Blood Pressure Measurement using Pulse Transit Time (PTT)

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Abstract— **The present blood pressure (BP) measurement devices are mostly built on the principle of auscultation, oscillometry or tonometry, all of which use an inflatable cuff. This paper aims to develop a cuff-less and continuous technique for measuring BP by pulse transit time (PTT). PTT will be measured as the time interval from the peak of R wave of Electrocardiogram (ECG) to a characteristic point at predetermined thresholds on the Photoplethysmogram (PPG) of the same cardiac cycle. Simultaneous recording of ECG and PPG shall be acquired from fingertips of the subject by stainless steel electrodes and a pair of light emitting diode and photo detector is used to estimate the PTT.A multiple regression model which could estimate unspecified people's blood pressure (BP) conveniently & continuously is proposed.**

Keywords—**Blood Pressure, Electrocardiogram (ECG), Photoplethysmogram (PPG), PulseTransitTime (PTT) .**

I. INTRODUCTION

Blood Pressure (BP) is the pressure exerted by circulating blood upon the walls of blood vessels. It is created primarily by the contraction of the cardiac muscles. It is measured or recorded by two numbers. The first, Systolic Pressure, is measured when the heart contracts which is highest. The second, Diastolic Pressure, is measured when the heart relaxes or expands and is lowest. Normal resting blood pressure in an adult is approximately 120/80 mm Hg. This cuffs less & non-invasive monitoring of pressure using PTT is explained by Poon [1], Dingli [5] &Fung [8].

Blood Pressure can be estimated either by invasive or non-invasive methods. Continuous monitoring is seen in invasive techniques. This technique involves direct measurement of arterial pressure by placing a cannula needle in an artery, but it is tough to set up and infection prone too. The non-invasive techniques [2], [7], [9] are the Auscultatory and Oscillometry methods [6] all of which use an inflatable cuff. The need of a cuff in these devices limits the further reduction in size and power consumption, and restricts the frequency and ease of their usage. Therefore, this paper aims to develop a cuff-less and continuous technique for measuring BP by pulse transit time (PTT). PTT will be measured as the time interval from the peak of R wave of Electrocardiogram (ECG) to a characteristic point at predetermined threshold on the Photoplethysmogram (PPG) of the same cardiac cycle.

Simultaneous recording of ECG and PPG shall be acquired from fingertips of the subject by stainless steel electrodes and a pair of light emitting diode and photo detector is used to estimate the PTT.

1.1 Electrocardiogram (ECG)

ECG is the electrical activity of the heart. As the heart undergoes depolarization and depolarization, the electrical currents that are generated spread not only within the heart, but also throughout the body. This electrical activity generated by the heart can be measured by an array of electrodes placed on the body surface. A typical ECG tracing is shown in Figure1.1.1. The complete waveform is called an electrocardiogram with labels P, Q, R, S, and T indicating its distinctive features. The P wave arises from the depolarization of the atrium. The QRS complex arises from depolarization of the ventricles. The magnitude of the R-wave within this complex is approximately 1mV. The T wave arises from re-polarization of the ventricle muscle.

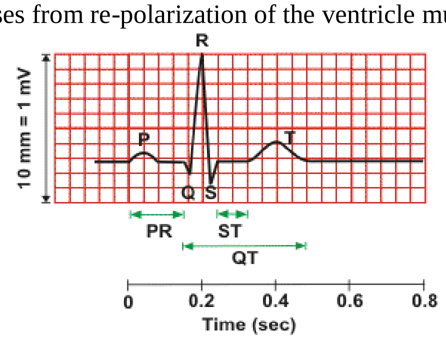

Figure1.1.1 A typical ECG tracing

1.2 Photoplethysmography (PPG):

Photoplethysmography (PPG) is an optical measurement technique that can be used to detect blood volume changes in the micro vascular bed of tissue.

