Scientific Journal Impact Factor (SJIF) : 3.518
International Journal of Modern Trends in Engineering and Research
ISSN (ONLINE) : 2349 - 9745 ISSN (PRINT) : 2393 - 8161

Comparison of HRV Indices of ECG and BCG Signals

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Abstract- Electrocardiography (ECG) is a transthoracic interpretation of the electrical activity of the heart. It plays a vital role in the diagnosis of heart related problems. The processed ECG signal provides accurate, fast and reliable information of clinically important parameters like duration of QRS complex, the R-R interval, occurrence, amplitude and duration of P, R and T waves which are used to evaluate the patient's cardiac conditions. Inorder to monitor patient's health conditions during sleep or to evaluate autonomic nervous system, many annoying electrodes has to be attached to the subject's body. It can disturb comfortable sleep and moreover it is very expensive, so continuous sleep monitoring is difficult. The best method to overcome these disturbances is to use Ballistocadiography (BCG) which records the mechanical activity of the heart, instead of ECG. The BCG can be acquired using sensor's that can be laid under the bed (non invasive). Here in this work the HRV indices of simultaneously acquired ECG and BCG signals are compared and found that the BCG signal can provide satisfactory results as that of ECG, so for long term monitoring BCG can be used instead of ECG.

Index Terms- Ballistocardiography (BCG), Electrocardiography (ECG), Heart Rate Detection (Algorithms), HRV Indices, Heart Rate Variability (HRV).

I. INTRODUCTION

The modern era of noninvasive cardiology uses several measurement techniques such as electrocardiography (ECG), impedance-cardiography (ICG), phonocardiography (PCG) and so on for diagnosing the cardiac functions. The ECG is a generalized method to evaluate the condition of a patient's heart, from both the heart rate and ECG wave analysis [1]. It is a transthoracic interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the surface of the skin and recorded by a device external to the body [2]. A typical ECG consists of 5 waves - P, Q, R, S and T [3]. An unobtrusive alternative to the electrocardiography (ECG) is the ballistocardiography (BCG).

BCG is a recording of the movements of the body caused by shifts in the center of mass of blood in the arterial system and to a lesser extent of the heart, caused by cardiac contraction. So in short BCG is a technique for producing a graphical representation of repetitive motions of the human body arising from the sudden ejection of blood into the great vessels with each heart beat [4]. It is a vital sign that consists of eight fiducial points (G, H, I, J, K, L, M and N) and lies in the 1-20 Hz frequency range [5],[6],[7].

Recently several groups have developed low-cost, compact instrumentation for BCG measurement including piezoelectric sensors (EMFi), static-charge-sensitive beds, force plates, and modified commercial weighing scales [8],[5].The main advantage of BCG over electrocardiography is that, in general no electrodes, textiles, or similar devices have to be attached to the patient's body[9]. Therefore ballistocardiographic systems are well suited for monitoring cardiopulmonary activity at night over longer periods of time [6]. The patient safety and comfort is more in BCG than ECG and due to the more no of fiducial points in the BCG it gives more information about the heart and cardiovascular diseases [7].

Heart rate variability (HRV) is considered to be an important non-invasive tool to assess cardiac autonomic activity. HRV is commonly computed from beat to- beat (RR) interval series

derived from electrocardiograms (ECGs). High-quality ECG/BCG recordings provide the best basis for HRV analysis.

This work mainly focuses on comparing the HRV Indices (Time Domain-SDNN, RmSSD, pNN50 and Frequency Domain- VLF, LF and HF) of Electrocardiogram and Ballistocardiogram of 20 subjects having an age in between 20 and 40 (Includes both male and female with different Body Mass Index (BMI) categories (under weight, normal and obese)).

II. DATA ACQUISITION SYSTEM

A. Electrocardiogram

The ECG signal was acquired using 3 lead ECG acquisition system [10]. This 3 lead ECG acquisition system has a bio-amplifier within it, which does the pre amplification (noise removal) of the acquired signal.

B. Ballistocardiogram

The BCG signal was acquired by means of piezoelectric sensors [11], [12], [13]. For getting good signal two piezoelectric sensors were connected in series. The connected assembly of the piezoelectric sensors was mounted on a small single sided copper board. National Instruments 9201 data acquisition (DAQ) card was used for acquiring data. The NI 9201 is having 12 bit resolution and 8 analog inputs. It supports Wi- Fi connectivity also. The wireless NI CDAQ 9191 was connected to DAQ so that it will be easy to interface it to a laptop. The NI Measurement Automation Explorer (MAX) was used for establishing 20 wireless connections between DAQ and laptop.

