BIOCYBERNETICS AND BIOMEDICAL ENGINEERING 35 (2015) 304–316

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/bbe

Original Research Article

Real-time estimation of the spectral parameters of Heart Rate Variability

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A R T I C L E I N F O

Article history:
Received 22 November 2014
Received in revised form
11 May 2015
Accepted 18 May 2015
Available online 5 June 2015

Keywords:
Heart Rate Variability
HRV
Instantaneous HRV

A B S T R A C T

Spectral Heart Rate Variability (HRV) parameters, LF (low frequency) and HF (high frequency), have an important role in interpreting slower and faster heart rate modulations. An online analysis method of HRV spectral parameters based on the modified Hilbert–Huang Transform (HHT) is proposed in the paper. A number of novel methods have been put forward to meet the demand of causal pre-processing of interbeat time intervals (IBI) series prior to application of HHT. Also in the real-time implementation of the HHT which is the combination of the Empirical Mode Decomposition and Hilbert spectral analysis an original extrapolation method of intrinsic mode function related to LF and HF spectral parameters was applied. The proposed algorithm allows temporal estimation of HRV spectral parameters in real-time with delays being reduced up to 60% with respect to the Short Time Fourier Transform (STFT) analysis. Such reduction in analysis delay can have an important significance in a number of cardiologic invasive procedures, e.g. in cardio-resynchronisation therapy (CRT).

1. Introduction

Combined efforts of clinicians and engineers have made it possible to use the data extracted from the Heart Rate Variability (HRV) to aid the diagnosis and prediction of various heart illnesses as well as ailments originating from different human organs but indirectly influencing the Autonomous Nervous System (ANS). A comprehensive review of HRV analysis techniques and their significance in diagnosing health status is available in [1]. A large number of computer analysis methods defined in the time-domain or the frequency-domain have been proposed to attain a more complete characterisation of HRV parameters and their diagnostic validity [2,3].

Time-domain methods are predominantly based on statistical analysis of the RR time series. The RR time series is obtained by detecting consecutive R waves in ECG recordings and noting time distances between them. The R waves are large amplitude ECG signal peaks of short duration that delineate the onset of the contraction of the cardiac ventricles, hence they are straightforward to detect (see Fig. 1). Variations over time in RR intervals allow to estimate the Heart Rate Variability (HRV). Example statistical parameters characterising RR time series are: the mean and standard deviation of the series, the root mean square of differences between consecutive RR time intervals and a number of geometric indices derived from the histogram of the RR intervals.

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http://dx.doi.org/10.1016/j.bbe.2015.05.002

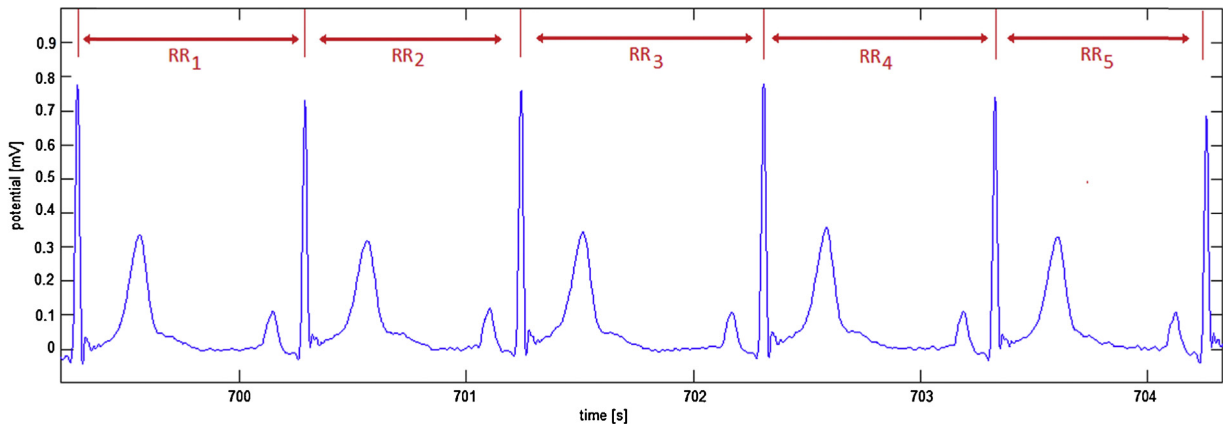

Fig. 1 – Derivation of RR intervals from an ECG (ECG recorder: Medea Kardio PCMu, lead II).