Figure1.2.1 A typical PPG finger probe

The basic form of PPG technology requires only a few Opto-electronic components: a light source to illuminate the tissue (e.g. skin), and a photo detector to measure the small variations in light intensity. PPG is most often employed non-invasively and operates at a red or a near infrared wavelength.

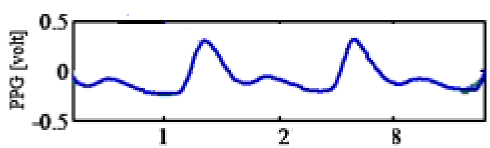

Figure 1.2.2 A typical PPG tracing

1.3 Pulse Transit Time (PTT)

Pulse transit time (PTT), the time interval for a blood pressure (BP) pulse to travel from one arterial site to another. Photoplethysmographic (PPG) signal is employed to indicate the pressure pulse in peripheral arteries and the R-wave of electrocardiogram (ECG) is used to initiate PTT, Figure 1.3.1 illustrates the definitions of PTT-peak.

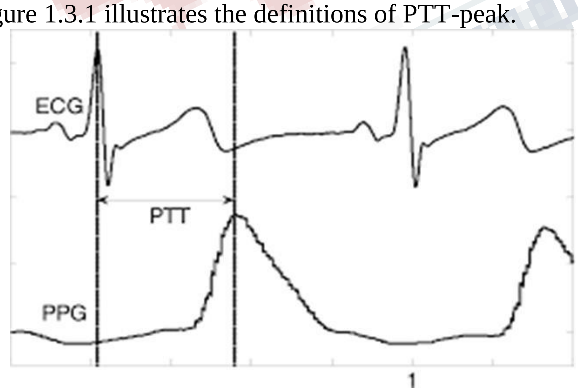

Figure 1.3.1 An illustration of the definitions of PTT-peak

II. HARDWARE DESIGN

A. Band Pass filter

Second order Butterworth high pass filter and low pass filter are used. Band pass filter has a cutoff frequency of:-High pass filter: FL=0.5Hz Low pass filter: FH=100Hz (for ECG): FL=0.5Hz, FH=20Hz (for PPG).

$$F=\frac{1}{2\pi RC} \quad \text{.........} \ (2.1)$$

B. Notch filter

Cutoff frequency of 50 Hz is used.

$$Fc=\frac{1}{2\pi RC} \quad \text{.........} \ (2.2)$$

C. Buffer Amplifier

It is used for impedance matching.

D. Gain Amplifier

Gain Amplifier with gain 37 is used

$$G=\frac{R1+R2}{R1} \quad \text{......} \ (2.3)$$

2.1 ECG BLOCK DIAGRAM

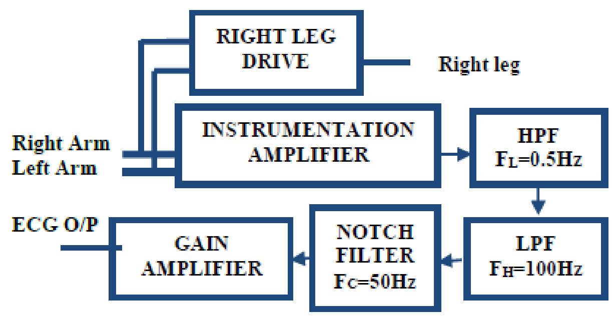

Figure 2.1.1 ECG block diagram

E. Electrodes

Is a transducer which converts ionic potential into electronic potential. Here Silver/Silver Chloride electrodes are used as they are non-polarizable and as they exhibit less electrical noise especially at low frequencies. ECG recordings are obtained from the finger tips of the subject by stainless steel electrodes.

