Detecting and Quantifying T-Wave Alternans Using the Correlation Method and Comparison with the FFT-Based Method

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Abstract

In this study, we have introduced an open-source program that can be used for the detection and analysis of different waves in the ECG signal. The effect of noise is first reduced by applying an adaptive least-squares method to the signal using a sliding window. The maximums and minimums of the signal are determined, and the R-waves are then detected using a signal-slope test. Waves located between two consequent R-waves, are next classified based on their distance from the left R-wave. Then, using the hypothesis test the detected signal is divided into five equal segments from its peak to the base line. The presented program is capable of computing the arc length of each segment, calculating correlation coefficients and also performing other non-parametric tests. Correlation and FFT-based methods were finally applied to the TWA database of the CinC 2008 challenge and the results are represented.

1. Introduction

The detection of T-wave alternans (TWA) in surface ECG signals has been recognized as a marker of vulnerability to cardiac instability, and is hypothesized to be related with patients at increased risk for malignant ventricular arrhythmias.

Unfortunately, because of the body motion observable during the exercise and an increasing tidal volume due to the effort, it exists a large modulation of the ECG signal added to a baseline wander larger than during resting conditions. ECG amplitude modulation and the baseline are also present in classical TWA records. It exists very few studies linking the TWA analysis performance to these sources of artifacts [1]. A selection of best ECG leads to get the significant TWA was aimed in another study [2]. A group of 16 patients with implantable cardioverter defibrillator (ICD) was examined in their work. A new method for detecting TWA was proposed in another study [3] based on 3-channel Holter ECG recordings. The presented method, based on spectral analysis of each signal lead, enabled low amplitude alternans detection at the microvolt level. However, the method required a controlled test environment where the mean heart rate was artificially increased.

Among all ECG components, QRS complex is the most significant feature. Entropy based method for the detection of QRS complexes (cardiac beat) in the single lead Electrocardiogram (ECG) was proposed in another paper [4]. Digital filtering techniques were used to remove noise and base line wander in the ECG signal. Entropy criterion was used to enhance the QRS complexes. Support Vector Machine (SVM) was used as a classifier to delineate QRS and nonQRS regions.

T-wave features suitable for automatic T-wave alternans detection in low signal-to-noise ratio electrocardiograms were explored in [5] using a correlation-to-template-based algorithm for detecting T-waves of variable duration. Amplitude and area features of T waves were found to be notably less sensitive to template selection than are duration features. T wave alternans features and measures which could be determined more stably provide better classification accuracy of patients with and without coronary artery lesions.

In another study, a Generalized Likelihood Ratio Test (GLRT) approach was analyzed to TWA detection [6]. They used several noise models considering Gaussian and Loplacian distributions as well as three stationarity degrees.

An evaluation study of a method for detecting ST-T complex alternans based on the Complex Demodulation approach (CD) was presented in another paper [7], and its application to the European STT Database was demonstrated.

They determined the ability of their correlation method [8] to identify TWA in ECGs sampled at lower frequencies. TWA was identified in long-QT-syndrome patients, whose ECGs were originally acquired at 1000 sps and then re-sampled at 100, 250, 500, and 750 sps. They found that TWA can be effectively detected with the CM using sampling fiequencies as low as 250 sps.

In another study, a new correlation method (CM) was developed for TWA detection [9], and the ability of CM's to detect non-stationary TWA was tested in comparison with accepted spectral method (SM).

2. Methods

The denoising algorithm of the presented program is robust to the noise effects and base-line wander. The signal-to-noise ratio of this algorithm is mostly close to the absolute value of the signal to the noise. The general algorithm of this program is illustrated in Figure 1. Using this method, different waves in the ECG signal are detected and then divided into five segments. (Figure 2). For each of the segments, the program is able to calculate the surface area, arc length, derivative function, and other statistical estimations such as correlation coefficient, correlation function, and non-parametric tests. The results are restored in an envelope for each of the segments. (Figure 3) This program can also be applied to signals of low signal-to-noise ratio, as well as signals with base-line wander that have a fast-moving behavior.

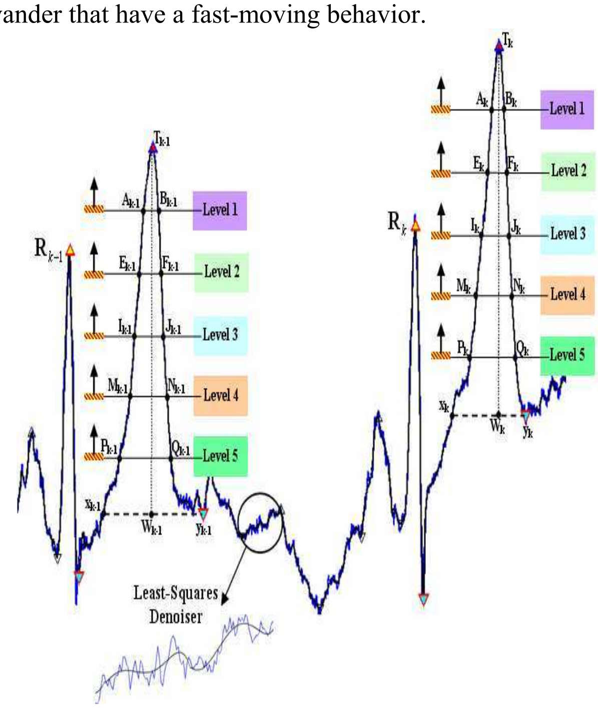

Figure 2. Multi level detection of T-Wave and Least-Squares denoiser effect.

