Design of Low Cost Equipment using Bio Sensors for Acquiring Signals

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Abstract

Respiration induced variations in ANS are one of the factors instigating the variations in Heart Rate (HR). There are several methods for studying these variations, by which the role of respiration induced variations in parasympathetic and sympathetic activities can be evaluated. The method which gives a stronger negative correlation with respiratory frequency is considered to be better. This usually occurs in the high frequency band (0.12-0.4 Hz) of HRV. Many researchers have studied this band using commercially available equipment to simultaneously acquire Electrocardiography (ECG) and the respiration signal. ECG is used to determine the High Frequency (HF) band of HRV. The equipment used is generally bulky, costly and power consuming. This study presents the design of portable, low cost, low power consuming, and compatible with USB of Laptop/PC data acquisition system that matches in the performance with the standard commercially available equipment.

Keywords: Heart rate variability (HRV); Correlation; Respiration Frequency; low cost; data acquisition system

1. Introduction

The variation in the time interval between two consecutive heartbeats is known as Heart Rate. There are numerous factors affecting HRV through Autonomic Nervous System (ANS) as shown in Figure 1[1-6]. Modulations in ANS control the natural rhythm of the Sino Atrial (SA) node which is imitated in the time interval variation between two consecutive heartbeats known as HRV [7].

Sympathetic and parasympathetic activity make up the two branches of the ANS). It's interesting that sympathetic activity causes the heart to beat more frequently but faster. It means that although the heart rate rises as a result of improved regularity, the heart rate variation falls. In a similar manner, parasympathetic activity lowers heart rate while raising HRV.

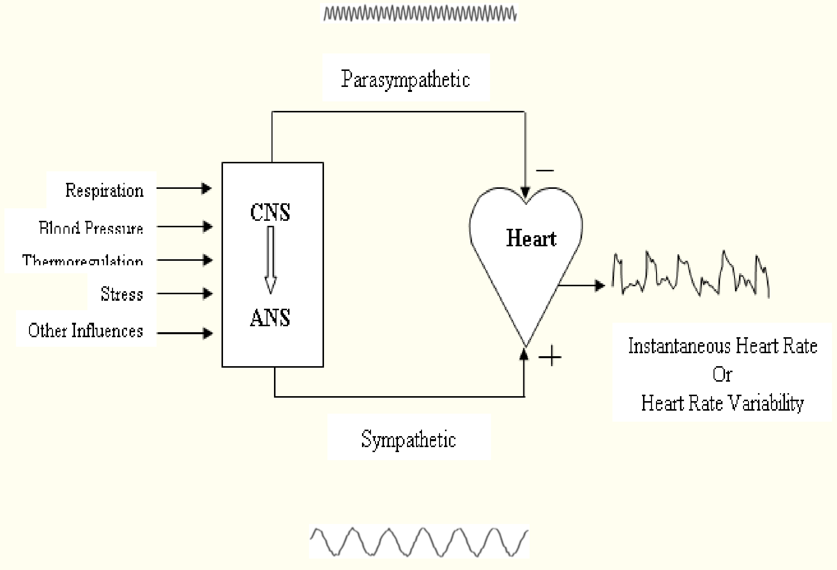

Figure 1. Heart rate variability model of the autonomic nervous system

In recent years, researchers have studied HRV with an intention of discovering new parameters or criteria helpful in diagnosing diseases associated with ANS. The effect of various drugs or any external stimuli on ANS can also be examined through the analysis of HRV. Therefore analyzing HRV data can provide a tool to understand the mechanisms of ANS.

Spectral analysis of HRV is often performed to compute the effect of modulations in ANS on variations in heart rate. The two main frequency bands of the HRV spectrum are Low-Frequency (LF) band (0.04 to 0.12 Hz) and the High-Frequency (HF) band (0.12 to 0.4 Hz) [8]. High-Frequency (HF) band appears to be almost exclusively governed by parasympathetic (vagal) nerve activity [9-10] while the Low-Frequency (LF) band is a marker of sympathetic tone but is also controlled by vagal activity [11–12].

In the last few years, the correlational study of respiration and HRV has become an attractive area for researchers. For correlational studies, spectral bands of HRV are extracted using various methods. HF-HRV band power is negatively correlated with respiratory frequency [13] This negative correlation becomes stronger with better HF-HRV band power estimation using various methods. For estimating respiration induce variations in ANS from traditionally defined HF-HRV band, that is, 0.12 to 0.4 Hz, information not related to respiration is likely to be included in this broadband. To get a better estimation of respiration induce modulation in ANS, fixed HF band boundaries are changed to restricted boundaries like $\text{respiratory frequency} \pm \delta$, where δ is taken as 0.05Hz [14, 15].