III. PREPROCESSING

Preprocessing of both ECG and BCG signals were done in MATLAB platform. The preprocessing part consists of amplification and denoising of the acquired signal.

ECG: The signal from the bioamplifier was passed through a band pass filter having cutoff frequencies at 5 Hz and 20 Hz. The band pass filter was realized using a low pass filter of cutoff frequency 20 Hz and a high pass filter of cutoff frequency 5 Hz. Band pass filtering removes noises as well as baseline wandering also.

BCG: The acquired BCG signal was amplified using instrumentation amplifier made up of AD620 having a gain 10. The raw BCG signal was having amplitude in the range of 30-70 mV before amplification. The amplified signal was then band pass filtered to get signal in the range 0.1 - 30 Hz, which removes the baseline wandering also.

IV. HEART RATE CALCULATION

ECG: The QRS complexes of the ECG signal were detected using Pan-Tomkins algorithm [14]. This algorithm gives the locations of the peak and the corresponding amplitude. The instantaneous RR intervals and mean RR interval were calculated. The heart rate was calculated from mean RR interval.

BCG: The peaks of the BCG signal were detected using BCG Heart Beat Detection- Method [15]. This method gives the locations of the peaks and corresponding amplitude. The instantaneous JJ intervals and mean JJ interval are calculated. The heart rate was calculated from mean JJ interval.

V. HEART RATE VARIABILITY ANALYSIS

Heart rate variability (HRV) is considered to be an important non-invasive tool to assess cardiac autonomic activity [2].HRV is commonly computed from beat to- beat (RR) interval series derived from electrocardiograms (ECGs). High-quality ECG/BCG recordings provide the best basis for HRV analysis [16].

In ECG, RR intervals show the variation between consecutive heartbeats. Heart rate variability (HRV) measurements analyze how these RR intervals change over time. From the RR intervals both

the frequency domain and time domain indices were determined by means of MATLAB programming. In the time domain SDNN, RMSSD, and pNN50 are determined and VLF, LF and HF in frequency domain were also determined [17], [18].

In BCG, JJ intervals can be used instead of RR intervals in ECG. From the determined JJ intervals the time and frequency domain indices were evaluated as in the same manner that has been done for ECG.

VI. RESULTS

A. Electrocardiography

1) ECG Signal Preprocessing: The Acquired ECG signal was first passed through a Band Pass Filter and it is then averaged using a moving window integrator. This integrated signal's derivative was taken and from the derivative the square of the signal is calculated. These results are shown in figure1.

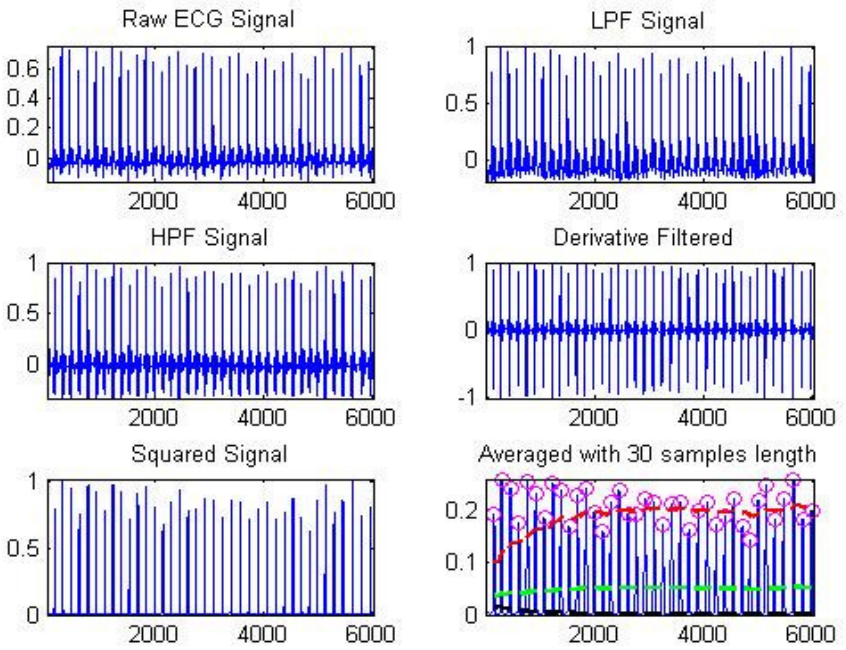

Figure1: ECG Signal Preprocessing

2) QRS Complex Detection: Using the band passed and integrated signal QRS complexes were detected. This is shown in figure 2.

