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Cranial PPG Brain Signal based Cardiovascular Parameter Estimation

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Abstract: Peripheral photoplethysmogram (PPG) is widely used for the measurement of blood oxygen saturation. Estimation of Blood Pressure (BP), Heart Rate (HR) and Respiratory Rate (RR) from peripheral PPG are area of interest for most of the researchers. The work has been carried out by the authors on Cranial PPG (CPPG) recorded from head of the subject by using a designed prototype. Prototype is an optical sensor which uses a Red LED as source and OPT101 as a detector to capture CPPG. The system has been tested on ten real subjects of both the genders (3 males and 7 females) aged between 18-40 years. Automatic BP machine was used as a standard for estimation of cardiovascular parameters. It was observed that the various cardiovascular parameters estimated form CPPG brain signal were matching the automatic BP machine.

Keywords: Photoplethysmogram, Blood Pressure, Heart rate, Cardiovascular Parameters, Brain Signal.

1. INTRODUCTION

Plethysmogram is widely used in the medical field for the measurement of blood oxygen saturation, the additional information from PPG signal such as RR, HR and BP along with the blood oxygen saturation will gain better weight age in the same filed. It is a non-invasive, easy, lightweight system and can be used for continuous measurement of BP [7]. RR, HR and BP monitoring is significant in clinical diagnosis therapeutics, prognosis, during surgical procedures, post - operative care units, in addition to, monitoring sleep disorders, drug administration and cardiopulmonary disorders. RR recording is generally carried out by using spirometer, pneumotachometer, nasal thermister based system or whole body plethysmography. HR recording is generally carried out by using automatic BP machine or from Electrocardiogram (ECG) [2]. Classical method of BP measurement is by using Sphygmomanometer or by using automatic BP machine. Sometimes is estimated indirectly from two signals; ECG and PPG from peripheral site [3]. Instead of using various dedicated instruments for the measurement of RR, HR and BP, a single system based on CPPG brain signal is developed by the authors. It is a continuous, non-invasive, non-occlusive, electro-optical method of recording cardiovascular parameters from a single sensor based brain signal.

1.1 PPG Waveform and Blood Pressure

Blood Pressure (BP) is the pressure of the circulating blood against the walls of blood vessels. BP is indicated by two terms systolic blood pressure (SBP) and diastolic blood pressure (DBP) [8]. SBP is the pressure during the left ventricle of the heart and DBP is the pressure after the contraction of the heart while chambers of the heart are refilled with blood. The normal value of SBP/DBP is 120/80 mm of Hg.

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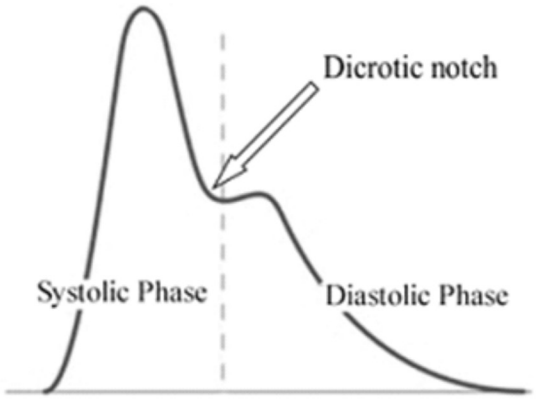

Figure 1: Anacrotic, Catacrotic Phase and Dicrotic Notch

2. MATERIALS AND METHODS

Cardiovascular parameters are generally estimated by recording a heart related signal such as ECG [8]. Studies related to the brain can be carried from various brain signals such as electrocardiogram (EEG) and CPPG. But the estimation of cardiovascular parameters from a brain signal such as EEG is a difficult task. It was found out the authors that the brain signal such as CPPG can reveal information related to brain activity as well as heart related activity. So this signal can be widely used in near future for the interpretation of Heart-Head interaction.