For correlational studies between HRV and respiration one necessary condition is that both the signals should be acquired simultaneously. Some of the data acquisition systems like BIOPAC are available for simultaneous data acquisition of both the signals but these are expensive, bulky, power consuming, and not portable. For example, the MP150 Biopac system costs around $8000, and ECG and respiration module cost another $2000 each. The cost of data acquisition system for conducting correlational studies is more than $12000 including all sensors. This does not include the cost of the associated Laptop/PC. To generate a large database for any application of the correlational study like distinguishing NSA subjects from NNSA, we require a less expensive and fast method. In addition to this in many cases data is to be acquired from different subjects available at different locations parallelly to make data collection faster. In such cases, we require a system that is easily portable and less expensive. Hence a new dedicated data acquisition system needs to be designed which is low cost, portable, compact, laptop-compatible, and operates on USB power, thus eliminating the need for an AC power outlet. Further, the ECG signal should be automatically validated. In case of any disruption in signal acquisition on account of the loose electrode or otherwise, an error message is generated.

2. Literature Review

Traditionally, data acquisition of ECG and respiration signals is done using commercially available biomedical devices like the Biopac system. Some researchers prefer to acquire data from the known subjects using a predefined protocol, while others take the data previously acquired and made available online at sites like physionet.org [16].

In 2007, Hansson-Sandsten and Jonsson founded whether a restricted frequency range of HF band in HRV or a new HF band described as respiratory frequency±0.05 Hz would better capture respiratory related heart rate variations. ECG and respiration signals were recorded at a sampling rate of 1 KHz by a computer based acquisition system MP 100WSW using software Aqknwoledge (BIOPAC system). From their study, it was found that narrow HF-HRV band power gives a stronger negative correlation with respiratory frequency [14].

In 2009, Carrasco-Sosa *et al.* founded whether postural change can affect the relationship between the HF component of HRV and respiratory frequency. For their study, ECG was acquired at the thoracic bipolar derivation CM5 using a bioelectric amplifier (Biopac system). Breathing was done using a chirp-type breathing manoeuvre; subjects performed a 70-second continuous and linear respiration frequency increase from 0.05 to 0.8 Hz at tidal volumes of 0.6 liters for women and 0.8 liters for men.

A set made up of a pneumotachometer, a differential pressure transducer, a carrier demod ulator, and an integrator was used to calculate tidal volume.

From this study, it was concluded that postural change affects the correlation between HF band and respiratory frequency. Correlational value changed from (-0.88±0.03) to (-.89±0.009) with the postural change from sitting to standing [17]. In 2014, Sengthipphany *et al.* presented a study in which breath-to-breath interval spectral was computed to find out the relation between respiration and HRV. In their study, ECG and respiration signals were recorded simultaneously. The ECG electrodes and respiration belt were connected to a multi-modality device for real-time computerization and data acquisition. The device used was BioHarness which operated on bluetooth transmitting data to the AcqKnowledge software of Biopac. For real-time data acquisition, it used USB docking for receiving data and then saving the data in a computer. All data were acquired at 250 Hz sampling rate. From this study, it was concluded that respiration makes more contributions in the HF band of HRV [18].

In a work they published in 2016, Mirmohamadsadeghi and Vesin suggested a technique based on short length-3 FIR notch filters to calculate the signal's instantaneous frequency at each sample. This technique was tested using a fake signal. Inter-beat intervals were recorded with a polar belt and the respiration signal was acquired with a spirometer. The evaluated algorithm was then used on real biomedical data for the estimation of the respiration rate from the ECG [19].

From this review, we observe that the data acquisition systems used for the correlational studies of HRV and respiration employ commercially available generalized equipment. These equipment are normally bulky, costly and power consuming. The need is to design a data acquisition system for these types of correlational studies, which is portable, low cost, low power consuming, and compatible with USB of Laptop/PC.

3. Design and development of hardware for data acquisition

For extensive data acquisition of respiration and heart rate signals used in the correlational study, custom designed equipment is proposed. This hardware is broadly divided into two modules. The first module is the ECG module dedicated to acquiring ECG signals for determining RR intervals. The respiration module is the second module responsible for the acquisition of data related to respiration using a respiration belt. Figure 2 on the next page shows the internal connections of the hardware.

