MONITORING OF PROGRESS OF ECG SIGNAL T-WAVE ALTERNANS IN TIME DOMAIN USING MODIFIED SPECTRAL METHOD

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ABSTRACT

The classical spectral method (SM) is considered as a golden standard in detection of T-wave alternans of electrocardiographic (ECG) signals. The method was modified using sliding window. In the presented article, we discuss the ability of modified spectral method (MSM) to detect and track changes of T-wave alternans in time domain.

1. INTRODUCTION

Microvolt-level T-wave alternans (TWA) present in ECG signals are defined as a consistent 2:1 variation in T-wave morphology. It means that T-wave is changed in its shape every second or it has different amplitude at least. The mechanism responsible for TWA is a dynamic (beat-to-beat) variation of the heart repolarisation sequence due to either an alternation of action potential duration, frequently associated with the long QT syndrome or an alternation of the time course of repolarisation frequently associated with myocardial ischaemia. The presence of microvolt-level T-wave alternans in surface electrocardiograms is recognized as a marker of electrical instability, and is related with patients at increased risk of suffering malignant ventricular arrhytmias and sudden cardiac death [1]. However, visually apparent microvolt T-Wave alternans is a rare electrocardiographic finding and lacks value as a clinical tool.

2. EXPERIMENTAL DATA

In this study, the experimental data measured at the Department of Internal Medicine and Cardiology, University Hospital Brno were used. The ECG signals were recorded at the heart rate 90-105 beats per minute with sampling frequency 3000 Hz. The resolution was 2.29 μV/LSB [2].

Typically, 128 beats were analyzed in each recording. This number provides a reasonable compromise between the ability to reduce noise and ability to track variations in the TWA level over time. The T wave alternans were simulated by addition Gaussian-window to every second ST-T complex. The TWA voltage level was usually chosen between 20 μV and 40 μV. In some cases, alternation was suddenly increased about 20 μV (sometimes till about 40 μV) by reason of testing of the ability of MSM to detect fast changes of TWA in time domain. The length of the steps was chosen between 32 and 64 beats.

The signals were processed using a FIR-filter based QRS detector followed by consecutive ST-T complexes selection and ordering to a matrix. Whole process is described in [3].

3. METHODS

3.1. SPECTRAL METHOD

Spectral method is one of the most widely used methods for TWA detection by reason of the simplicity and low computation requirements.

Beat-to-beat fluctuations in electrocardiographic amplitude are represented as power spectra by calculating the squared magnitude of the fast Fourier transformation of beat-to-beat fluctuations in the amplitude of each sample point of the 128 time-aligned heart cycles. Power spectra calculated for each point within and T wave are then summed, and the final results are represented by aggregate spectrum corresponding to the sums over each of these intervals. The spectrum depicts the frequencies at which beat-to-beat fluctuations in the amplitude of the T wave occur [4]. For example, the spectral peak at the frequency of 0.1 cycle per beat corresponds to periodic fluctuations in T-wave amplitude that repeat every 10th beat. Similarly, the peak at 0.5 cycle per beat is due to fluctuations in T-wave amplitude on every other beat; hence, the magnitude of this peak is a direct measure of electrical alternans.

Electrical alternans is expressed as follows:

$$V_{alt} = \sqrt{S_{alt}} \qquad [\mu\mathrm{V}] \qquad (1)$$

and alternans ratio:

$$k = \frac{S_{alt}}{\sigma_{NB}} \qquad [-] \qquad (2)$$

where S_{alt} is evaluated as alternans peak minus mean of noise and σ_{NB} represents standard deviation of the spectral noise estimated from the predefined noise window.

Since the cumulative alternans voltage V_{alt} is derived from the aggregate spectra, it represents the square root of the spectral alternans voltages summed over all sample points in the defined ST-T segment of the ECG signal.

The alternans ratio k reflects the extent to which the measured alternans exceeds the uncertainty (noise) of the measurement and conveys the statistical degree of confidence in the alternans measurement [4].

It is rate as a positive result, if the cumulative alternans voltage V_{alt} value is higher then 1.9 μV and alternans ratio k is higher then 3.