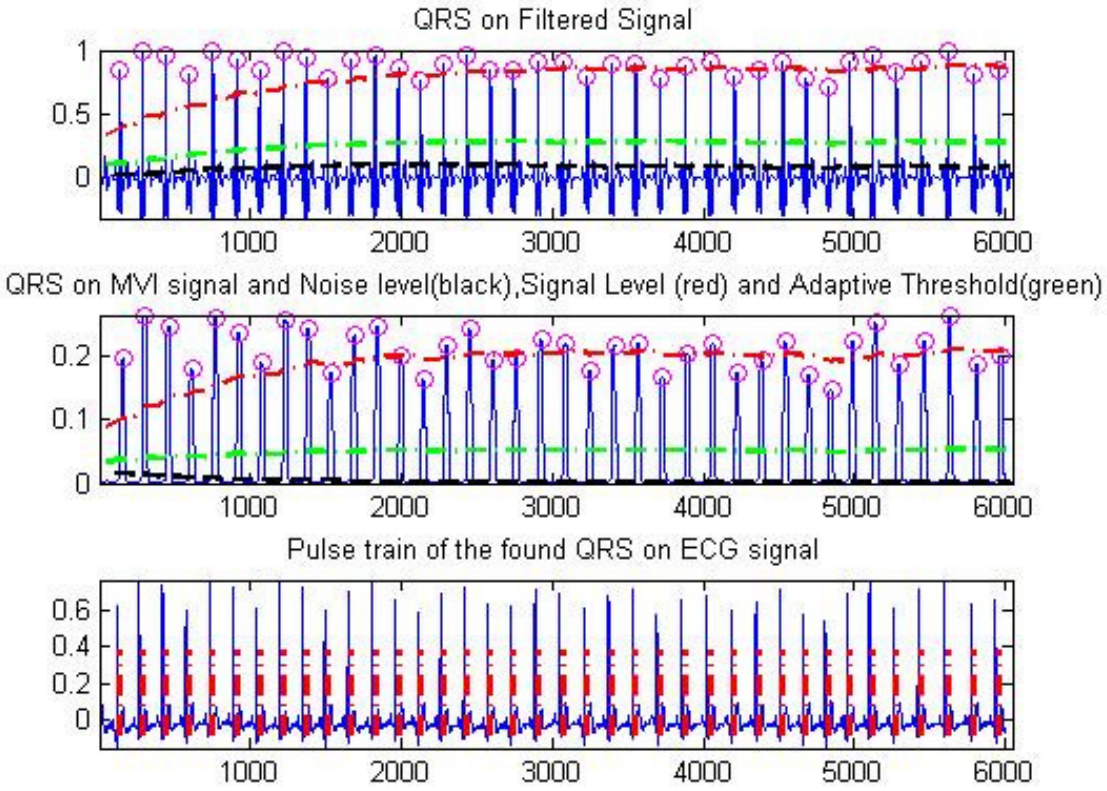

Figure 2: Detection of QRS Complexes

3) Heart Rate: The Heart Rate variations are shown in figure 3.

The Time Domain HRV Indices are,
Mean Heart Rate (in bpm)**:** 74.924
Standard Deviation of all normal RR Intervals (SDNN in ms)**:** 133.851
Root Mean Square Successive Diff (RMSSD in ms)**:**39.197
Percentage of differences between successive NN intervals that are greater that 50ms (percentage units)**:** 9.737

4) RR Intervals: The RR intervals are shown in figure 4.

5) Frequency Domain HRV Indices: The Power Spectral Density of the ECG signal is shown in figure 6.5.

B.Ballistocardiography

1) BCG Signal Preprocessing: The Acquired BCG signal was first passed through a Band Pass Filter and it is then averaged using a moving window integrator. This integrated signal's derivative was taken and the square of the derivative is taken. These results are shown in figure 5.