F. Instrumentation Amplifier

An instrumentation amplifier is a differential amplifier circuit providing high input impedances with ease of gain adjustment through the variation of single resistor. AD620 Instrumentation amplifier with gain of 2 is used in this case.

$$G=\frac{R1+R2}{RG}+1 \quad \text{.....} (2.4)$$

$$R1=R2=27k\Omega;\ G=2;\ RG=51k\Omega$$

2.2 PPG BLOCK DIAGRAM

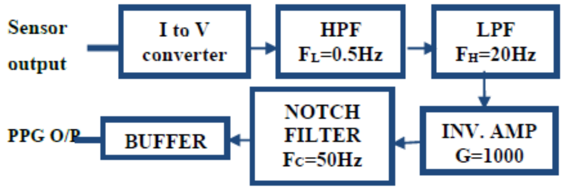

Figure 2.2.1 PPG block diagram

G. PPG Sensor

Nelcor-DS100 sensors are used. Sensor is connected to the board through a simple DB9 connector. The sensor already contains LED's, Red, Ired and the photo detector needed for light absorption detection.

H. I to V converter

Output generated by the photo detector is a current that represents the light absorption. This current needs to be converted into voltage in order to be properly filtered and treated. Conversion is performed using a current to voltage converter.

I. Inverting Amplifier

Output of I to V Converter is going to be inverted (negative), In order to obtain a positive output, in PPG circuit an Inverting amplifier is used.
Inverting amplifier with gain 1000 is used.

G=-R2/R1

Where R2=1MΩ;R1=1KΩ;

2.3 HARDWARE PICTURES

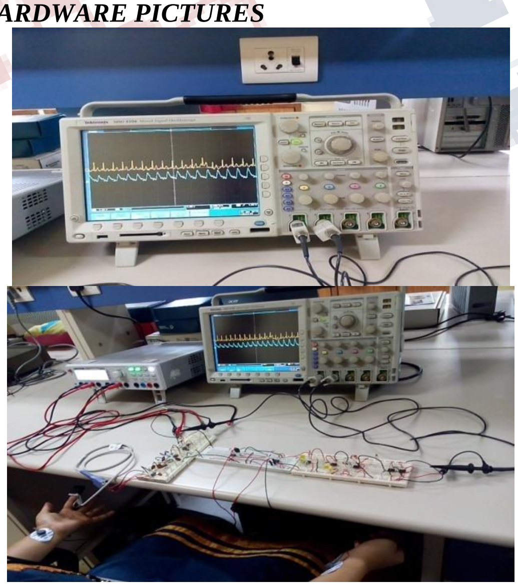

Figure 2.3.1 Signals obtained on CRO

III. SOFTWARE DESIGN

3.1 NOISE REMOVAL

ECG signal, the electrical interpretation using the cardiac muscle activity, can easily interfere with different noises while gathering and recording. The most troublesome noise sources are the Electromyogram (EMG) signal, Instability of electrodes, skin effect, 50/60 Hz power line interference and the baseline wandering. Such noises are difficult to be removed using filtering procedures.

3.2 PEAK DETECTION

The acquired ECG and PPG signals are processed to Compute ECG peak (ECGp), PPG peak (PPGp).

3.3 PTT CALCULATION

PTT is calculated using the ECGp and PPGp. The difference between the ECGp and PPGp yields PTT. The ECG peak obtained at A and PPG peak obtained at B in Figure 3.2.1 are considered.