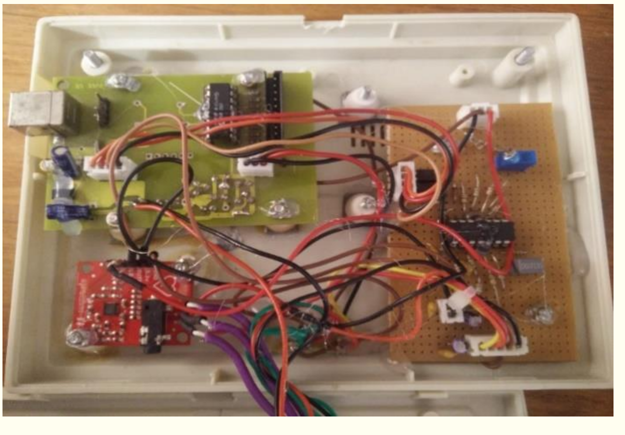

Figure 2. Internal connections of Hardware

3.1 Data acquisition procedure

ECG and respiratory signals were acquired simultaneously through custom-designed hardware as shown in Figure 3. ECG signals were obtained from lead one (LI) systems and respiration signals through respiration belts tied just below the rib cage of a subject. In the LI system, electrodes were placed on the right arm (RA) and left arm (LA) with respect to the right leg (RL). These signals were acquired at 400 samples per second for slightly more than half an hour. The acquired data was transferred into Laptop/PC using a USB cable and was stored in the form of ASCII files

Figure 3.ECE and Respiration signal acquiring set up

A. ECG Module

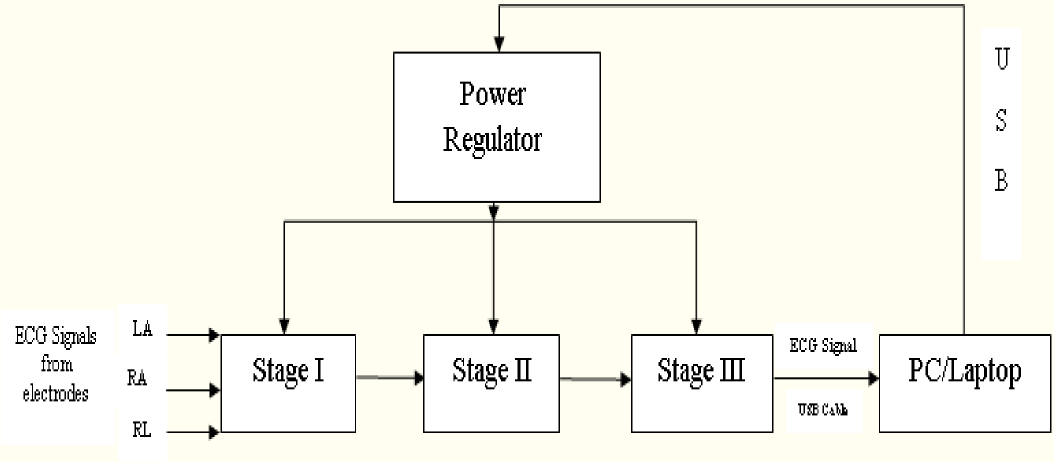

Figure 4. Schematics of ECG module

Figure 4 represents a schematic diagram of the ECG module. In this module, three ECG electrodes are used. For data acquisition, these electrodes are positioned with one electrode on Left Arm (LA), the second on the Right Arm (RA), and the third on the Right Leg (RL) taken as reference. This signal is fed to the ECG module which is divided into three stages. Each stage is dedicated to perform a specific job. The voltage supply to each stage is provided from a PC / Laptop through a USB cable and a power regulator. The power regulator is used to convert a common 5V logic supply or higher input supply voltage from USB cable to 3.3V.

Stage I

In this stage, conditioning of ECG signal acquired from the electrodes is done. A dedicated signal conditioning Integrated Chip (IC) is used. This dedicated IC helps in extracting, amplifying, and filtering the signal buried inside noisy conditions.

Stage II

The next stage of the ECG module is composed of amplifier IC. This IC is used to provide further conditioning of ECG signal obtained from stage one. The conditioned analog signal is fed to the analog input port of the microcontroller of stage III.

