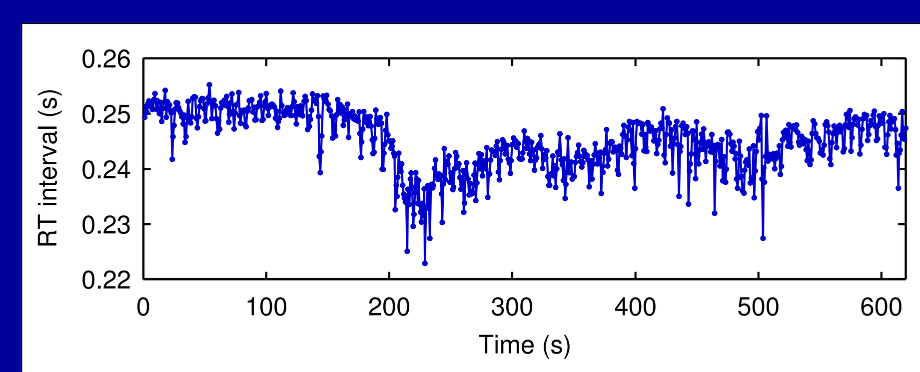

Fig. 1. RT intervals extracted from the original high speed recording.

- The ECG recording was then downsampled to 500 Hz and the RT segments were extracted as shown on top of Fig. 2.
- Each epoch was then normalized to unit norm. This diminishes the influence of ECG amplitude level changes on the PCR and, thus, PCR becomes more sensitive to the waveshapes of the epochs which is desirable here.

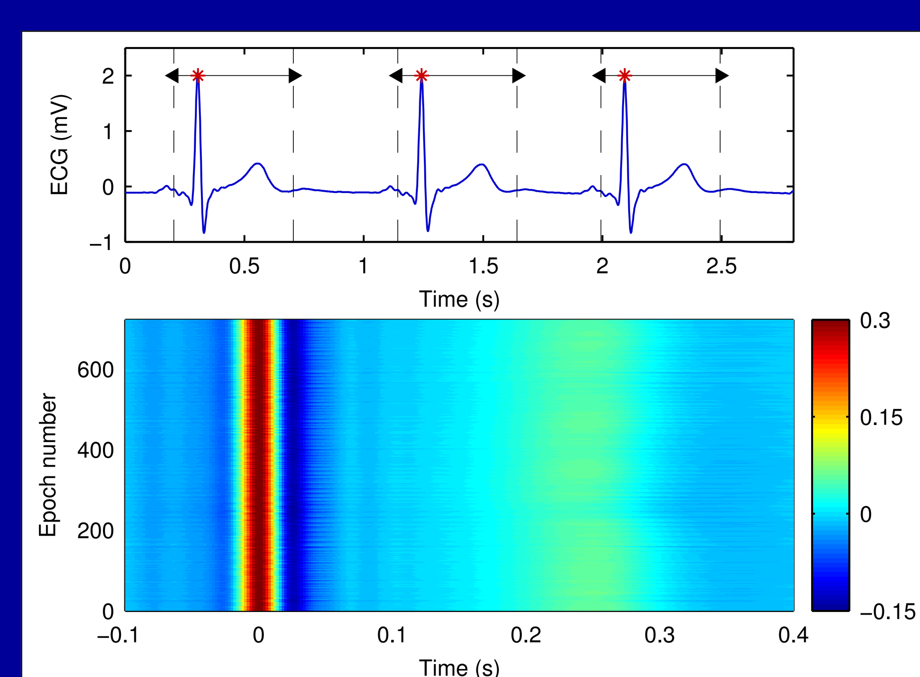

Fig. 2. ECG epochs obtained using windowing (top) and the extracted normalized segments as an image (bottom).

- PCR was then performed for the normalized ECG epochs. The first three eigenvectors of the data correlation matrix are shown in Fig. 3.
- The first eigenvector is clearly similar to the mean of the epochs and the third eigenvector seems to model the time variation of the T wave.

