HRV Performance Analysis in Photoplethysmography and Electrocardiography

Subhajit Bhowmick
Electronics and Instrumentation Enginerring Department
Techno Main Salt-Lake, Kolkata
subhajitsan@yahoo.co.in

Palash Kumar Kundu
Electrical Engineerng Department
Jadavpur University, Kolkata
palashm.kushi@gmail.com

Dharma Das Mandal
Electrical Engineerng Department
Techno Main Salt-Lake, Kolkata
dharma1_das@yahoo.com

***Abstract*— In the recent past, treatment of cardiovascular ailment and related research, stress level estimation in wearable sensor devices have been extensively using Heart rate variability(HRV). Due to some difficulties in ECG (Electrocardiography) measurements, PPG (Photoplethysmography) has evolved out as an alternative to ECG in HRV estimation, as PPG emulates cardiac rhythm. This study presents a reliable estimation of all the traditional HRV parameters from the PPG based method. A portable low-cost device is proposed here for acquiring combined ECG and PPG signals which can monitor, store and communicate to remotely located computers for measurement of HRV parameters. It is a promise to deliver a composite, non-invasive cardiovascular system diagnostic tool.**

Keywords— Electrocardiography, Heart rate variability, Photoplethysmography, RR interval

I. INTRODUCTION

In ECG (Electrocardiography) time series, HRV represents the time lag flanked by consecutive R waves. Autonomic nervous system (ANS) of the cardiovascular system is a function of HRV. The sympathetic and parasympathetic nervous system controls of the human body are also related to HRV [1-7]. Time and Frequency domain non-linear methods can decipher the physiological information entrenched in HRV. In the spectral domain, parting and assigning power distribution among diverse frequency bands corresponding to the consecutive inter-beat RR intervals of the ECG signal enables representation of HRV signal. The low frequency band is responsible for sympathetic nervous system activity, whereas the high frequency power distribution is responsible for respiratory sinus arrhythmia facilitated by parasympathetic. PPG (Photoplethysmography) has evolved out as an alternative to ECG in HRV estimation, as PPG emulates cardiac rhythm. To corroborate the fact, it can be mentioned that PPG-HRV is being used in commercial wearable heart rate monitors. In the present work, HRV has been estimated simultaneously on ECG and PPG of three male and female subjects of different age groups, which seems to be promising [8-9]. A comprehensive and systematic study between ECG and PPG based HRV parameter estimation has been presented. A portable low-cost, composite (ECG and PPG signals), non-invasive cardiovascular monitor based on HRV is being proposed.

II. EXPERIMENTAL SET-UP

Heart rate variability (HRV) helps assessing ANS activities of the cardiovascular system. Following are the components of the experimentation.

A. ECG Sensor

Single Lead cost-effective Heart Rate Monitor board equipped with AD 8232 Spark Fun, an integrated signal conditioning module for ECG was used to measure the electrical actions of human heart. These electrical engagements of heart evolved as Electrocardiogram and output as an analog reading. The board is designed to extract, amplify, and filter small bio potential signals in the presence of noise interferences. The module was energised by 3.3 V DC supply and the pins SDN, LO+, LO-, OUTPUT provide essential support to this monitor to work in an Arduino or other development board. RA (Right Arm), LA (Left Arm), and RL (Right Leg) pins are also attached to use custom sensors. Additionally, there is an LED indicator light that pulsates to emulate the rhythm of a heart beat[10-15].

B. PPG Sensor

A photoplethysmogram (PPG) can be used to detect blood volume changes through the tissues. Transmittance and reflectance are two basic types of photo plethysmography. A typical reflectance type PPG sensor (HRM2511E Easy Pulse Plug in V1.1) module consists of IR transmitter and receiver were closely placed to each other[16-18].

The single lead probes for ECG with and output lead of reflectance type fingertip PPG sensor are fed to 2 –analog channels of ATMEGA328 (ARDUINO UNO R3) embedded controller shown in Fig.1(a). The data acquisition programmer by embedded C (ARDUINO C) runs to capture PPG and ECG signatures with sampling rate of 1000Hz and 250 HZ, respectively, from a human subject simultaneously shown in Fig. 1(b). The ATMEGA328 (ARDUINO UNO R3) embedded controller is connected to computer to save the raw data file (.txt)containing sampled data of ECG and PPG signals both.