Correlation Method (CM)

In this method, each consecutive T-wave (Tm) is compared to the median T-wave (Tmdn) computed from all T-waves contained in the rows of the Amxn data matrix. For every beat the Alternans Correlation Index (ACI) is calculated.

$$ACLI_m = \frac{\sum_{n=1}^{N} T_m(n) T_{mdn}(n)}{\sum_{n=1}^{N} [T_{mdn}(n)]^2} \tag{1}$$

where Tm – the m-th T-wave vector, Tmdn – median T-wave vector, n – sample number. Equation 1 contains the cross-correlation between Tm and Tmdn in the nominator and the auto correlation of T_{mdn} in the denominator. The ACIm value greater than 1 indicates that T_m is „larger" then T_{mdn}, while the ACI_m value smaller than 1 indicates that T_m is „smaller" then T_{mdn}. Thus, ACI_m can measure morphological changes of each of the consecutive Tm waves in comparison to T_{mdn}.

The T-wave alternans occurs, when ACI value fluctuates around 1 for at least seven successive heart beats. The correlation method can deliver the information about the amplitude and the temporal location of the alternans episode in the ECG signal.

FFT- based method (FFTM)

In the FFT-based method, power spectrum for each sample point (columns of Amxn matrix) of 128 time-aligned T-waves is calculated by squaring the magnitude of the fast Fourier transform. The cumulative power spectrum is estimated by summing the power spectra obtained for each sample point. In the cumulative spectrum, the beat-tobeat fluctuation of the T wave amplitude appears as the spectral peak at the frequency of 0.5 cycles per beat; hence, the magnitude of this peak is a direct marker of the alternans. From the cumulative spectrum alternans ratio (AR) can be obtained:

$$AR = \frac{P_{0.5} - noise}{\sigma_{noise}} \tag{2}$$

Where, P0.5 -amplitude of the spectral peak at the frequency 0.5 cycles per beat; noise, σnoise - mean level and standard deviation of the noise registered in the spectrum in the predefined window located outside the alternans frequency (0.5 cycles per beat). According to Rosenbaum et al. (2), a patient is classified as an alternans positive" if the alternans ratio (AR) exceeds 2.5. The FFT-based detector enables the registration of the Alternans along the T-wave by analysis of the power spectrum for each sample point. The disadvantage of this method is assessment of the alternans signal as a stationary sine wave with constant amplitude and phase, which is not true in general.