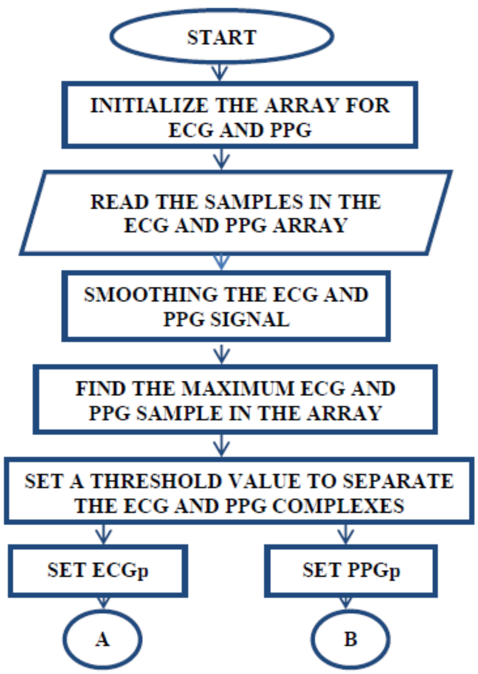

Figure 3.2.1 ECGp and PPGp detection

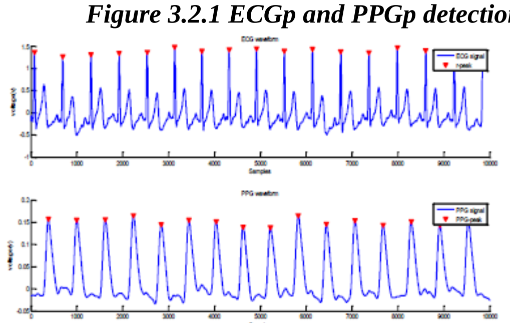

Figure 3.2.2 Detection of ECG & PPG peaks through MATLAB operation

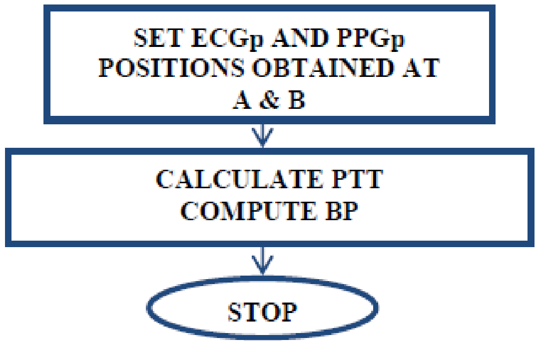

Figure 3.3.1 PTT calculation

3.4 METHODOLOGY

Pulse transit time (PTT) is commonly accepted as a candidate due to its good correlation with BP during steady state and dynamic exercise. It is well known that the relationship between vascular volume (V) and Transmural pressure (Ptm), which is defined as the difference of internal and external pressure, is commonly fitted as a sigmoid curve.

$$V = \frac{a}{1+\exp[-bP_{tm}]} = \frac{a}{1+\exp[-bP]}, \quad \ldots\ldots (3.4.1)$$

where a and b are fitting parameters. In this paper, as external pressure equals to zero, the Trans mural pressure equals to internal pressure. The Bram well–Hill equation describes how pulse wave velocity (PWV) relates to arterial distensibility.

$$PWV = \sqrt{\frac{V\Delta P}{\rho\Delta V}}, \quad \ldots\ldots (3.4.2)$$

Where Δp and ΔV are the changes of blood pressure and volume, while ρ is the blood density. Adding above equations and re-arranging the equation with Taylor expansions, we obtain the relationship between PWV or PTT and Ptm as,

$$PWV = \sqrt{\frac{\exp[bP]+1}{\rho b}} \approx \frac{1}{\sqrt{\rho b}} \frac{\sqrt{2}}{(1-\frac{bP}{4})} \equiv \frac{1}{cP-c/4}, \quad \ldots(3.4.3)$$

It is well known that velocity is equal to distance traveled by time taken.

V= Distance traveled / Time taken

i.e., PWV = L / PTT....... (3.4.4)

Substitute (3.4.4) in (3.4.3), we get

PTT = L (*cP-c/4*)….. (3.4.5)

Where L is the distance the pulse travels (roughly equals to the arm length), and c is a constant determined by experiment data fitting.

Now let’s generalize it as follows:

PTT = L (cP + d)….. (3.4.6)

Where c and d are two independent values to be determined

□ P = ((PTT/L)-d)/c….(3.4.7)

The above equation can be generalized as follows

P =X + A*PTT + B*L….. (3.4.8)

This equation indicates that one point calibration can roughly determine the relationship between PTT, Arm length and Pressure.

A lot of researchers asserted that Age, PTT, Arm circulation, Arm length, Height, Weight, Percent of body fat, and Mass of body fat are associated with BP.