2.1 System Block Diagram

Figure 1 shows the system block diagram. Optical sensor developed by the authors is used to capture the photoplethysmogram (PPG). Study was carried out by the authors using two optical sensors with different source wavelength (Source LED: RED 660 nm & Source LED: IR 860 nm). To capture the cranial photoplethysmogram (CPPG) optical sensor with a source wavelength of 860 nm on AC modulated supply (2MHz, 10 V) was used (Revati Shriram et al, 2015). Automatic Blood Pressure (BP) machine was used as a standard value for BP. PPG signal was captured for 10 subjects at two sites; finger and forehead. BP was estimated from finger PPF and CPPG and lastly it was compared with the reading of the BP obtained from automatic BP machine.

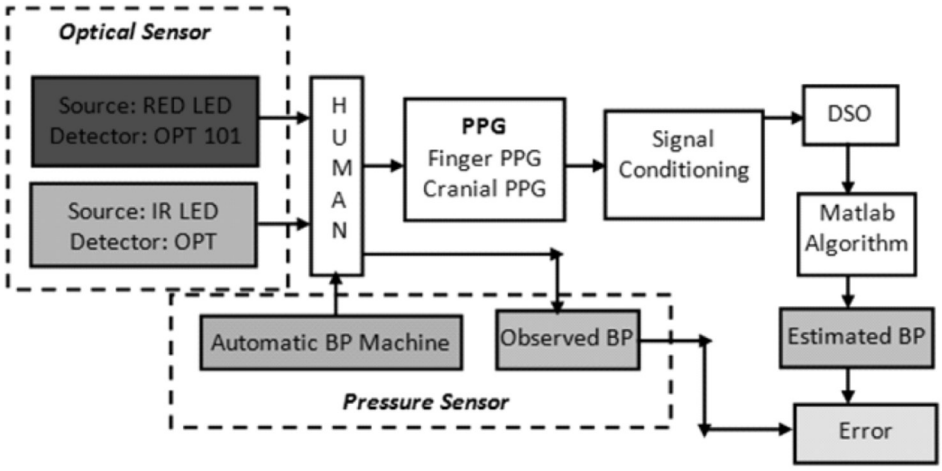

Figure 2: System Block Diagram

2.2 Signal Conditioning Circuit

Signal conditioning circuit consists of various blocks such as, filter, buffer and amplifier stages. Generally biosignals are very small in amplitude so direct amplification of signal with amplify the noise present in the signal as well. So filtering is done to remove the noise related to the AC supply and base line wonder. Output of the sensor is applied to the signal conditioning circuit through shielded cable. After amplification and filtration, signal shifted using level shifting circuit to get positive shift in the signal [5,6].