Stage III

The final stage in the ECG module comprises of microcontroller. It is dedicated to performing the task of converting the analog ECG signal to digital form. Flash memory of the microcontroller is programmed to perform this conversion. This digitized data is then transferred through USB cable to a PC/Laptop.

The ECG so acquired by the PC/Laptop is analyzed for R peaks. The spike like a high peak that occurs in ECG periodically for each heartbeat is called R-peak. The time between two consecutive R peaks is taken as the RR interval. They are stored in the form of text file on PC. RR interval represents the interval between two consecutive heartbeats and hence represents heart rate and is mathematically expressed in (1).

$$HR = \frac{60}{RR_i} \tag{1}$$

Where, *HR* represent heart rate in beats per minute and RR_i represents RR interval in seconds

In addition to the text file, the ECG signal is also displayed graphically in real-time.

B. Respiration Module

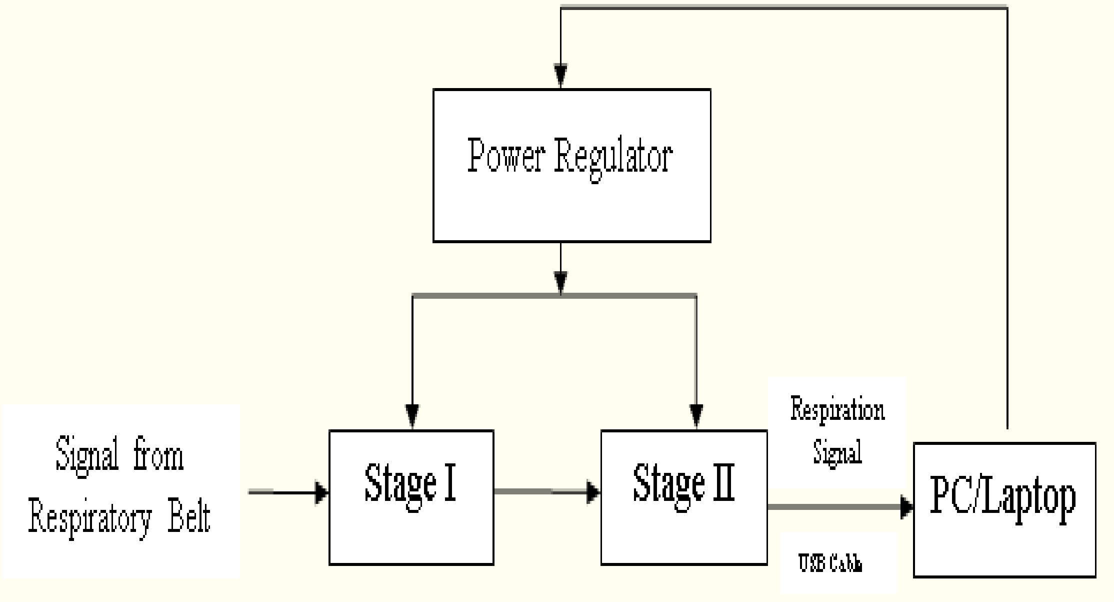

Figure 5. Schematics of respiration module

In the Respiration module, data is acquired from the respiration belt. In the respiration belt, magnetic sensors (Hall Effect sensors) are used to measure the respiratory expansion of the thoracic region. The signal from the respiration belt is analog voltage which is conditioned (amplified/filtered/digitalized) and acquired and displayed on PC/Laptop. Like the ECG module, the respiration module is divided into two stages and each stage is dedicated to performing a specific job. The power supply to each stage in the respiration module is similar to that of the ECG module. Figure 5 illustrates this module schematically.

Stage I

The first stage in the respiration module is of amplifier IC. This stage is used for amplifying and filtering the acquired respiration signal.

Stage II

Conditioned respiration signals obtained from stage one are in analog format. Stage II is dedicated to convert this analog signal to digital format. Flash memory of the microcontroller in this stage is programmed to perform this conversion. The digitized and serial data containing both ECG and respiration signals are transferred to the Laptop/PC through USB.

The total cost of this proposed data acquisition system comprising of ECG and respiration module along with electrodes and sensors comes out to be less than $250. This, however, does not include the cost of a general-purpose Laptop/PC with preloaded windows.