Physical characteristic parameters which might affect BP are selected with the standard that can be measured easily and conveniently, and assumed that the physical characteristic parameters were PTT, Heart Rate, Arm length and Age.

3.5 REGRESSION MODEL

In this study, 10 healthy subjects aged from 20 to 30 years were joined. Figure 3.5.1 shows general block Diagram for calculating Calibration constants and Blood Pressure. The experiment was conducted as follows

Step1) Let the subject relax for about 5 minutes

Step2) Measure SBP and DBP with standard BP meter.

Step3) Measure ECG and PPG with the designed instrument and calculate PTT from them.

Step4) Repeat step2 and step3 at different conditions.

Step5) Measure Arm length, heart rate and Age.

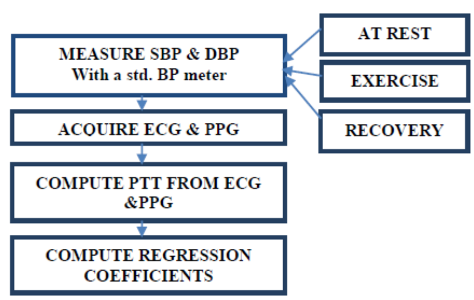

Figure 3.5.1 Data collection for calculating correlation coefficients

Using age, arm length, HR and PTT valid parameters, the multiple regression analysis is made. Statistical analysis was performed in Microsoft Excel. Multiple linear regression analysis was performed and results are reported as partial regression coefficients of predictor variables and to compare the actually measured BP with these estimated BP. The estimated SBP and DBP through the multiple regression equations are compared with the actual measured SBP and DBP. The procedure of regression analysis is shown Figure 3.5.2.

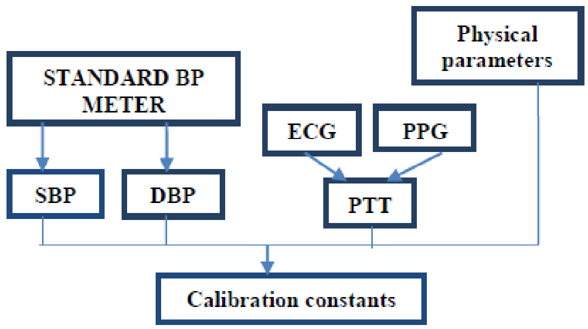

Figure 3.5.2 Procedure of multiple regression analysis with
PTT and valid physical characteristic parameters

The calibration constants are obtained by performing regression analysis in Microsoft EXCEL and the equations are derived for calculating SBP and DBP. An equation can be formed from the coefficients shown in Table 3.5.1:

	Systolic BP	Diastolic BP
Arm length	19.5142	16.5536
PTT	0.0430	0.0079
AGE	-0.7753	-1.1052
Heart rate	0.3627	0.0691
Constant	-50.0629	-26.8856
R^2 value	0.4274	0.4916

Table 3.5.1: Derived Coefficients of multiple regression equation.

Equations derived
SBP=-50.0629+(19.5142*Armlength)+(0.0430*PTT)-(0.7753*Age)+(0.3627*Heartrate) ……..(3.5.1)
DBP=-26.8856+(16.5536*Armlength)+(0.0079*PTT)-(1.1052*Age)+(0.0691*Heartrate) …….(3.5.2)

IV. RESULT AND DISCUSSION

PTT is measured from simultaneous acquired ECG & PPG recordings from finger tips using MATLAB.

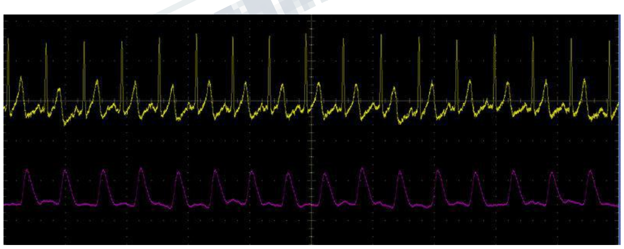

Figure 4.1 simultaneous acquired ECG & PPG recordings

The method of measuring PTT from ECG and PPG waveform is a good technique for non-invasive BP measurement during steady state and dynamic exercise and is comfortable for the subject.

