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Detectability of T Wave Alternans in ECG Signal by Principle Component Analysis Method

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Abstract— T-wave alternans (TWA) is a cardiac phenomenon related with the mechanisms leading to sudden cardiac death. It appears in the surface electrocardiogram (ECG) as a beat-to-beat alternation in the morphology of the repolarization, and its amplitude can be so low that it is invisible to the naked eye. Numerous techniques exist to automatically detect and estimate TWA in the ECG on a single-lead basis, and their main shortcoming is their poor sensitivity to low-amplitude TWA. This paper aims to provide a methodological overview of the different approaches to TWA analysis. It also propose a multilead analysis scheme for to improve the detection and estimation of TWA in the ECG and that to increase the clinical value of TWA as a risk index. The proposed scheme is an extended version of a usual single-lead scheme with two additional stages, such as signal transformation and signal reconstruction, which are included to increase the detectability of TWA and to improve the estimation of TWA amplitude and waveform.

Index Terms— Spectral methods, multilead analysis, principal component analysis (PCA), T-wave alternans detection (TWA), MMA

I. INTRODUCTION

A T-wave is part of the electrical wave of the ECG & it is created when your heart beats. TWA is defined as beat to beat variation of T-wave morphology and/or polarity at constant heart rate, which means the morphology and/or polarity change in ABAB form. . TWA is a pattern in the ECG characterized by two distinct forms of T-waves appearing in alternation. A microvolt T Wave alternans test can show tiny differences in the T-wave from heartbeat to heartbeat. These tiny variations can indicate a problem with your heart's electrical system. T-wave alternans (TWA) is a cardiac phenomenon related to the mechanisms leading to ventricular arrhythmias and sudden cardiac death (SCD). It appears in the surface electrocardiogram (ECG) as a beat-to-beat alternation in the morphology of the repolarization, and its amplitude can be so low that it is imperceptible to the naked eye. Several signal processing methods have been proposed to detect TWA in the ECG and to quantify its amplitude. A number of methods have been proposed for TW Analysis, some of the most widely used are the spectral method (SM), the complex demodulation (CD) method , the correlation method (CM), methods based on the Karhunen-Loève Transform (KLT), the modified moving average (MMA) method, the Laplacian likelihood ratio method (LLR), and the latest multilead analysis schemes. The improvements in the detection performance and in the accuracy of TWA estimation over a single-lead scheme are quantified for all the multilead alternatives.

This paper aims to provide a methodological overview of the different approaches to TWA analysis. Framework of this paper is as follows: In Section II, a brief historical scenery of TWA methods is represented. In Section III, we proposed a multilead analysis system Section IV is dedicated to Database. Finally result and discussion are expressed in Section V, and conclusions are given in Section VI

II. SUMMARY OF TWA ANALYSIS METHODS

We present the different methodologies which have been proposed for automatic TWA analysis as follows,

A. Energy Spectral Method

Adam and Cworkers [1] found TWA in the ECG [Adam et al., 1981], various methods have been proposed to automatically examine TWA in ECG signals. The primary indication was that alternans is usually observed as a 0.5 cycles-per-beat (cpb) fluctuation in the beat-to-beat measured T wave energy. TWA magnitude was measured as the periodogram evaluated at 0.5 cpb of the normalized T wave energy series minus an estimate of the spectral background noise.

B. Spectral Method (SM)

The SM was offered in 1988[2] by Smith as an enlarged version of the ESM. Digitized ECG beats are aligned in the SM, and periodogram based power spectral evaluations are calculated for every sample in the segment of interest. If TWA is present, the value of an aggregate spectrum at 0.5 cpb is compared with the spectral noise level. The SM aligns the ECG beats, and creates beat-to-beat series with the amplitudes of corresponding points in succeeding ST-T complexes. Then, the beat-to-beat series of amplitude fluctuations are subjected to spectral analysis using the Fast Fourier Transform. As the resulting spectrum is based on

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measurements taken once per beat, its frequencies are in units of cycles per beat (cpb). The frequency that corresponds to an oscillation occurring on every other beat is 0.5 cpb, and is referred to as the alternans frequency. The alternans power (in μV) is defined as the difference between the power at the alternans frequency and the power at an adjacent frequency band, which is taken as a reference for noise measurement. Detection is performed by means of a significance measure called the TWA Ratio (TWAR), which is calculated as the ratio of alternans power divided by the standard deviation of the noise in the reference frequency band.