Two groups of methods are applied for estimating the HRV spectrum: the non-parametric spectrum estimates are the power spectrum density (PSD) or the Welch's periodogram [4] and the parametric approaches are autoregressive (AR) modelling, moving average (MA) modelling and combination of the both (ARMA) [5]. The frequency-domain methods allow for a better assessment of the fluctuations in HRV as a result of the modulation influence of the ANS. These fluctuations have been subdivided into low rate fluctuations characterised by the low frequency (LF) spectrum components (0.04–0.15 Hz) and by the higher rate fluctuations termed high frequency (HF) components (0.15–0.4 Hz) in the HRV spectrum [6]. According to the clinical interpretation, the sympathetic ANS control is related to the LF band and the parasympathetic ANS control is related to the HF band of the HRV spectrum. Thus, to quantify these two antagonistic regulatory mechanisms of the HRV the key spectral index characterising HRV is the LF/HF power ratio.

It is important to note that both the time-domain methods and the frequency-domain methods require an analysis of sufficiently long sequences of RR time intervals to provide reliable estimates of the HRV parameters. Such analyses perform poorly in an online HRV analysis tasks that are aimed at the assessment of instantaneous coupling variations between the heart and the ANS. Such variations occur during functional tests like tilt tests, body position changes, deep breathing, handgrip etc. Also, the results of recent research [7] indicate a new potential application of temporal HRV analysis. Namely, for patients who underwent cardio-resynchronisation therapy (CRT) it is possible to assess whether the resynchronising electrodes were properly placed. The anticipated improvement can be observed in the temporal variations of the LF and HF parameters.

In order to detect temporal changes of HRV parameters during the CRT procedure, real-time HRV analysis is necessary. There have been very few documented attempts to analyse HRV in real-time [8]. In this paper an online analysis method of HRV spectral parameters based on the modified Hilbert–Huang Transform is proposed.

In the standard off-line analysis, prior to estimation of HRV spectral components, the series of interbeat intervals (IBI) requires proper preprocessing. As shown in Fig. 2, for real-time HRV analysis standard methods for off-line analysis available in the literature [1] are not suitable. The major limitation of the online methods is that they need to be causal. Another problem hindering instantaneous analysis of the HRV spectral parameters comes from slow HRV signal variations, i.e. at the rate of fractions of cycles per second. Hence, derivation of reliable estimates of a spectral parameter requires processing of at least several entire cycles of the signal. In this paper both the analysis and necessary preprocessing steps in real-time are addressed, what results in a complete algorithm for real-time HRV analysis.

2. Preprocessing of HRV for real-time analysis

Prior to HRV analysis, a series RR time intervals also termed heart inter-beat intervals (IBI) needs to be properly preprocessed. This is because the elements of the HRV series are not uniformly spaced in time. There are also signal events that need to be corrected before further processing, e.g. occurrences of premature ventricular beats and false positive or false negative beat detections. Preprocessing consists of artefact correction, interpolation and uniform resampling.

In real-time processing and analysis the future samples are unknown. Therefore, artefact detection can only be based on analysis of previous samples. In many cases, it is much more difficult to distinguish between an artefact and an actual physiologic, sudden change in the heart rhythm. Hence the methods available for off-line analysis cannot be successfully adapted to real time processing.

In case of artefact deletion and interpolation into the gap, the interpolation can only be performed when the artefact has terminated and several valid samples have been measured. This introduces a significant delay as well as erroneous results since there are fewer nodes for interpolation.

Finally, a critical problem in real-time preprocessing of HRVs is the signal interpolation method itself. In many earlier works [6,9] cubic splines have been suggested as the most convenient interpolation method. In our case, the interpolated series is constantly updated by newly arriving samples and the new value significantly influences the recent part of the interpolation curve.