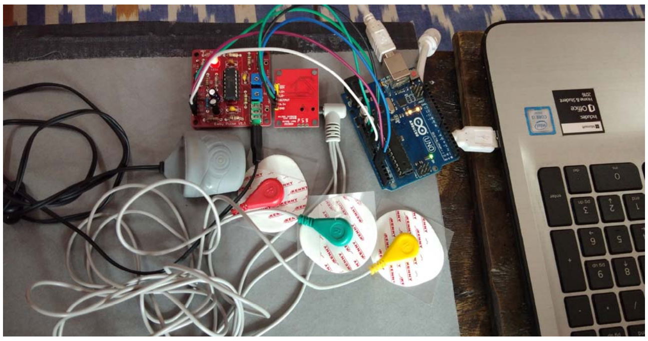

Fig. 1(a). ECG and PPG combined sensors module

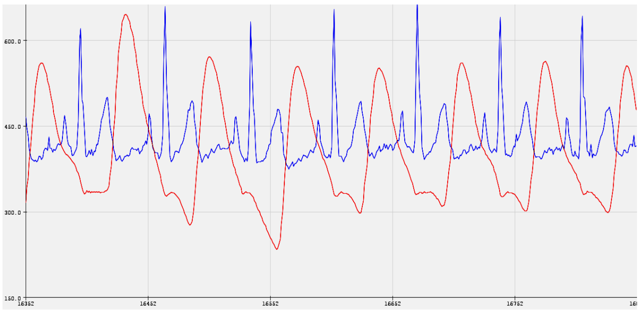

Fig. 1(b). ECG and PPG combined waveform recorded by ARDUINO IDE.

III. DATA PROCESSING & ANALYSIS

Captured ECG and PPG signatures were processed separately. The raw data files including sampled data of ECG and PPG data sets of different subjects are processed by removing base line drift and filtering noise (using band pass filter having band width of 3 Hz to 75 Hz for ECG and 2HZ to 40 Hz for PPG) using MATLAB 15B.The detected R crests of the ECG and P peaks of PPG signals are shown in Fig. 2(a), (b) and Fig. 3(a), (b) respectively at rest and after exercise condition[19-20]. HRV parameters (in time domain), namely, mean of NN interval, standard deviation of NN interval (SD_{NN}), the square root of the mean squared differences of consecutive NN intervals (SSD_{rM}),Percentage of pairs of adjacent RR intervals ($pNN50_{RR}$) and PP intervals ($pNN50_{PP}$) which exceeds 50 ms. Poincare plots of short-term HRV (SD1) vs long term HRV (SD2) were constructed by plotting the RR interval and PP intervals of ECG and PPG signal as functions of themselves and with delay by one sampling instant[21-22].

IV. RESULT

HRV parameters for 6 subjects with 3 males and 3 females having age of 12, 22 and 55 years are presented in TABLE–I (A), (B) and II (A), (B). The detected R-peaks and P-peak for ECG and PPG waveforms are shown in Figs. 2(a), (b) and Figs. 3(a),(b). HRV analysis is done beat wise on ECG and PPG signatures.

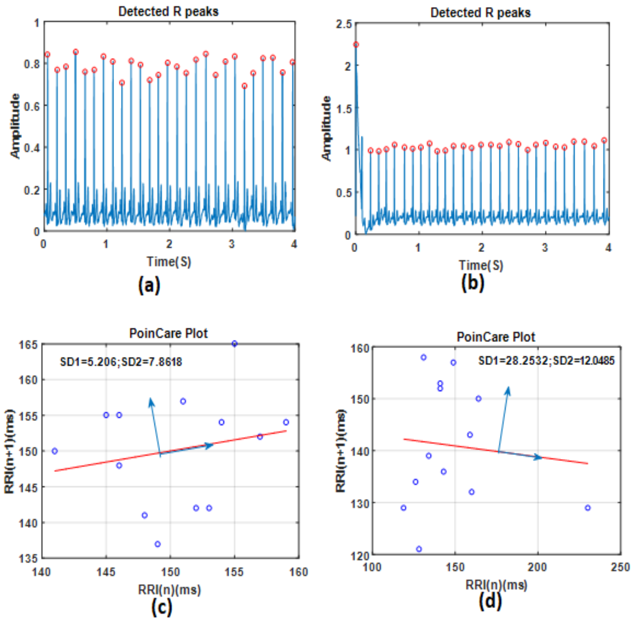

Fig. 2. detected peaks in ECG (a). at rest, (b).after exercise , Poincare plot (c). at rest, (d). after exercise

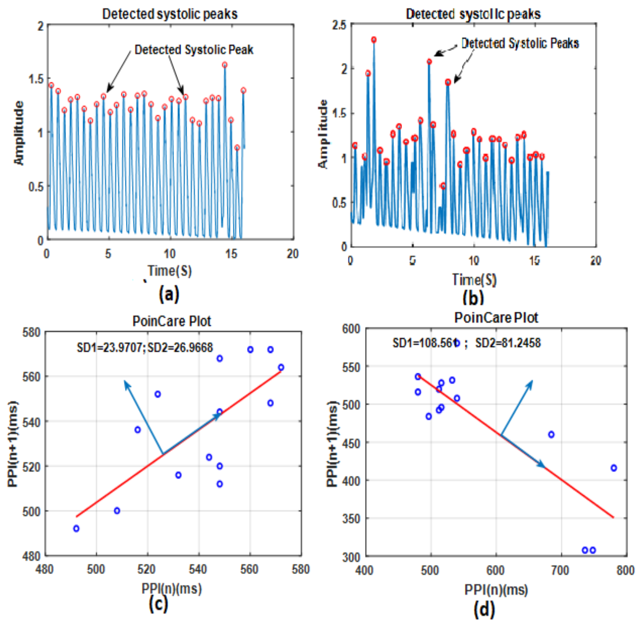

Fig. 3. detected peaks in PPG (a). at rest, (b).after exercise , Poincare plot (c). at rest, (d). after exercise

