Turtle Shell Publications

Efficacy of Non-contact Ballistocardiography system to determine Heart Rate Variability

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The cardiovascular system comprising the heart and blood vessels is a self-regulating system designed to achieve hemodynamic stability by autonomic control of heart rate, blood pressure and other factors that are influenced by physical and metabolic demands [1]. The heart and cardiovascular system changes rapidly and reactively to internal and external stimuli such as ischemia, metabolic demands, physical and mental activity both at rest and activity [2]. Heart rate is regulated by the autonomic nervous system (ANS) that innervates SA node [3]. While sympathetic stimulation through adrenergic fibres increases heart rate, conduction system and contractility; the parasympathetic stimulation through cholinergic fibres slows down the heart rate [4]. Fluctuations of the heart rate can be used to analyse the autonomic regulation of the heart and is called as heart rate variability (HRV).

The fluctuations in the heart rate variability occurs when we are exposed to a stressful situation [5]. The heart rate variability (HRV) is the body's adaptation for fight or flight response and likewise a relaxation response as well [6]. Changes in HRV have emerged as an early biomarker of compromised health [7]. While high HRV is a sign of good heart health and indicates good adaptability of the autonomic nervous system, low HRV is a sign of poor health and is an indicator of insufficient adaptability [8]. Studies since the early 1970s have shown HRV to be related to arrhythmic events and increased mortality in survivors post myocardial infarction [9]. HRV has emerged as a strong indicator of risk in patients with a wide range of lifestyle related metabolic and non-communicable diseases [10].

We explore the feasibility of a novel health and vital parameter monitor, Dozee, based on contactless ballistocardiography (BCG) to accurately measure HRV parameters. Ease of use, contactless operating and low cost make it a promising candidate for continuous monitoring of HRV parameters.

HRV Calculation

Heart Rate Variability can be measured by acquiring the intervals between successive heartbeats from various techniques, e.g. Electrocardiography (ECG), Photoplethysmography (PPG), BCG, etc. The heartbeat intervals obtained from any of these sources are then used to determine the parameters representing HRV.

HRV Parameters

Time Domain Parameters

(a) SDNN: referred to as the standard deviation of all NN intervals, SDNN denotes the median of the variability. It is the measure of changes in the heart rate, due to the cycles exceeding 30 seconds [11].
(b) RMSSD: referred to as the square root of the mean of the squares of the successive differences between adjacent NN's. It reflects beat to beat variance in heart rate. The RMSSD values can be obtained every 30 seconds. Higher values of RMSSD denote higher Parasympathetic activity [11].

Frequency Domain Parameters

(a) LF: denotes Low-frequency respiratory band, which lies in the range of 0.04 to 0.15Hz (as shown in Figure 3) and is recorded over a minimum of 2 minutes' period. LF power may be produced by both Parasympathetic and Sympathetic system [12].

(b) HF: denotes high-frequency respiratory band, which lies in the range of 0.15 to 0.40 Hz (as illustrated in Figure 3) and is typically recorded over a minimum of 1-minute period. HF band represents the parasympathetic activity and corresponds to the heart rate variations related to the respiratory cycle [12].

(c) LF/HF: It is the ratio between parasympathetic and sympathetic activity, typically based on 24 hours of recording, during which both Parasympathetic activity and sympathetic activity contributes to LF power, whereas PNS activity contributes to HF power [13].

Data Collection

We collected data of 24 subjects in the age group of 24 to 60 years with a total of 54 overnight recordings. We used a 3 channel ECG Holter machine to capture ECG signal of the participants while Dozee was used to capture the BCG signal as shown in Figure 1.

Signal Processing

BCG signal is split into multiple sub-signals such that each new sub-signal is free from all undesired artifacts. This signal is then passed through our previously published algorithm to detect heartbeats[14].

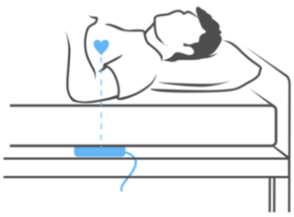

Figure 1. Dozee in use

Results

This interval varies with the hemodynamic state of the subject which can be altered by manoeuvre like Valsalva technique, paced breathing etc. [15]. Studies have shown a variation of approximately 50ms during these manoeuvres. We assume a variation of 10ms during sleep for analysis in this study. Due to the variation in the hemodynamic state, the difference in HRV parameters calculated using ECG signal from LabChart and BCG signal calculated by our algorithm was bucketed into three tolerance levels each. For SDNN the threes buckets were with a tolerance of 10ms, 15ms and 20ms, for RMSSD these buckets were of 10ms, 20ms and 30ms and for LF/HF these buckets were of 0.5, 0.75 and 1. Table 1 shows the distribution of epochs for each HRV parameter in different buckets.

Table 1. Percentage of epochs in each bucket for the HRV parameters

HRV Parameters	Percentage of epochs within		
	Bucket 1	Bucket 2	Bucket 3
SDNN	90.24	95.47	97.92
RMSSD	93.90	98.06	99.27
LF/HF	90.21	96.27	98.84

Figure 2 shows the mean number of epochs in each bucket of SDNN, RMSSD and LF/HF for every subject's sleep recording, while Figure 3 shows synchrony between HRV parameters calculated via Lab chart on ECG signal with HRV parameters calculated by us on BCG signal.

Conclusion

A method to conveniently monitor heart rate variability parameters for long term was presented in this work. It was also demonstrated that the method is effective and accurate in comparison to the gold standard to compute HRV parameters - ECG. The system used is contactless, doesn't require technicians to install and can work remotely. This enables collection of high-fidelity health data remotely on a mass scale to enable a variety of research and screening.

