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Time-varying assessment of heart rate variability parameters using respiratory information

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Abstract

Analysis of heart rate variability (HRV) is commonly used for characterization of autonomic nervous system. As high frequency (HF, known as the respiratory-related) component of HR, overlaps with the typical low frequency (LF) band when the respiratory rate is low, a reference signal for HF variations would help in better discriminating the LF and HF components of HR. The present study proposes a model for time-varying separation of HRV components as well as estimation of HRV parameters using respiration information. An autoregressive moving average with exogenous input (ARMAX) model of HRV is considered with a parametrically modeled respiration signal as the input. The model parameters are estimated using smoothed extended Kalman filtering. Results for different synthetic data show that our proposed joint model outperforms the classical AR modeling in estimation of HRV parameters especially in the case of low respiration rate. In addition, the possibility of using pulse transit time (PTT) and the amplitude of photoplethysmogram (PPG_{amp}) as surrogates of the input respiratory signal has been investigated. To this end, electrocardiogram (ECG), PPG and respiration have been recorded from 21 healthy subjects (10 males and 11 females, mean age 27.5 ± 4.1) during normal and deep respiration. Results show that indeed PTT and PPG_{amp} offer good potential to be used as references for the respiratory-related variations, thus avoiding additional devices for recording respiration.

Keywords: Heart rate variability, Time-varying analysis, Respiration , ARMAX , Smoothed Kalman filtering

1. Introduction

Heart rate variability (HRV) analysis has been widely used to assess the function of autonomic nervous system (ANS) in regulation of cardiovascular system [1, 2]. ANS activity has been investigated through analysis of HRV -also known as R-R interval (RRI) variability- or studying the interaction between heart rate (HR), blood pressure (BP) and respiration variations [3, 4]. HR is affected by BP through the baroreflex system, while respiration mediates cardiovascular parameters through both ANS and mechanical paths [5].

In general, two frequency components in HR spectrum are of significance: low frequency (LF) component (with a typical band of 0.04-0.15 Hz) which is thought to be affected by both sympathetic and parasympathetic tones, and high frequency (HF) component (0.15-0.4 Hz) which is mostly mediated by respiration known as respiratory sinus arrhythmia [1, 6]. HF component is mainly of parasympathetic (vagal) origin. The ratio between the powers of these two components (LF/HF) is considered as a measure of sympatho-vagal balance [1].

Some indices of HRV in stable conditions (e.g., short-term and long-term variability measures and LF/HF ratio) have been established for clinical diagnosis of ANS function [7]. Furthermore, time-varying analysis of HRV is of importance in order to assess HRV parameters continuously in healthcare monitoring systems or during non-stationary conditions. Different parametric and non-parametric methods have been considered for this purpose [1, 4, 8, 9, 10, 11, 12, 13]. The main shortcoming of most studies on HRV is that they do not consider respiration information. When the respiration rate is very low, the HF component of HRV interferes with the typical LF band. This leads to an unreliable estimation of the LF and/or HF powers [14, 15, 16]. To address this problem, some studies have considered adaptable frequency bands depending on the respiration frequency [17].