The RRI and PPI values for ECG and PPG waveforms are better illustrated in Poin care plots with SD1 and SD2 values shown in Fig. 2(c),(d) and 3(c), (d).

TABLE I(A). HRV FACTORS FOR 6 SUBJECTS BASED ON BEAT-WISE ANNOTATION OF PPG SIGNATURE(at rest)

	Age(Yrs)	***SD_{NN} (ms)***	***SSD_{rM} (ms)***	***$pNN50_{PP}$***	***Mean (ms)***	***SD1 (ms)***	***SD2 (ms)***
Male	12	16.10	26.20	70.80	611.00	18.20	15.00
	22	16.50	22.20	75.00	618.00	16.20	16.70
	55	25.20	13.30	44.10	440.00	23.70	25.20
Female	12	25.50	18.30	57.10	538.00	24.00	27.00
	22	31.70	36.20	73.90	642.00	31.30	33.30
	55	16.20	20.70	71.00	483.00	15.30	16.40

TABLE I(B). HRV FACTORS FOR 6 SUBJECTS BASED ON BEAT-WISE ANNOTATION OF PPG SIGNATURE(after exercise)

	Age(Yrs)	***SD_{NN} (ms)***	***SSD_{rM} (ms)***	***$pNN50_{PP}$***	***Mean (ms)***	***SD1 (ms)***	***SD2 (ms)***
Male	12	25.10	29.30	91.30	640.00	23.70	27.30
	22	11.00	16.80	66.70	544.00	13.40	85.20
	55	17.00	11.70	34.30	423.00	16.00	18.20
Female	12	47.30	70.90	84.60	572.00	51.50	43.70
	22	47.30	70.90	84.60	572.00	51.50	43.70
	55	34.20	29.20	56.30	474.00	21.90	39.20

TABLE II(A). HRV FACTORS FOR 6 SUBJECTS BASED ON BEAT-WISE ANNOTATION OF ECG SIGNATURE(at rest)

	Age(Yrs)	***SD_{NN} (ms)***	***SSD_{rM} (ms)***	***$pNN50_{RR}$***	***Mean (ms)***	***SD1 (ms)***	***SD2 (ms)***
Male	12	13.00	9.05	12.50	157.00	17.90	7.00
	22	5.52	6.09	20.00	148.00	5.38	5.74
	55	5.52	6.09	35.50	148.00	5.38	5.74
Female	12	3.39	2.46	00.00	111.00	3.31	3.61
	22	6.60	9.32	39.10	159.00	6.16	7.27
	55	3.39	2.46	10.00	111.00	3.31	3.61

TABLE I I(B). HRV FACTORS FOR 6 SUBJECTS BASED ON BEAT-WISE ANNOTATION OF ECG SIGNATURE(after exercise)

	Age(Yrs)	***SD_{NN} (ms)***	***SSD_{rM} (ms)***	***$pNN50_{RR}$***	***Mean (ms)***	***SD1 (ms)***	***SD2 (ms)***
Male	12	8.28	3.99	12.50	140.00	8.46	8.36
	22	3.34	2.35	40.00	112.00	3.65	3.12
	55	10.20	11.00	8.00	141.00	9.97	10.70
Female	12	10.20	11.00	8.00	141.00	9.97	10.70
	22	17.50	24.70	62.50	155.00	10.04	20.90
	55	17.50	24.70	62.50	155.00	10.04	20.90

V. DISCUSSION

In present work, PPG signal measured from a finger and thereof waveform data has been studies for HRV analysis. The experiment has been performed with 3 male and 3 female subjects at rest and after movement. The result shows that pNN50 values at rest in ECG and PPG are lesser than that after exercise. The PPG pulse is generated due to contraction in the heart muscle leading blood flow to the peripheral tissues. This mechanical action of heart is responsible for the lagging of PPG waveform to the R wave of ECG and is called pulse transit time (PTT). PTT varies due to age, sex, conditions of rest and movement. HRV parameters are also affected by age, gender and are measure-dependent patterns. There exists a correlation between the ECG and PPG derived HRV parameters. A plot of beat-to-beat RR interval versus PP interval shows a high correlation coefficient. Hence, PPG based method can be used for estimation of short term and long term monitoring of HRV aiming diagnostics and prognostics of cardiovascular diseases.

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