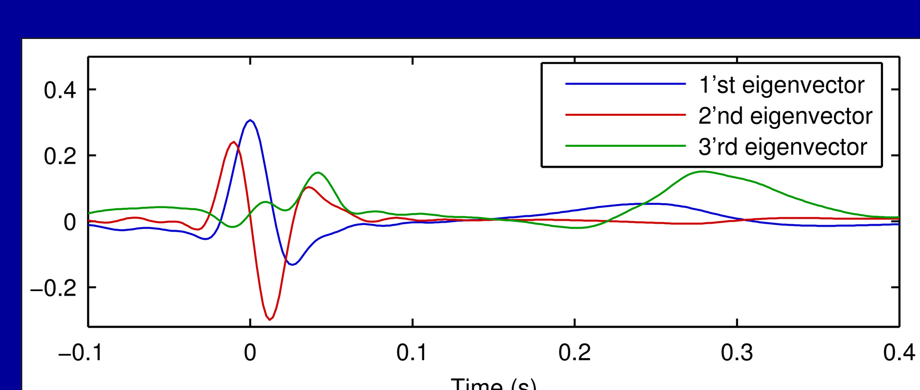

Fig. 3. Eigenvectors of the data correlation matrix corresponding the three largest eigenvalues $\lambda_1 = 0.9938$, $\lambda_2 = 0.0028$, and $\lambda_3 = 0.0019$.

- The modelling of the time variation of the T wave is demonstrated in Fig. 4, where the first and the third eigenvectors are shown in different scale.
- The peak of the first eigenvector corresponds to the mean occurrence time of the T waves and the superposition with the third eigenvector moves the peak as shown in Fig. 4 (b).
- If the weight related to the third eigenvector is positive, the peak is moved to the right. Correspondingly, a negative weight moves the peak to the left.
- These two eigenvectors are thus capable to model the variation in T wave occurrence time. The shape and width of the waveform in the 3'rd eigenvector itself would serve as measures of variation of the QT interval.
- When the eigenvectors are used as basis vectors in linear fitting of the measurements, the variation of the duration of each individual QT interval should be seen in the variation of the parameter corresponding to the 3'rd eigenvector.
- This is clearly observed from Fig. 5, where the parameters (or principal components) corresponding to first three eigenvectors are shown.
- The variation in the third principal components is clearly similar to the true QT-intervals. The actual QT interval times (or RT interval in this case) can be further estimated if necessary.

