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Preprocessing effects in time–frequency distributions and spectral analysis of heart rate variability

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ABSTRACT

Heart rate variability (HRV) is very significance noninvasive tool for autonomic nervous system (ANS) analysis. HRV signal includes both slowly changing components and rapidly changing transient events. This study presents effects of preprocessing of HRV in time–frequency analysis and spectral estimations. Preprocessing includes two levels as detrending of trend using smoothness prior method and correction of ectopics using integral pulse frequency modulation (IPFM). The datasets used in this study are obtained from the Spontaneous Ventricular Tachyarrhythmia (VTA) database. Datasets include least one ventricular tachyarrhythmia (VT) or ventricular fibrillation (VF) episode. Effects of preprocessing are investigated for time–frequency analysis using continuous wavelet transform (CWT) and spectrogram and for spectral analysis using periodogram, Welch's periodogram and Burg's periodogram. Performance of these methods in determination of VT or VF episode is analyzed. Importance of preprocessing is explained comparing of obtained results.

1. Introduction

Electrocardiograms (ECG) present variation of electrical activities of heart and include P and T waves and QRS complexes which describe the electrical forces generated by ventricular depolarization. R-R intervals are obtained with using time intervals in between consecutive R-R peaks. HRV can be described as variation of R-R intervals with respect to the time or beat number. HRV that is a nonstationary signal gives information about parasympathetic and sympathetic activity of ANS [1,2].

HRV records include both slowly changing trends and ectopic beats. Ectopic beats, arrhythmic events, missing data or noise effects can alter the estimation of the power spectral density (PSD) and time–frequency analysis of HRV [1]. There are different kinds of ectopic beat sources. For example, some additional pacemakers may interpose additional electrical impulses that appear premature beats. In addition, QRS misdetections can generate a similar effects [3,4].

HRV signals can be interpreted depending in time–frequency analysis and spectral analysis. Time–frequency analysis reflects variation of signal in time and frequency resolutions. This analysis can be determinative for detections of various diseases [5,6].

Spectral analysis includes estimation of PSD and can be called frequency domain analysis [2]. PSD provides information about variation of power with respect to the frequency. PSD estimation methods are generally classified as parametric and nonparametric methods [7,8]. PSD analysis is very significance for exact interpretation of variations of ANS [1,2].

Various methods have been proposed for correction of ectopic beats as sliding window average filter [9], IPFM [3,4], and impulse rejection filter [10]. Removing of the slow nonstationary trends is required different methods. In [11], HRV

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data is systematically tested and only nonstationary segments are analyzed. Others generally try to remove trend before analysis [12,13]. Smoothness prior method operates like a time-varying FIR high-pass filter [14].

In this study, ventricular tachyarrhythmia database was used. Ventricular tachyarrhythmia that appears on ventricles is a kind of heart arrhythmias and includes ventricular fibrillation (VF) and ventricular tachycardia (VT). While VT is defined as three or more ventricular extra systoles in succession at a rate of more than 120 beats/min is a series of three or more repetitive complexes that originate from the ventricles, VF that is the commonest arrhythmia that causes sudden death out of hospital is usually defined as a primary cardiac event, and with early direct current cardio version the prognosis is relatively good [15].

This study presents effects of preprocessing in time–frequency analysis and spectral estimation. Preprocessing includes two stages as ectopic removing with IPFM and detrending with smoothness prior method. Effects of preprocessing were evaluated for time–frequency analysis using spectrogram and CWT and for spectral analysis using periodogram, Welch's periodogram and Burg method. In addition, especially ventricular tachyarrhythmia database which covers least one VT or VT episode was chosen and location of this episode was analyzed. Applications were done on all datasets and obtained results from 0003.vt1 were illustrated as a specific example. All results were compared for 4 situations that are with ectopics and trend, no trend, no ectopics and without ectopics and trend and presented as graphically.

2. Preprocessing method

2.1. IPFM model for correction of ectopic beats

The IPFM model presupposes a modulating signal, which generates the beat occurrence times when acting through the model [4]. A continuous time generalization of the IPFM model can be formulized as

$$\int_0^t \bigl(1+m(\tau)\bigr)\,d\tau = \kappa(t)T_0, \tag{1}$$

where T_0 is mean interval length between successive events and $m(\tau)$. This integral is proportional to index function $\kappa(t)$ whose value at t_k is identical to integer beat index k.

IPFM model closely related corrects for occasional presence of ectopic beats. This model includes s parameter that can be explained as a jump in the resetting of integral [3]. Heart time is described as

$$d_{\mathrm{HT}}(t_k) = \begin{cases} kT_0 - t_k, & k = 0,\ldots,ke, \\ (k+s)T_0 - t_k, & k = k_e+1,\ldots,K, \end{cases} \tag{2}$$

where and t_k is kth beat time.

Heart time (HT)-based correction which is associated with heavy computations as holter recordings may become prohibitive. Therefore more computational a new technique based on IPFM was introduced in [4]. This new technique presents a much lower computational complexity than the other techniques. In correction techniques, ectopic beat shifts the occurrence times of following normal heartbeats by the time δ. HT signal is presented as

$$d_{\mathrm{HT}}(t_k) = \begin{cases} kT_0 - t_k, & k = 0,\ldots,ke, \\ kT_0 - t_k + \delta, & k = k_e+1,\ldots,K, \end{cases} \tag{3}$$

$$\hat{\delta}_N = \sum_{n=0}^{N+1} (-1)^l \binom{N+1}{l} t_{ke+1-l}, \tag{4}$$

where N is the order of δ, T_0 is mean interval length between successive events, k_e is ectopic beat number, K is total beat numbers. This method has efficient performance for correction of ectopic beats in short-time records.

2.2. Detrending with smoothness prior method

In this work, presented method in Ref. [14] was used. This method is based on smoothness priors approach and performs like a time varying FIR high-pass filter.

R-R time interval series is presented as

$$z = (R_2 - R_1, R_3 - R_2, \ldots, R_N - R_{N-1})^T \in R^{N-1}, \tag{5}$$

where R is the number of R peaks. The R-R series include two components.

$$z = z_{\mathrm{stat}} + z_{\mathrm{trend}}, \tag{6}$$

where z_{stat} is the nearly stationary R-R series component and z_{trend} is low frequency aperiodic trend component. z_{trend} is denoted as

$$z_{\mathrm{trend}} = H\theta + v, \tag{7}$$