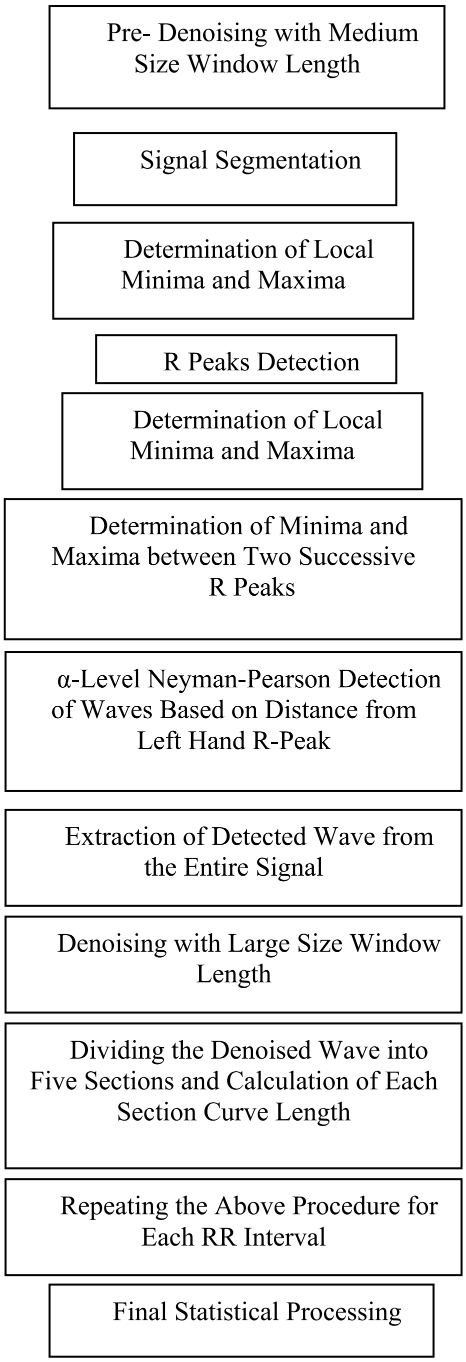

Figure 1. The Architecture of waveform detector program

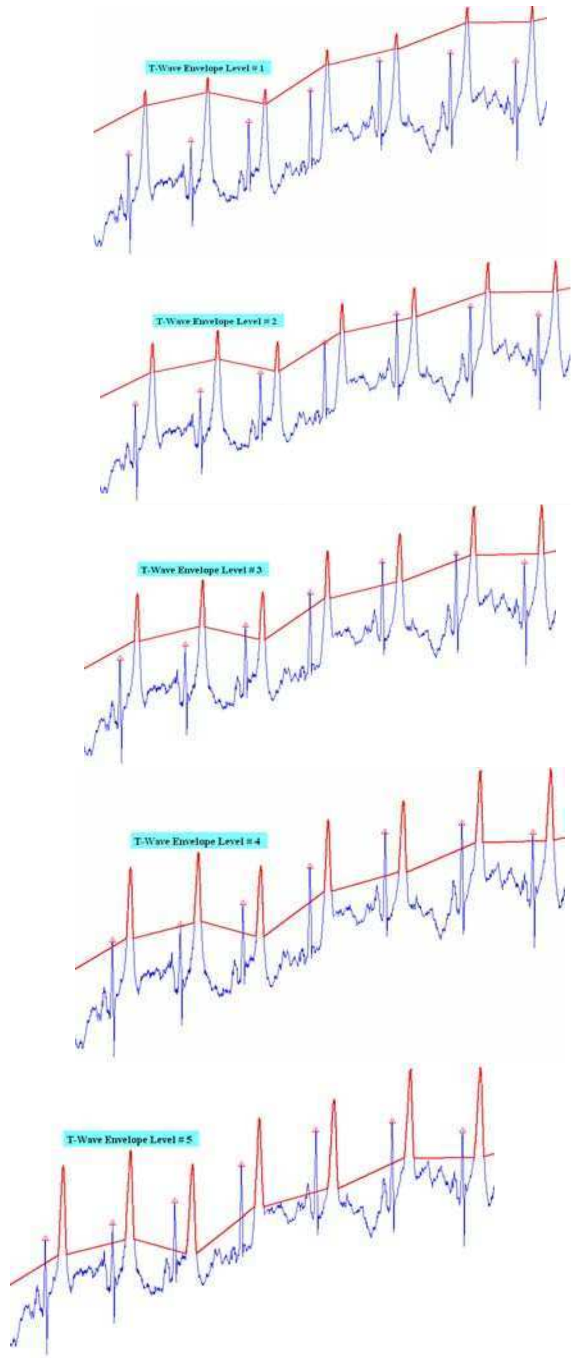

Figure 3. An example of the Multilevel T-wave enveloping

3. Results

We evaluated the method on CinC/PhysioNet Challenge 2008 database. The results obtained are depicted for two of the data in Figure 4.

4. Discussion and conclusions

The results disclose the effectiveness and efficiency of the method. The obtained results also address it as one stable and reliable method, Moreover, simplicity and fast implementation of the method are two of its major advantages. At the end, it should be noted that the method can also be applied to signals of low signal-to-noise ratio, as well as signals with base-line wander that have a fast-moving behavior. The robustness of the method to the noise and base-line wander is its main characteristic.

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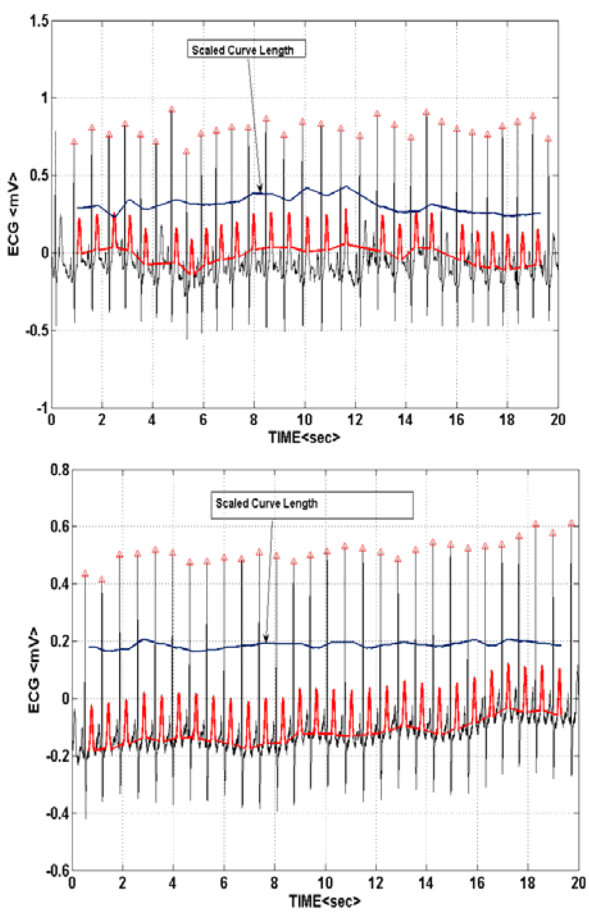

Figure 4. The effect of the program on T-wave detection

and calculation of each wave curve length

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