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An Online Heart Rate Variability Analysis Method Based on Sliding Window Hurst Series ⋆

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Abstract

Heart Rate Variability (HRV) analysis is based on variability between each heartbeat which is used as a diagnosis method for assessing the cardiovascular modulation of autonomic nerve system. Up to now, most HRV analysis has been done offline. However, in many relevant applications, HRV should be analyzed online such as the analysis of stress level and the detection of the drowsiness while driving. This paper proposes an online analysis method which can be used in platforms for human robot cooperation. This online analysis method based on a sliding Hurst window can be applied to estimate the heart status. By the sliding Hurst series, the two indices, cumulative mean of Hurst series (CMHurst) and cumulative standard deviation of Hurst series (CStdHurst) are introduced as indicators to distinguish heart health status. Using this method, the hardware requirement is significantly low, and the execution time is short. Some databases from the PhysioBank are used for test these indices. The results show this method can distinguish between the groups who have normal rhythm and abnormal rhythm.

Keywords: Heart Rate Variability (HRV); Hurst Parameter; Fractional Differintegration; Sliding Window Hurst; Human-robot Interaction

1 Introduction

As technology is becoming more ubiquitous, there is an increasing amount of interaction between robots and people in various activities [1, 2]. Diverse methods are applied in these interactions, such as vocal intonation, gestures and postures, facial expression and psychological states. With an ability to recognize psychological states, human-robot platforms help people perform tasks better, especially some tasks in risky environments. Psychological signals can be utilized to determine the underlying psychological and affective state of persons. Heart Rate Variability (HRV) is the physiological phenomenon of variation in the time interval between heart beats. HRV can be a reliable reflection of physiological status and can even be used for the diagnosis of coronary artery heart disease, hypertension, sudden cardiac death, stress detection [3], drowsiness

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estimation [4], and also for health status analysis [5]. RR time series is the series of heartbeat interval, where R is a peak point respect to each heartbeat of the electrocardiography (ECG) wave, and RR is the interval between successive R.

Three major classes of HRV analysis techniques are defined: time-domain analysis, frequency-domain analysis and non-linear dynamics analysis. The most popular tool for HRV in clinical practice is the time-domain analysis due to its intuitive interpretation. The most employed indices in time domain analysis are mean of RR time series and standard deviation of RR time series. In HRV frequency domain analysis, the power spectrum signal has been widely used. Commonly used methods in non-linear dynamics analysis of RR time series are Fractal Dimension (FD), Fractional Brownian Motion (FBM), and approximate entropy.

Many studies have shown physiological series are more likely to be "fractal", or more accurately to be Long Range Dependent (LRD) and fractal statistics. The application of nonlinear dynamics and fractal statics to physiologic phenomena has enabled physicians to uncover and interpret a new richness in physiologic time series [6]. Previous papers have utilized fractal techniques in human respiration [7], brain activity [8], gait [9], and immune patterning [10] research. Similar to other physiologic signals, the nature of HRV time series or RR time series are fractal-like. RR time series display non-stationary characteristics and exhibit long-range dependence (memory) [11]. An LRD process can be characterized by the Hurst parameter or Hurst exponent. The Hurst exponent has close relationship with power law, long memory, fractal, fractional calculus and chaos theory. Therefore Hurst exponent estimation is crucial to fractional system identification and forecasting [12].

In this paper, we introduce a novel online method of analyzing RR time series utilizing a sliding window Hurst. This paper will focus on the Hurst series analysis which is computed from RR time series based on sliding window. Based on the Hurst series, the two indices cumulative mean of Hurst Series (CMHurst) and cumulative standard deviation of Hurst series (CStdHurst) are proposed. The two indices are tested by 43 healthy and unhealthy subjects from three different databases. The result shows the two indices can serve as the indicators of heart status.

2 HRV Analysis

2.1 Hurst Parameter

A stationary process is said to have Long-range Dependence (LRD) if its auto-correlation function (assuming that the process has finite second-order statistics) decays slowly as $k \to \infty$. The Auto-correlation Function (ACF):

$$\rho(k) = \frac{E[(x_t - \mu_t)(x_{t+k} - \mu_{t+k})]}{\sigma_t \sigma_{t+k}} \tag{1}$$

where μ is the mean and σ is the standard deviation. The ACF measures the correlation between x_t and x_{t+k}. The following functional form for the ACF is often assumed

$$\rho(k) \sim C_\rho |k|^{-2(1-H)} \tag{2}$$

where $C\rho$ is assumed asymptotically constant for slow varying at infinity, and H is the Hurst parameter.