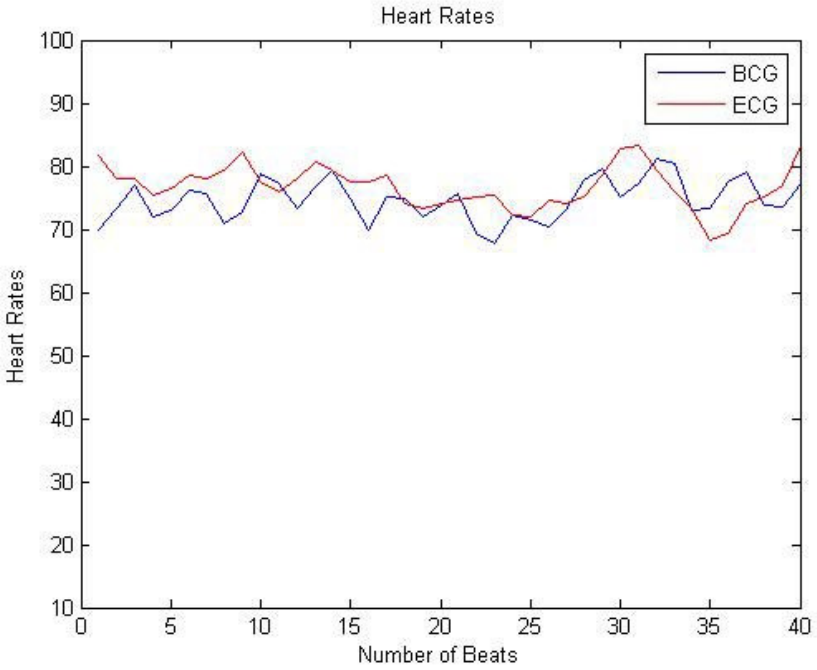

Figure 3: Heart Rate

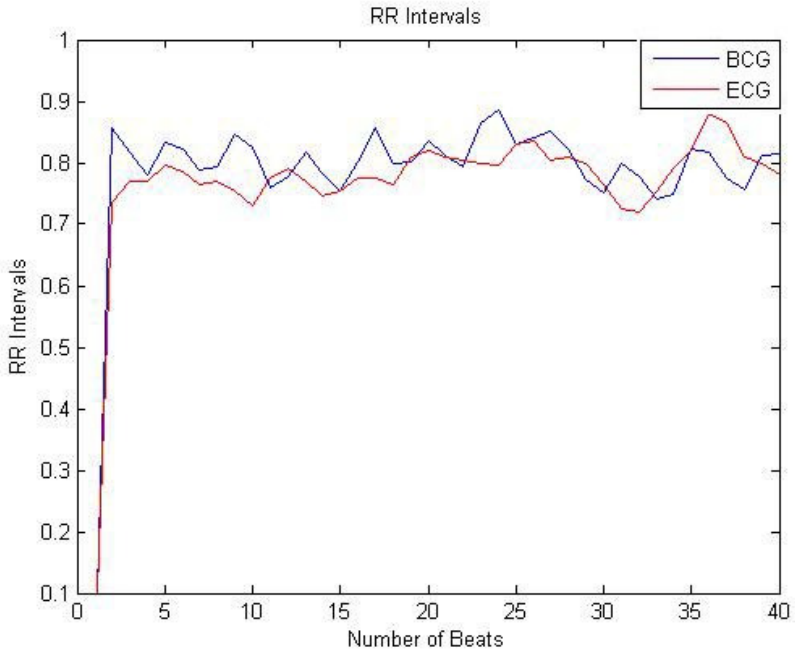

Figure 4: RR Intervals

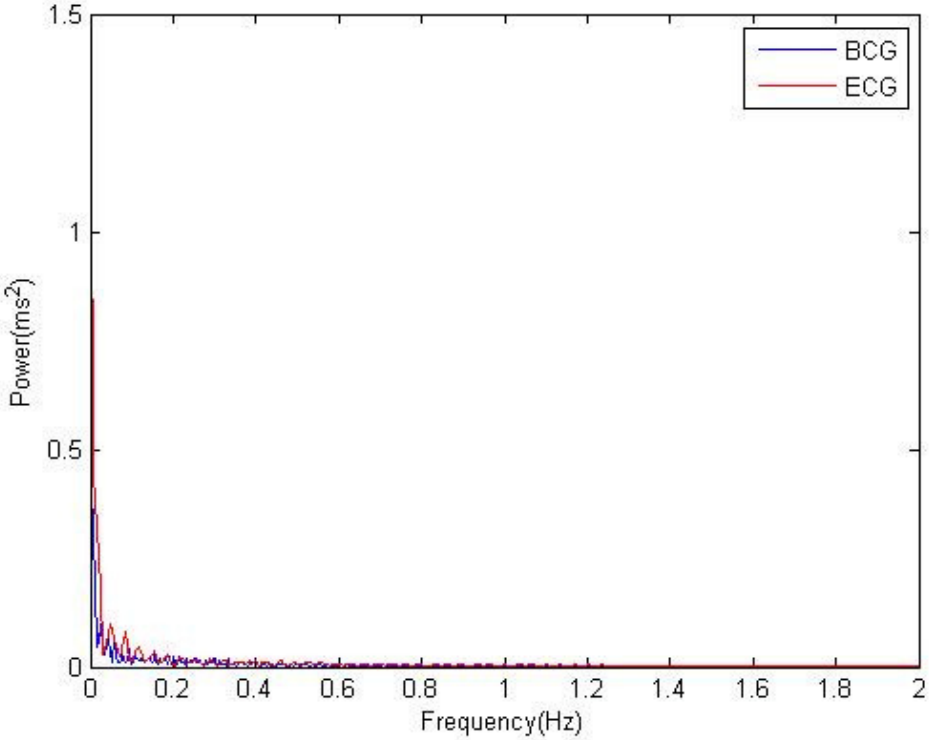

Figure 5: Power Spectral Density of the Signals