C. Complex Demodulation Method (CD)

The CD was performed in 1991 by Nearing and Verrier [6] as an alternate to the SM, permitting dynamic tracking of TWA. In this method, the beats are aligned, and TWA is showed in each series as a sinusoidal signal of frequency and variable amplitude and phase. TWA amplitude in each beat-to-beat series is projected by demodulation of the 0.5-cpb component and low-pass filtered to obtain a continuous beat-to-beat alternans measurement.

D. Correlation Method (CM)

The Correlation Method (CM) [10] is a time-domain approach proposed by Burattini and coworkers in 1997. Two main modifications occur with respect to the previous ones: a) the ST-T complex is calculated, reducing all the existing information in every beat to a single cross-correlation coefficient, and b) the single beat-to-beat series of coefficients is evaluated by a time-domain zero-crossing counter. The CM has been used to analysis TWA in coronary artery syndrome and LQTS.

E. Karhunen-Loève Transform (KLT)

To compress the energy of the ST-T complex in a reduced number of coefficients done by truncated KLT [11] [12]. Two schemes have made use of this transform: a) By Laguna et al. in 1996, reduced each ST-T complex to the first four coefficients of the KLT. b) Each beat-to-beat series of coefficients was spectrally analysed by the periodogram (KLSM). This method was tested in ambulatory ischemia records. The KLT was also used by our group in 2000 but analysing the resulting coefficient series by means of complex demodulation (KLCD).

F. Capon Filtering Method (CF)

CF was proposed as a variant of the CD [12]. In CD, a previous designed low-pass filter is used to distinguish the demodulated alternant component from non-desired components. In CF, a FIR filter that reduces the power of the output signal though conserving the alternant component is applied instead of an invariant low-pass filter. The optimal Capon filter depends on the autocorrelation function of the input signal.

G. The Modified Moving Average Method (MMAM)

Modified Moving Average Method (MMA): In 2002, MMA was proposed by the authors of CD as a more robust analysis approach [5]. The time-domain analysis procedure consists of continuously computing a recursive running average of odd and even beats, where a limiting nonlinearity is applied to the innovation of every new beat to avoid the effect of impulsive artifacts. Since its publication, it has been used to assess risk in post myocardial infarction patients and in patients with implantable cardioverter defibrillators [19]. It is included in commercial equipment such as CASE-8000 (GE Medical Systems, Milwaukee, WI).

H. Laplacian Likelihood Ratio Method (LLR)

In 2002[16] [17], a detection theoretical approach to TWA detection presented. Given a signal model including alternans and noise terms, the maximum likelihood estimator (MLE) and the generalized likelihood ratio test (GLRT) can be derived for alternans estimation and detection, respectively. The physiological noise was shown to be leptokurtic: that is, the tails of the distribution are heavier than those of a normal distribution, and therefore, we proposed a Laplacian noise model. The MLE and GLRT for this model are based on median filters. In the model was extended to account for nonstationary noise. The LLR has been used to robustly detect TWA in patients undergoing coronary angioplasty.

III. MULTILEAD ANALYSIS SYSTEM

The block diagram of the proposed multilead scheme [21] is shown in Fig. 1. It consists of five stages: signal preprocessing, signal transformation with PCA, TWA detection, signal reconstruction, and TWA estimation.

A. Signal preprocessing

Moving averaging of samples in one period of power line interference was performed. This filter is meant to eliminate the power-line interference. Its frequency response is having a first zero at interference frequency 50 Hz (60 Hz). A smoothing procedure for EMG noise suppression is applied. It uses the least-squares approximation method, applied for defining the weighting coefficients for each sample of the selected smoothing interval of 60ms. A high-pass recursive filter for drift suppression with a cutoff frequency of 0.64 Hz. QRS detection using combined adaptive thresholding was applied. T wave onset and offset delineations were automatically performed, and the T amplitude was calculated, in a combined lead simulating the spatial vector or another all-inclusive signal, rather than in the separate leads. The transform to the orthogonal leads (X, Y, Z) was performed in using 'primary leads', i.e. the 8 potential differences referred to the electrode of the left leg F. These primary leads were obtained from the 12-lead ECG recordings, following the conversion formulae:

$$R_F = -II; \quad L_F = -III; \; C_{if} = V_i - (II+III)/3$$

The orthogonal leads were evaluated by:

$$X=0.5*abs\ (C4_F - C1_F); \tag{1}$$

$$Y=abs\ (R_F); \tag{2}$$

$$Z=abs\ (R_F - C2_F); \tag{3}$$

The combined lead (CL), which is the spatial vector in this case, is calculated by:

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CL=0.5(X+Y+Z+0.25(abs(X-Y)+abs(X-Z)+abs(Y-Z)));(4)

In cases of 3-leads ECG:

X=Lead1; Y=Lead2; Z=Lead3.

In cases of 2-leads ECG:

X=Lead1; Y=Lead2; Z=0.

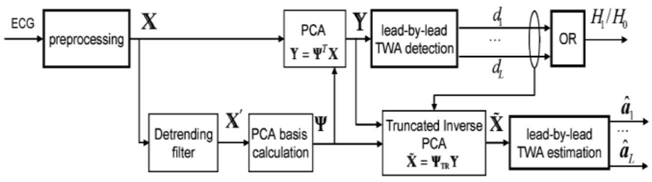

Fig.1. (a) Block diagram of multilead analysis system [21].

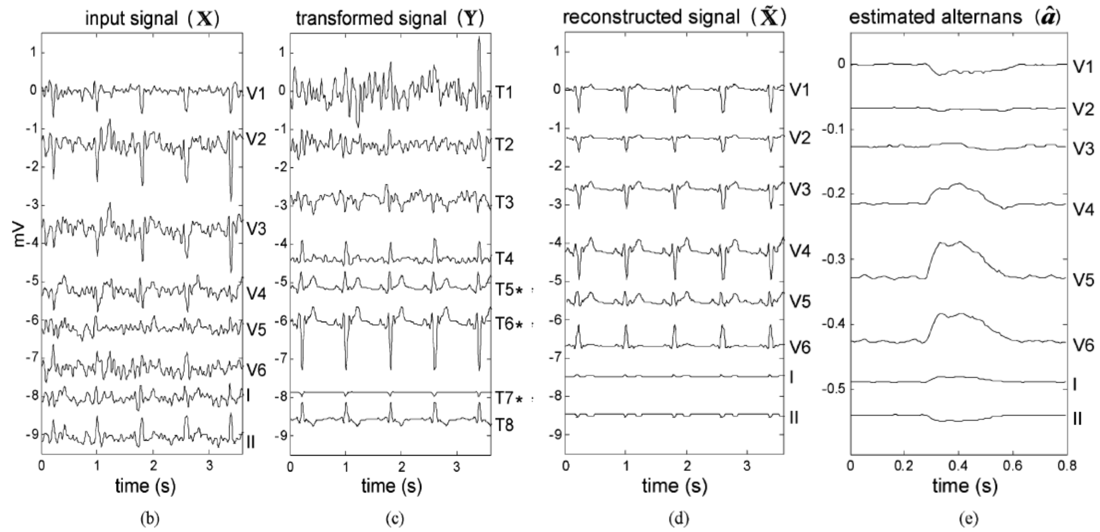

Fig.2. (b) Simulated input signal (c) Transformed signal after PCA. Asterisks indicate the leads where TWA is detected (d5 = d6 = d7 = 1). (d) Reconstructed signal after truncated inverse PCA. (e) Estimated TWA waveform [21]. Note that TWA is visible in T5 and V5 in the reconstructed signal

B. Signal Transformation with PCA

After the preprocessing stage, a detrending filter is applied to X cancel the background ST-T complexes. The resulting matrix to X' has same structure has X the same structure as X (this time with K − 1 beats), i.e., the l^{th} row contains the concatenation of the detrended complexes corresponding to the l^{th} lead. PCA basis is then calculated from matrixX'.