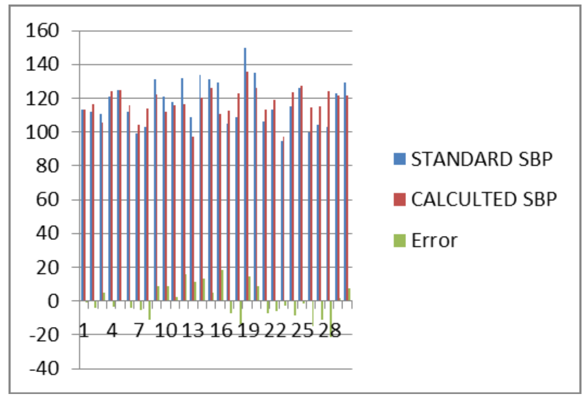

Figure 4.2 Bar graph showing comparison of calculated SBP with the standards

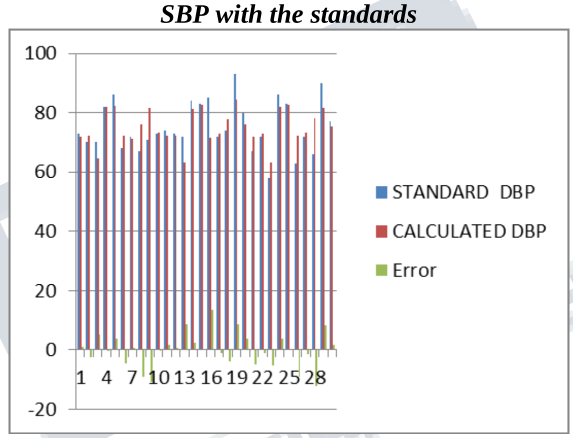

Figure 4.3 Bar graph showing comparison of calculated DBP with the standards

Table 4.1 shows the standard and calculated values of Systolic Blood Pressure.

Sub	Std. SBP			Calculated SBP		
	AT REST	EXERCISE	RECOVERY	AT REST	EXERCISE	RECOVERY
1	113	118	106	113.1	115.9	113.2
2	112	132	113	116.2	116.2	119.3
3	111	109	95	105.8	97.36	97.48
4	121	134	115	124.2	120.4	123.7
5	125	131	126	124.6	126.3	127.3
6	112	129	100	115.9	110.9	114.9
7	99	105	104	104.1	112.3	115.1
8	103	109	103	113.8	122.8	124.3
9	131	150	123	122.3	135.5	121.4
10	121	135	129	111.9	126	121.5

Table 4.1 Standard and Calculated SBP

Table 4.2 shows the standard and calculated values of Diastolic Blood Pressure.

Sub	Std. DBP			Calculated DBP		
	AT REST	EXE RCIS E	RECO VERY	AT REST	EXER CISE	RECO VERY
1	73	74	67	71.83	72.34	71.84
2	70	73	72	72.39	72.41	72.98
3	70	72	58	64.78	63.22	63.25
4	82	84	86	82.13	81.42	82.03
5	86	83	83	82.22	82.53	82.72
6	68	85	63	72.35	71.46	72.16
7	72	72	72	71.37	72.89	73.41
8	67	74	66	76.05	77.71	77.99
9	71	93	90	81.77	84.29	81.63
10	73	80	77	73.42	76.07	75.22

Table 4.2 Standard and Calculated DBP

V. CONCLUSION

The PTT can be taken as the determining factor for BP measurement as the average error estimated is found to be within the AAMI standards (that the error mean should be smaller than or equal to ±5 mmHg). The method of estimating the blood pressure was non-invasive without using the cuff. The blood pressure was estimated using PTT from PPG & ECG signals. This technique will be extended to the development of a portable real-time system and system capable of continuously monitoring patients for a long period of time.

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