Journal of Fiber Bioengineering and Informatics 6:4 (2013) 415–425
doi:10.3993/jfbi12201306

The Segmented Dynamic Time Warping Algorithm for Beat-to-Beat Heart Rate Estimation based on Ballistocardiogram Signals

Chunwu Wang [a,b,*], Xu Wang [a], Xin Xiong [a], Renjun Wang [c]

[a] *Sino-Dutch Biomedical and Information Engineering School, Northeastern University Shenyang, Liaoning 110819, China*

[b] *College of Information and Technology, Jilin Normal University, Siping, Jilin 136000, China*

[c] *School of Life Science, Jilin Normal University, Siping, Jilin 136000, China*

Abstract

In order to improve the accuracy and speed of beat-to-beat heart rate estimation, a Segmented Dynamic Time Warping (SDTW) algorithm based on Ballistocardiogram (BCG) signal was presented. The beat-to-beat heart rate obtained through this algorithm was evaluated using 20 healthy subjects with synchronized lead I ECG as standard. The mean bias between JJ and RR interval was 0.2 ms and the confidence interval of 95% was ±19 ms. It indicates that the obtained beat-to-beat intervals are in better agreement with that of ECG. The mean relative error and matching time for heart rate estimation with the algorithm were 1.37% and 0.77 s, respectively. The results were superior to that of the traditional template matching algorithms. It establishes the foundation for heart disease monitoring based on BCG signal.

Keywords: Ballistocardiogram; Electrocardiogram; Dynamic Time Warping; Beat-to-beat Heart Rate

1 Introduction

Ballistocardiography (BCG) is a non-invasive technique used to measure the cardiac contraction and ejection force of blood into the aorta, which can be used to estimate cardiac output and contractility change [1]. Compared with Electrocardiogram (ECG), modern BCG measurement systems [2-4] does not required attaching sensors to patients' body during recording. Therefore, the BCG system is more suitable for automatic health monitoring at home [5]. Among the current heart rate estimation algorithms based on BCG signal, power spectral density [6], auto-correlation coefficient [7] and continuous wavelet transform [8] cannot reflect beat-to-beat heart rate variation but only offer statistical estimations of the heart rate, so it is difficult to estimate abnormal heartbeat. Other estimation algorithms relied on fiducial points [9, 10] can extract beat-to-beat heart rate, but they are sensitive to peak change so that they lack robustness.

*Corresponding author.
Email address: wang_chunwu@163.com (Chunwu Wang).

The main peak (J-wave) amplitude of the one-beat cycle BCG varies from beat to beat, but the signal patterns repeats themselves with each heart beat. The pattern is consisted of several peaks instead of a single outstanding peak. Therefore, template matching is more suitable for heart beats recognition [11].

The Cross-correlation Template Matching (CCTM) algorithm [3, 12] can be used to estimate the beat-to-beat heart rate. It can not reflect the amplitude difference but can reflect the phase difference between the two signals. Accordingly, when there is a larger amplitude difference in two signals with the similar waveform patterns, it would be wrongly judged. Alternatively, Euclidean Distance Template Matching (EDTM) can also be used to estimate the beat-to-beat heart rate [11]. However, it is sensitive to the waveform fluctuation and also leads to a wrong judgment easily. In order to solve these problems, we presented a Segmented Dynamic Time Warping (SDTW) algorithm for estimating beat-to-beat heart rate quickly and accurately. It will establish the foundation for heart rate variability detection based on BCG signal.

2 Data Preparation

2.1 Data Acquisition System

When someone stands on an electronic weighing scale, the strain gages will detect both the weight and the force of the heart beat [13]. Upon this principle, we have designed the BCG signal acquisition system based on a modified electronic weighing scale. The block diagram of the system is shown in Fig. 1. In this system, the TM7708 module integrates programmable amplifier, digital filtering and A/D conversion coefficient. It can effectively reduce the difficulty of the hardware circuit design and debugging, and improve the integration of the system. We chose the band pass filter with the cut-off frequency of 0.6-20 Hz to remove background and respiratory noise. As reference, the ECG is simultaneously acquired using I lead. The wireless data transmission module based on Wi-Fi technology is used to transfer signals into a PC where the signals will be processed in real time.

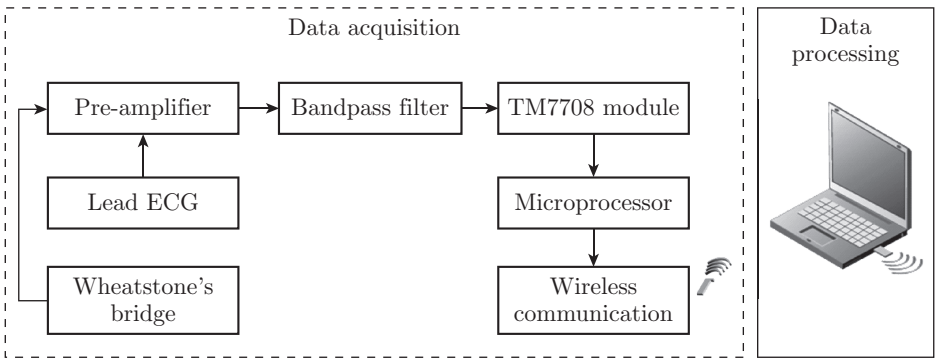

Fig. 1: The acquisition system for BCG and ECG signals

2.2 Signal Preprocessing

Although the original signal is filtered using the internal circuit of the BCG detection system, the filtered signal still contains much noise. So we have applied the polynomial least square's method