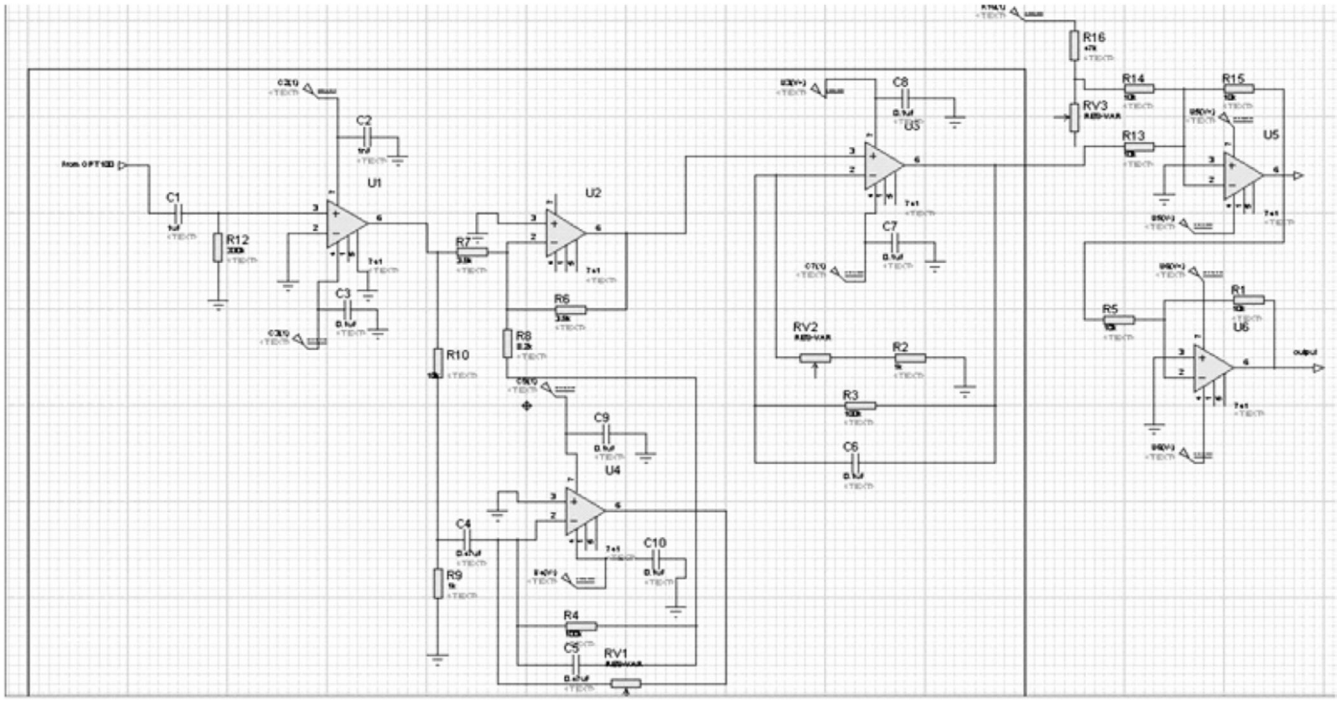

Figure 3: Signal Conditioning Circuit

2.3 Correlation Factor Calculations

Before the estimation of BP, correlation factor has to be calculated. Following are the steps to calculate correlation factor:

- Using Automatic BP machine SBP and DBP is measured. (It is a cuff based non invasive method. Cannot be used for continuous measurement)
- Then PPG waveform is captured at fingertip and at forehead (CPPG) using IR LED source of wavelength of 860 nm.
- Similarly PPG waveform is captured at only fingertip using RED LED as source. Penetration of RED light (visible) is lesser, so by using this source CPPG cannot be captured.
- 1st highest peak voltage and 1st lowest peak voltage is measured for PPG and CPPG waveform using both the sources.

$$\text{Correlation factor for SBP} = \frac{\textit{1st highest peak voltage}}{\textit{SBP value from Automatic BP machine}} \quad (1)$$

$$\text{Correlation factor for DBP} = \frac{\textit{1st lowest peak voltage}}{\textit{DBP value from Automatic BP machine}} \quad (2)$$

- In this fashion prepare the look up table for at least 10 subjects. Once the look up table is ready captured only the PPG waveform for the 11th subject and carry on the procedure below for the SBP/ DBP estimation.

$$\text{SBP estimation from PPG} = \frac{\textit{2nd highest peak voltage}}{\textit{Correlation factor for SBP for that voltage}} \quad (3)$$

$$\text{DBP estimation from PPG} = \frac{\textit{2nd lowest peak voltage}}{\textit{Correlation factor for DBP for that voltage}} \quad (4)$$

- The accuracy of the system increases with the larger look up table of correlation factor for SBP and DBP. Or by calculating the correlation factor from average highest peak value and average lowest value.

Based on figure 4 sample calculation of Correlation factor are as shown below:

Highest Peak Voltage: 9 V and Lowest Voltage: 1.8 V

Reading on automatic BP M/C for the same subject is: $\frac{SBP}{DBP} = \frac{95}{55}$ mm of Hg (5)