C. TWA Detection

After PCA transformation, TWA detection is performed in the transformed data. The GLRT is applied to each transformed lead. The result of this lead-by-lead detection is denoted as dl: dl = 1 if TWA is detected in the l^{th} transformed lead and dl = 0 otherwise. The overall TWA detection is positive if TWA is detected at least in one transformed lead.

D.Signal Reconstruction with Inverse PCA

After TWA detection, a new signal in the original lead set is reconstructed. This is necessary because TWA must be measured in the original leads to be useful in clinical practice. A diagonal matrix is defined from the lead-by-lead detection.

E. TWA Estimation

To estimate the TWA waveform and amplitude, the maximum likelihood estimation is applied to the reconstructed data

IV. DATABASE

The Physionet T-Wave alternans database is a publicly available resource compiled for the PhysioNet/Computers in Cardiology Challenge 2008 [Moody, 2008]. It contains one hundred real and synthetic ECG records, sampled at 500 Hz and with an approximate duration of two minutes. The synthetic subset of the database consists of thirty-two 12- lead ECGs containing artificial TWA in calibrated amounts. The remaining 68 records are real signals from different databases, 56 of which belong to patients with known cardiac risk factors. Synthetic records have 12 leads, and real records have 2, 3 or 12 leads. We have developed Matlab based software tool for detection of abnormalities. Also we have tested the proposed estimation and detection algorithm on the 100 ECG recordings included in the 2008 Challenge data base in which the presence of alternans was not known. Finally studied the detection performance and the accuracy of the estimation.

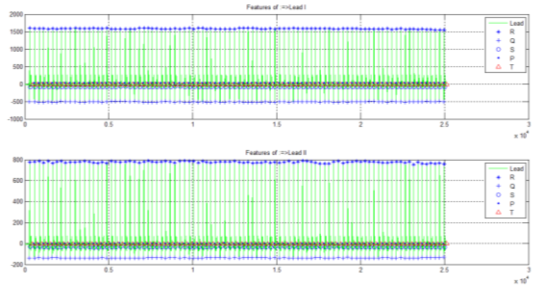

Fig.4 Feature extracted signal of twa04m sample

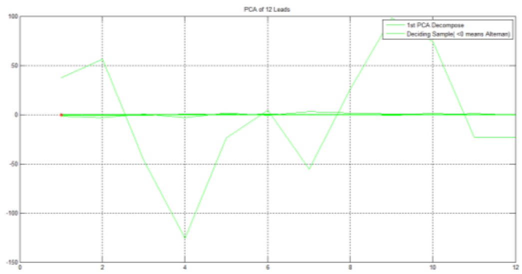

Fig. 5 TWA detection using PCA multilead analysis system.

V. RESULTS

- Signals were processed with the multi-lead using PCA multilead scheme.
- ECG signal is affected by various kinds of noises, among which baseline wander is the important artifact. Hence median filter is used to remove baseline wander.
- Median filter removes baseline wander more effectively and gives more stable ECG waveform.
- Various features are extracted from input ECG signal which shown in fig 4. Finally principle multilead analysis system is implemented for automatic classification of normal and abnormal signal.
- Wavelet transform is used to remove high frequency components (noise) from ECG signal. Fig 3 shows filtered outputs of various leads.
- The PCA method gives us TWA detection as shown in fig.5.

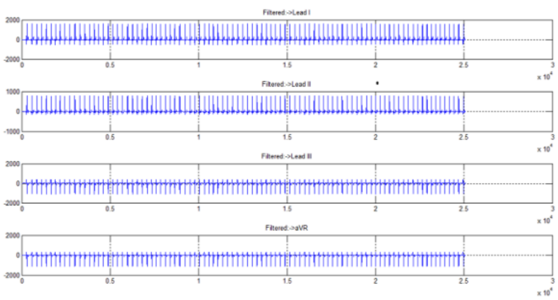

Fig.3 Filtered signal of twa04m sample

VI. CONCLUSION

1. ECG signal is affected by various kinds of noises, among which baseline wander is the important artifact. Hence median filter is used to remove baseline wander.
2. Median filter removes baseline wander more effectively and gives more stable ECG waveform.
3. Wavelet transform is used to remove high frequency components (noise) from ECG signal.
4. Multilead analysis system is implemented for automatic classification of normal and abnormal signal.
5. The PCA method gives us TWA detection.

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