3.2. MODIFIED SPECTRAL METHOD

The main disadvantage of classic spectral method is inability to detect sudden changes of TWA in signal. It was empirically found out, that alternation presented in signal only for short time, is not clinically significant and could be interpreted as positive result. For these reasons, progress of TWA in time domain is current trend in TWA research. A modified spectral method was developed as a complement to a classical spectral method, but ability to use as independent classifier was also examined.

The method is realized by using a sliding window. This window is moved in the same matrix of ST-T segments needed for SM with one cycle step. The aggregate power spectrum is computed the same way as in classical method for each window at the same time. The V_{alt} value is also calculated from this spectrum, so that for 128 windows position we gain 128 V_{alt} values, which represents the progress of TWA in time domain. The number of window positions is the same as number of ST-T complexes (T-waves), because the cycles missing at the end of matrix are inserted from the beginning of the matrix. The whole principle of this method is shown in Fig 1.

The alternans ratio k is not computed, because number of samples is too small. For example, for window size 32 cycles, the result spectrum is only 32 samples long. Hence, the noise window is only 2 samples long and standard deviation computed from this window has got no interpretation.

The resulting course is shifted by (window size)/2 samples forward (not shown), because the beginning of each variation of TWA is detected about window size earlier.

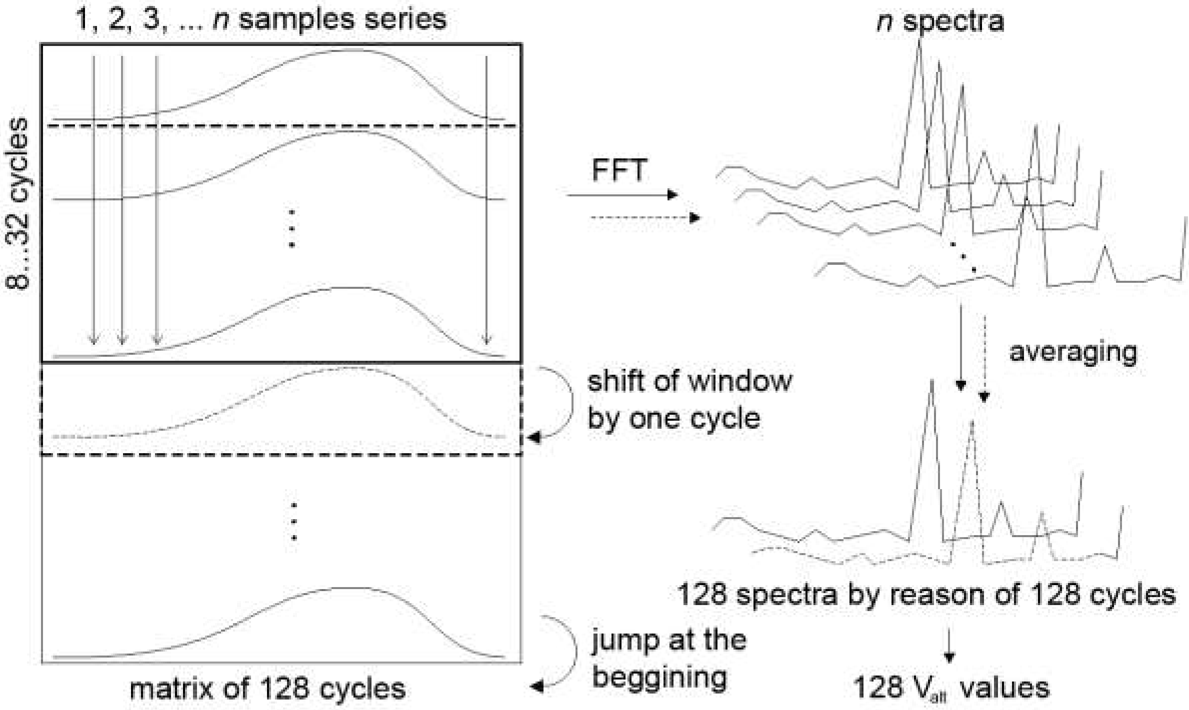

Fig. 1: The principle of modified spectral method

4. RESULTS

Following figures show the progress of TWA (represented by V_{alt}) obtained by MSM with different window size (from 8 cycles to 64 cycles). Grey areas signify parts with inserted temporary alternance.