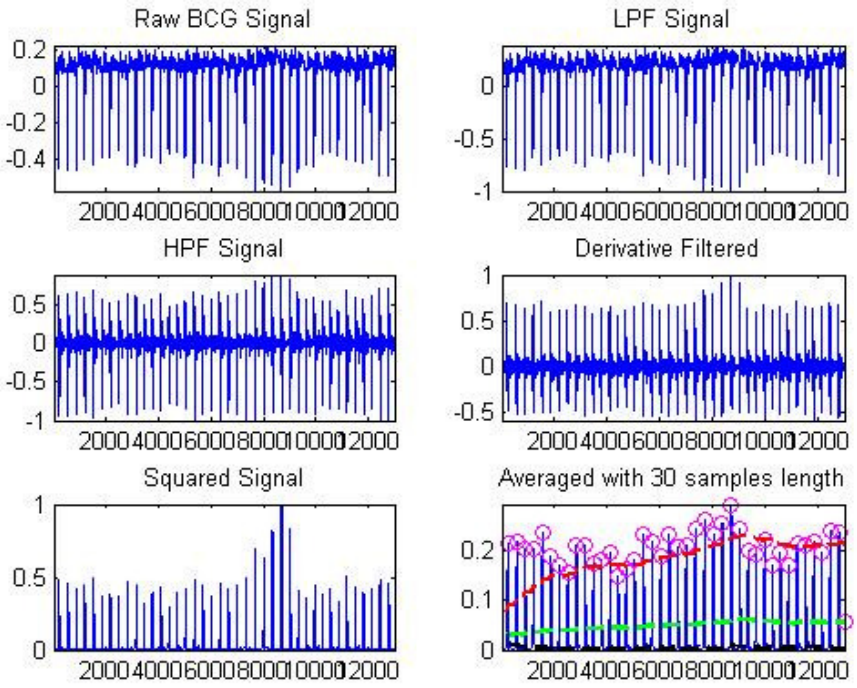

Figure 6: BCG Signal Preprocessing

2) J Peak Detection: Using the band passed and integrated signal the J peaks were detected. This is shown in figure 6.