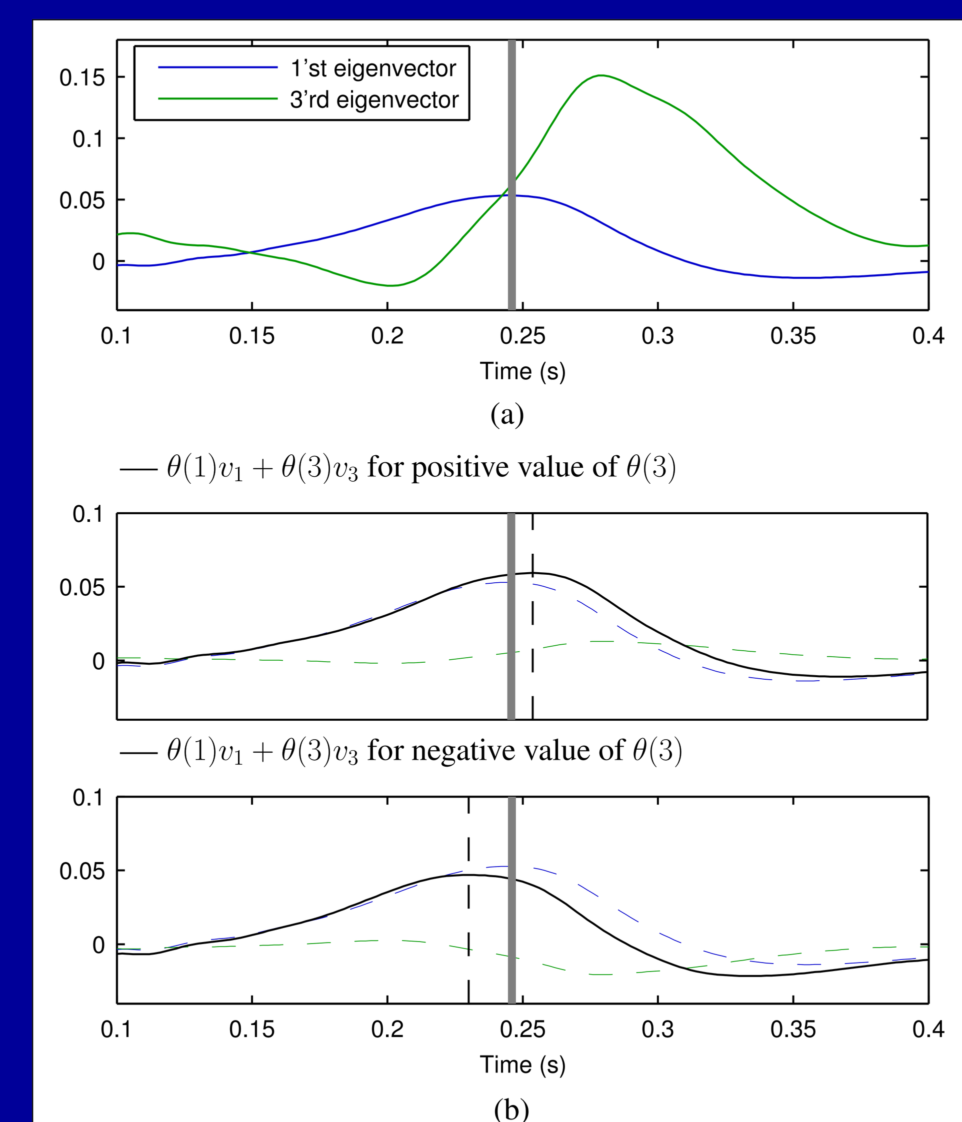

Fig. 4. The superposition of the first and third eigenvectors with different weights. (a) The first and third eigenvectors and (b) the superposition of these eigenvectors for weights $\theta(1) = 0.993$ and $\theta(3) = 0.087$ (top) and for weights $\theta(1) = 0.990$ and $\theta(3) = -0.136$ (bottom). The peak positions of the resulting superpositions are indicated with dashed vertical lines and the peak position of the first eigenvector itself with vertical gray line.

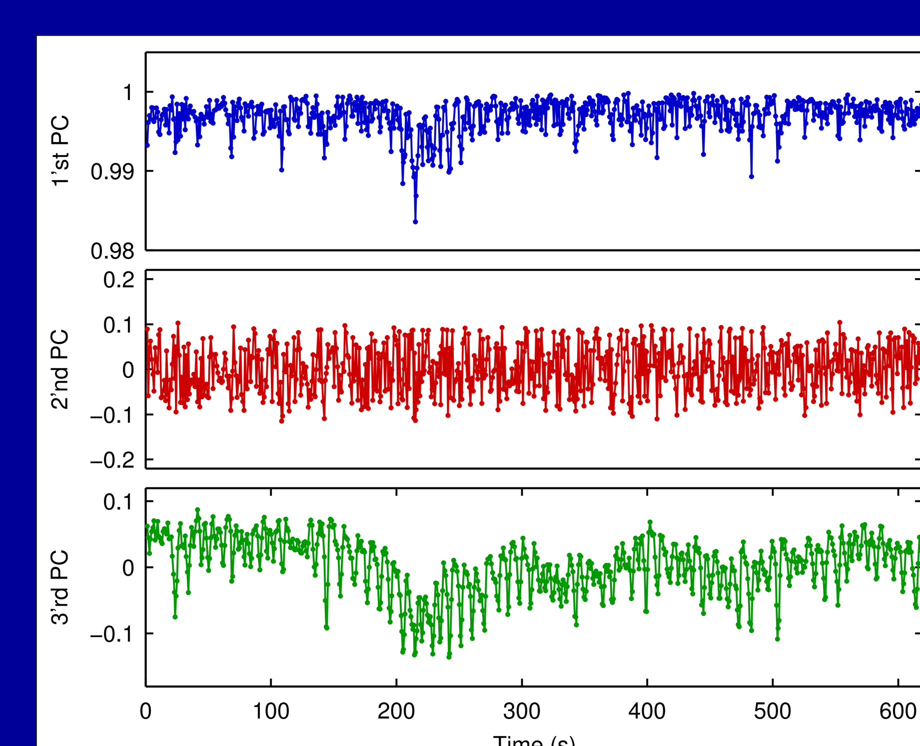

Fig. 5. Principal components corresponding the first, second, and third eigenvector (top, middle, and bottom, respectively).

Conclusions

- A PCR based method for estimating ventricular repolarization duration variability was presented.
- The main advantage of the presented method is that it does not necessitate detection of T waves. This is especially advantageous in situations when the signal-to-noise ratio of the ECG is relatively low.

References

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