Correlation factor for SBP = 0.094

Correlation factor for DBP = 0.032

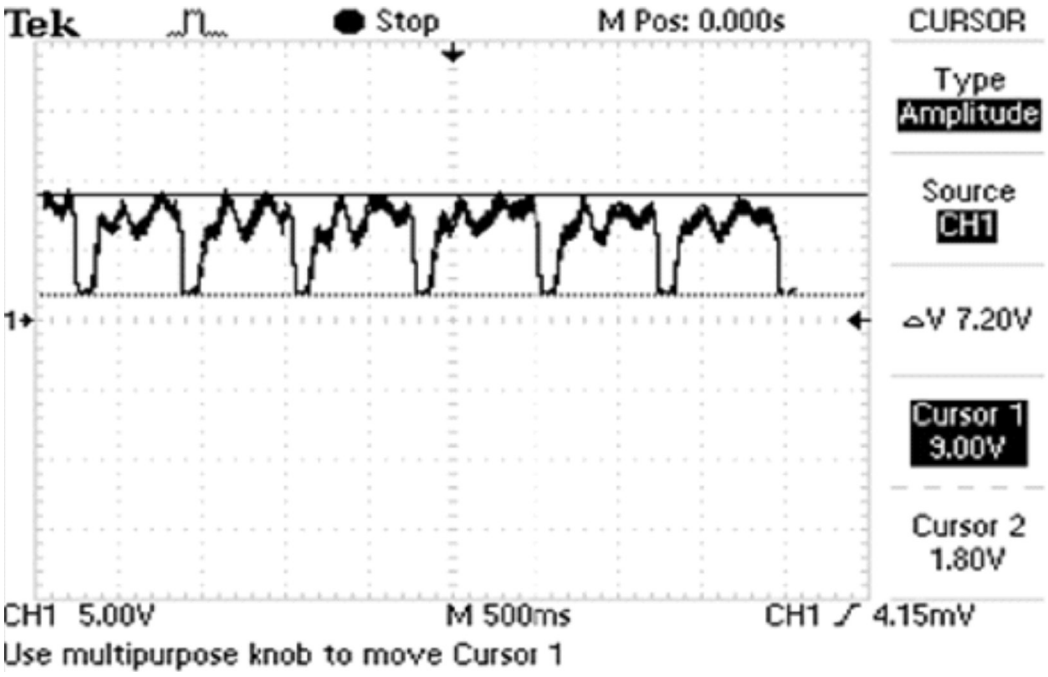

Figure 4: PPG waveform on DSO

3. SUBJECTS AND DATA ACQUISITION PROCEDURE

PPG and pulse-transducer data was simultaneously recorded for one minute from Cummins College of Engineering for women for six healthy volunteer subjects (2 male and 4 females, aged from 18 to 65 years). All subjects were in the seated position, their index fingers lying comfortably on the table and foot resting on the ground through sandals.

4. RESULTS

MATLAB based PPG data filtering is carried out before the further processing. PPG was captured at finger at cranial site (head) by using two PPG sensors; one with RED LED and other with IR LED. Penetration of IR light is more so the waveform obtained from a sensor with IR source has higher amplitude as compared to the RED source. Correlation factor is calculated for IR and RED LED at finger and at head. Table 1 shows the correlation facto calculated for 10 subjects with both the sources at finger. It can be observed that the correlation factor for IR source is a bit higher than the RED source.

Table 1

Correlation value for SBP and DBP

Automatic BP Machine (mm of Hg)		*IR LED Voltage (V)*		*IR LED Co-relation Factor for finger PPG*		*RED LED Voltage (V)*		*RED LED Co-relation Factor for finger PPG*	
SBP	*DBP*	*1st Highest Point*	*1st Lowest Point*	*SBP*	*DBP*	*1st Highest Point*	*1st Lowest Point*	*SBP*	*DBP*
113	67	3.90	2.93	0.0345	0.0437	3.42	0.912	0.0302	0.0136
109	62	3.60	2.60	0.0330	0.0419	3.64	0.2080	0.0333	0.0033
120	65	3.26	2.40	0.0271	0.0369	3.44	0.400	0.0286	0.0061
92	72	2.97	2.09	0.0322	0.0290	3.28	1.280	0.0356	0.0177
111	63	3.25	1.23	0.0292	0.0195	3.40	1.960	0.0306	0.0311
117	60	3.12	2.25	0.0266	0.0375	3.08	1.760	0.0263	0.0293
130	70	3.26	1.40	0.0250	0.0191	3.47	1.090	0.0266	0.0149
99	60	3.08	1.75	0.0311	0.0296	3.33	1.280	0.0336	0.0216
126	73	3.22	1.25	0.0252	0.0158	3.66	0.704	0.0290	0.0089
93	59	3.20	1.60	0.0344	0.025	3.76	0.400	0.0400	0.0062

From a captured PP and CPPG heart rate was calculated and then it was compared with the heart rate observed on automatic BP machine. It was seen that the HR calculated from PPG and CPPG was almost same and the mean error of 0.4 beats/minute was observed between the HR by automatic BP machine and the HR calculated from PPG or CPPG. Table 2 shows the comparison of HR and mean error in HR.