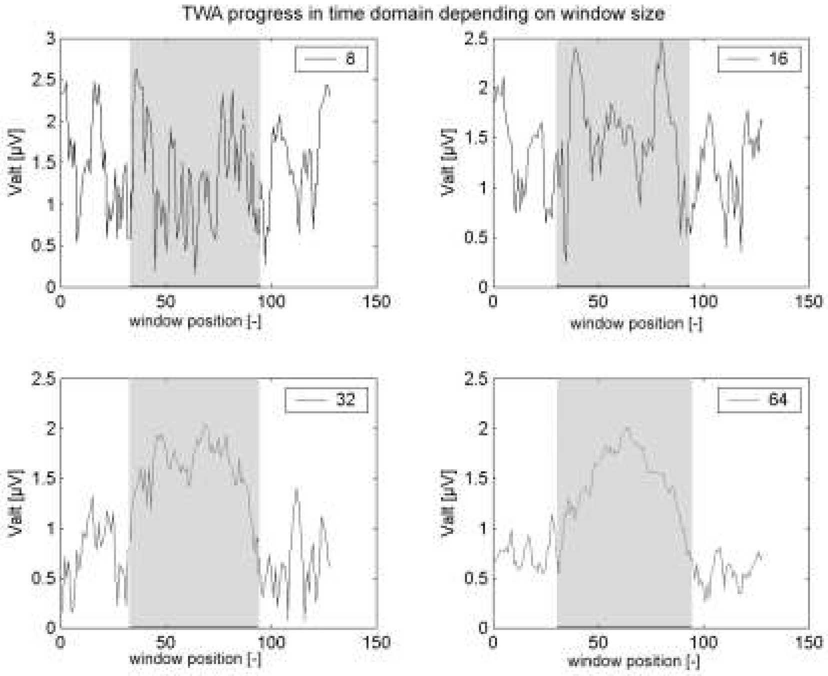

Fig. 2: Results of modified spectral method – analysed signal with high noise level

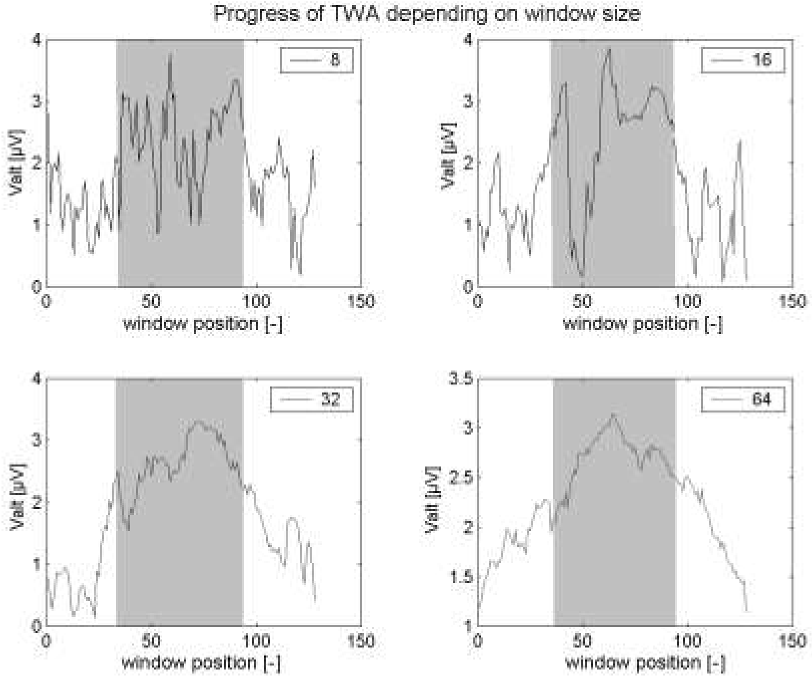

Fig. 3: Results of modified spectral method - analysed signal with low noise level.

5. CONCLUSION

The modified spectral method has been developed as complement to a classical spectral method. The MSM enable to detect changes of TWA in time domain, which has been demonstrated on real signals and on signals with inserted artificial steps. The only parameter of this method, that can be changed, is window size. According to our results, longer windows (16-32 cycles) are more resistant to noise and if the change remains for longer time (32 cycles and more), it might be better catch. Contrariwise, if we analyze signals with low noise level, we could use the shorter windows (8-16), which prove the progress of alternation more accurately.

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