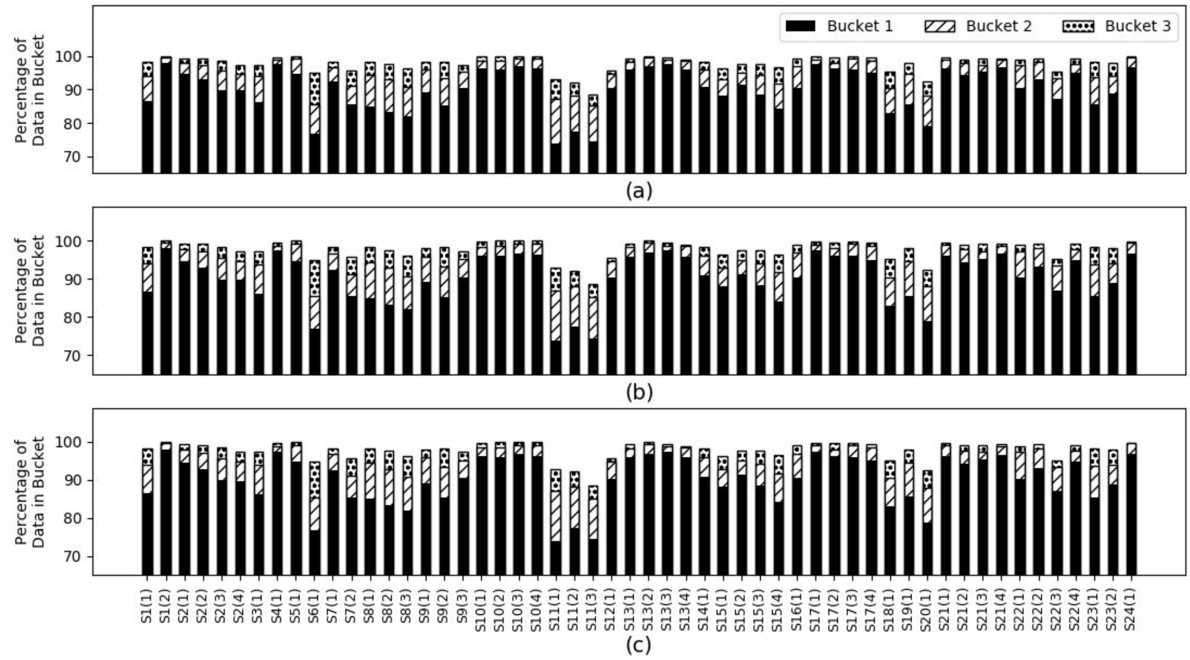

Figure 2. (a) Percentage of SDNN epochs in each bucket (b) Percentage of RMSSD epochs in each bucket (c) Percentage of LF/HF epochs in each bucket

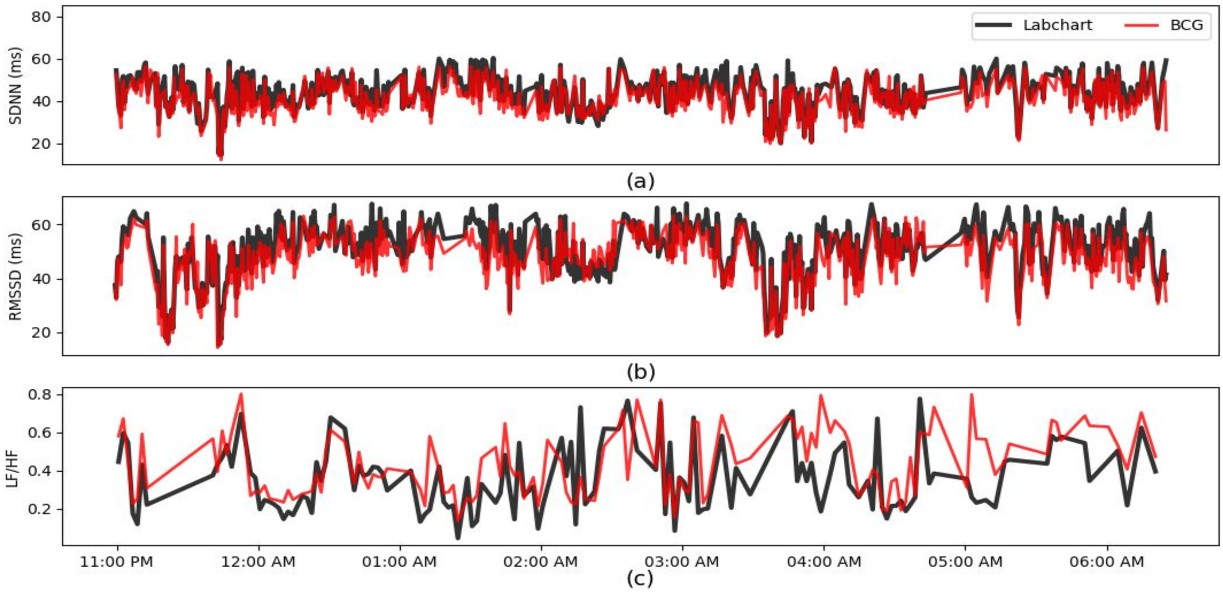

Figure 3. Synchrony between the (a) SDNN, (b) RMSSD and (c) LF/HF computed on ECG signal and on BCG signal

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