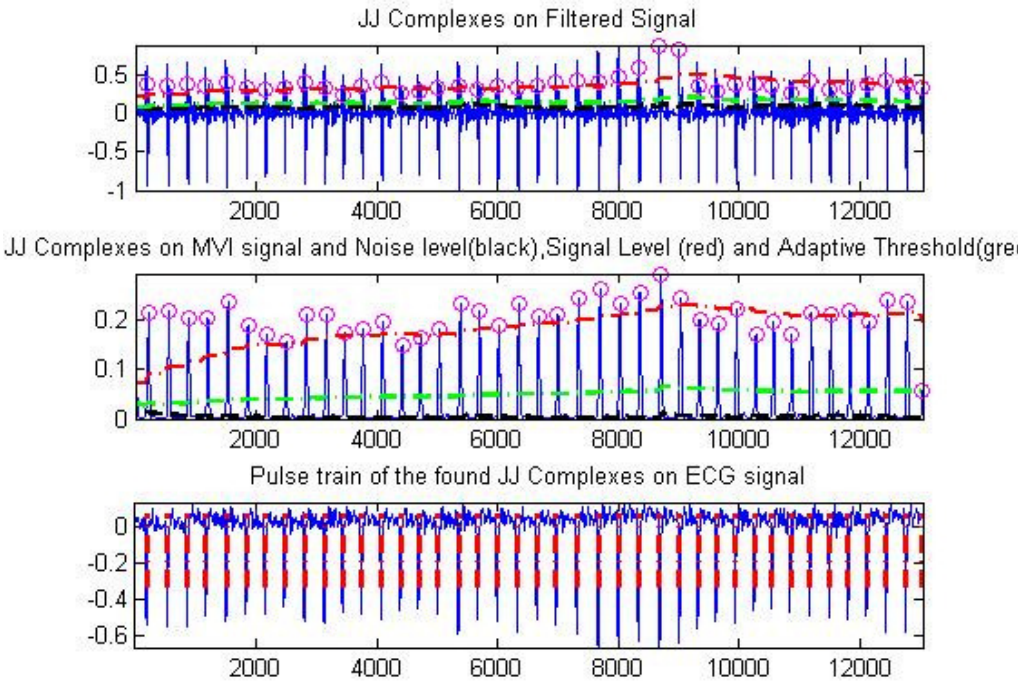

Figure 7: Detection of JJ Complexes

3) Heart Rate: The Heart Rate variations are shown in figure 3.

The Time Domain HRV Indices are;
Mean Heart Rate (in bpm)**:** 74.673
Standard Deviation of all normal JJ Intervals (SDNN in ms)**:** 132.568
Root Mean Square Successive Diff (RMSSD in ms)**:**40.19
Percentage of differences between successive NN intervals that are greater that 50ms (percentage units)**:** 9.756

4) JJ Intervals: The JJ intervals are shown in figure 4.

5) Frequency Domain HRV Indices: The Power Spectral Density of the BCG signal is shown in figure 5.

C. Comparison of HRV Indices of ECG and BCG

On comparing the HRV Indices it is understood that the Ballistocardiogram signals can also provide the same performance as that of the Electrocardiogram signals. The HRV Indices (Time domain and Frequency domain) of both the signals are highly correlated. For a single subject case, the SDNN obtained from ECG was 133.85 ms; the same parameter obtained from BCG was 132.57. As we go for the case of RMSSD it is 39.197 for ECG and 40.19 for BCG, the pNN50 from ECG was 9.7368 and from BCG were 9.7561. So it is clear that the time domain HRV indices obtained from ECG and BCG are highly correlated. Same the case of Frequency domain HRV Indices, it is quite clear from the figures 6.5 and 6.10. This is not only the case of a single subject but for about 20 subjects we obtained the same results which forced us to conclude that the HRV Indices obtained from ECG and BCG are highly correlated, so long term monitoring with BCG is indeed feasible.

VII. CONCLUSION

The goal of this work was to compare the Heart Rate Variability (HRV) Indices of Electrocardiogram (ECG) and Ballistocardiogram (BCG). After observing the HRV Indices of ECG and BCG of around 20 subjects we came to a conclusion that there is a high correlation between the HRV (time domain and frequency domain) indices of Electrocardiogram and Ballistocardiogram. It

was also found that BCG can be more comfortable to the subject than ECG during data acquisition. BCG uses only sensors that can be laid down under the bed for collecting data whereas ECG uses electrodes that has to be attached to the body of the subject (both BCG and ECG are non invasive cardiac data acquisition techniques), which disturbs the subjects freedom for long term monitoring cases. Since BCG acquisition assures subject more freedom of movement and moreover, since the HRV Indices of ECG and BCG are same, long term monitoring with BCG is indeed feasible and it ensures a good quality performance too.

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