4. Graphical user interface of data acquisition system

Data acquired from the hardware is transferred to laptop/PC through USB cable. This data is composed of ECG and Respiration signals, which are displayed on laptop/PC as shown in Figure 5. The raw non-stationary ECG signal is contaminated by numerous disturbances like power line interference, baseline wandering, channel noise, muscle artifacts, respiration, etc. For further analysis of ECG, firstly these noises are removed to obtain a clear and denoised ECG signal. Baseline wander in ECG signal is caused due to subject movement, the frequency of which ranges from 0.5 Hz to several Hz. In this software notch filter around zero frequency is used to remove this drift. To eliminate other noises savitzky-golay filter is used, which is based on the least square polynomial approximation method to get a smooth ECG waveform. In the savitzky-golay filter, a polynomial is fitted through the fixed number of measured data points using the least square approximation. These values of fitted polynomial give the smoothed values of measured data [20, 21]. Polynomial to be fitted through the ECG data $E_i(x)$ is denoted by $P_i(x)$ of degree M which can be expressed as in (2).

$$P_i(x) = \sum_{K=0}^{M} c_K (x - x_i/\Delta x)^K \tag{2}$$

In this, we assumed that the abscissa x_i is uniformly spaced with $x_{i+1} - x_i = \Delta x$. To fit the polynomial through the measured data utilizing least square approximation we have to determine the coefficients c_k such that

$$\sum_{j=i-n_L}^{i+n_R} (P_i(x_j) - E_i(x_j))^2 = minimum$$

From the smooth ECG signal, RR interval is computed by detecting two consecutive R peaks and then finding the time interval between them. The R peaks are detected using the Tompkins method. The RR interval data generated is stored in ASCII files. figure 7 depicts the algorithm used for creating RR interval from ECG signal. Similarly, an ASCII file is also generated for the respiration signal. This whole work is done in the software part of the system, which is installed on laptop/PC.

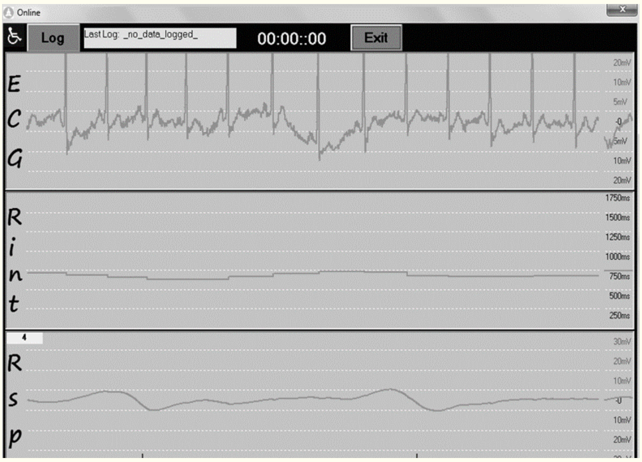

Figure 6. Data Acquired showing ECG signal, RR intervals, and respiration signal

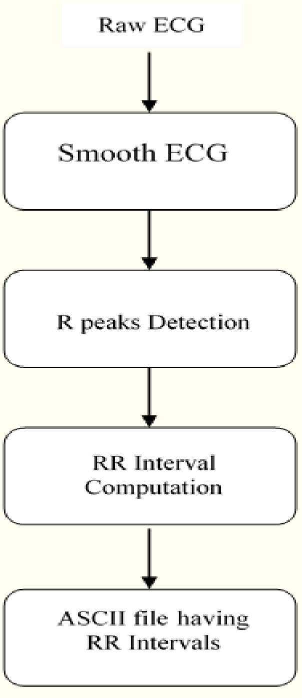

Figure 7. Represent RR algorithm

5. Conclusion

The interest of the researchers is growing towards the correlational studies between respiration and heart rate variability. For the correlational study, both the signals should be acquired simultaneously. Standard data acquisition systems are available for acquiring this type of data. These systems are normally bulky, power consuming, and costly. To eliminate all these drawbacks a new dedicated data acquisition system is proposed. The novelty of the proposed system is its compact size, portability, low cost, and laptop compatible with USB charging. The cost for one of the standard data acquisition system like Biopac (MP150) including ECG and respiration module is approximately $12000, while the proposed data acquisition system including ECG and respiration module will cost less than $250. The proposed system has built-in software to process the ECG signal, data R peaks, compute RR intervals, and directly output RR intervals in text file format, thus making it user-friendly and fast. In contrast to all these advantages, the data acquisition system holds a drawback in that it is not a wireless system. Further work can be done to make this system a wireless system.

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7. Conflict of interest

The authors declare that they have no conflict of interest

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