Table 2

Comparison of Observed and Calculated HR

Volunteer	*Gender*	*Age (Years)*	*Observed HR beats/minute*	*Calculated HR beats/minute*	*Error beats/minute*
1	Female	18	64	65	1
2	Female	21	73	73	0
3	Female	23	96	95	1
4	Female	36	110	110	0
5	Female	20	118	118	0
6	Female	63	98	98	0
7	Female	20	102	103	1
8	Female	39	114	114	0
9	Male	30	94	93	1
10	Male	34	92	92	0

Mean Error in HR: 0.4 beats/minute

Table 3

Observed and Calculated BP using Automatic BP Machine & IR LED at Fingertip (PPG)

Volunteer	*Gender*	*Age (Years)*	*Automatic BP Machine (mm of Hg)*		*BP from finger PPG (mm of Hg)*		*Error (mm of Hg)*	
			SBP	*DBP*	*SBP*	*DBP*	*SBP*	*DBP*
1	Female	18	113	67	106	61	5	6
2	Female	21	109	62	101	59	6	3
3	Female	23	120	65	128	61	8	4
4	Female	36	92	72	97	74	5	2
5	Female	20	107	77	108	71	1	6
6	Female	63	117	63	111	72	4	9
7	Female	20	111	63	107	58	2	3
8	Female	39	99	60	105	58	6	2
9	Male	30	126	73	121	73	3	0
10	Male	34	93	64	96	64	3	0

Mean Error in SBP = 4.3 mm of Hg
Mean Error in DBP = 3.5 mm of Hg

Table 4

Observed and Calculated BP using Automatic BP Machine & RED LED at Fingertip (PPG)

Volunteer	*Gender*	*Age (Years)*	*Automatic BP Machine (mm of Hg)*		*BP from finger PPG (mm of Hg)*		*Error (mm of Hg)*	
			SBP	*DBP*	*SBP*	*DBP*	*SBP*	*DBP*
1	Female	18	113	67	120	75	7	8
2	Female	21	109	62	116	57	7	5
3	Female	23	120	65	124	69	4	4
4	Female	36	92	72	99	77	7	5
5	Female	20	107	77	105	80	4	3
6	Female	63	117	63	122	67	5	4
7	Female	20	130	70	124	79	8	9
8	Female	39	99	60	104	64	5	4
9	Male	30	126	73	123	71	5	2
10	Male	34	93	59	97	55	4	4

Mean Error in SBP = 5.6 mm of Hg
Mean Error in DBP = 4.8 mm of Hg

Table 5

Observed and Calculated BP using Automatic BP Machine & IR LED at Forehead (CPPG)

Volunteer	*Gender*	*Age (Years)*	*Automatic BP Machine (mm of Hg)*		*BP from cranial PPG (mm of Hg)*		*Error (mm of Hg)*	
			SBP	*DBP*	*SBP*	*DBP*	*SBP*	*DBP*
1	Female	18	113	67	109	62	4	5
2	Female	21	109	62	114	60	5	2
3	Female	23	120	65	122	58	2	7
4	Female	36	92	72	101	69	9	3
5	Female	20	107	77	116	68	9	9
6	Female	63	117	63	118	58	8	5
7	Female	20	130	70	124	75	6	5

8	Female	39	99	60	105	67	6	7
9	Male	30	126	73	120	77	6	4
10	Male	34	93	59	97	59	4	0

Mean Error in SBP = 5.9 mm of Hg
Mean Error in DBP = 4.7 mm of Hg

CONCLUSION

It is a non-invasive cuffless continuous method of BP measurement. HR is estimated by measuring the distance between two consecutive peaks of CPPG or finger PPG. With change in the source wavelength of sensor, only magnitude/amplitude of the photoplethysmography pulse gets affected. Time duration between the consecutive photoplethysmography pulses is independent of the source wavelength used. So HR measured using source as IR LED of 860 nm and RED LED of 660 nm are same.

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