Scientific Journal of Impact Factor(SJIF): 3.134
e-ISSN(O): 2348-4470
p-ISSN(P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 2,Issue 5, May -2015

Dynamic Blood Pressure Parameter Estimation

Correlation of Pulse Transit Time and Systolic Blood Pressure

Piyush V. Patel[1], Mitul B. Patel[2]

[1]*Biomedical Department, Government Engineering College, Gandhinagar*
[2]*Biomedical Department, Government Engineering College, Gandhinagar*

Abstract — *Dynamic monitoring and analysis of blood pressure is very essential for patients having critical cardio-vascular instability. Current technology avails the intermittent analysis of blood pressure for post-operative monitoring or Intensive Care Units using arm cuff, which is inappropriate for acute pressure changes as well for long term analysis.*

In this paper we used a cuff less method to establish a relationship between Pulse Transit time (PTT), Pulse Transient Velocity (PTV), Heart Rate (HR) and Systolic Blood Pressure (SBP) for dynamic parameter estimation and experimental validation.

Keywords- *Dynamic BP Monitoring, Pulse Transit Time, Pulse Transient Velocity.*

I. INTRODUCTION

Continuous monitoring of blood pressure parameters is essential; especially in perioperative care; for in-patient surgeries of severe systemic disease, orthopedic or vascular surgeries, urologic, extended laparoscopic, obstetrics and gynecology surgeries, trauma surgeries etc. Non-invasive blood pressure measurement is done by intermittent arm-cuff based method, which provides adequate data for static analysis, but inadequate for dynamic measurements. The technique is known as vascular unloading technique (VUT), for which a pause of at least 1-2 mins between two BP measurements is required to avoid errors in the measurement. Furthermore, the cycle of continuous inflation-deflation of arm-cuff may cause discomfort to the patient and eventually cause alteration of BP. Both demerits of VUT based method are important while measuring BP variants during sleep. The alteration in cuff pressure also leads to an increase in the systemic blood pressure. High pressure changes in arm-cuff may resist normal blood flow in low BP patients and gradually create numbness in measuring arm.

An alternative approach for a dynamic, non-invasive and indirect measurement of BP is based on changes in Pulse Transient Velocity (PTV). PTV is the index of speed of a pressure pulse propagating along the arterial wall and can be easily calculated from Pulse Transit Time (PTT). PTT is the time delay between generation of electrical discharge (i.e. R-wave of ECG) from heart and flow of blood reaching to the pulse measurement site (i.e. Finger PPG peak)[1].

II. METHODOLOGY

2.1 Experimental Data Collection

Thirty Five volunteers (10 female and 25 males), aged 22.5±3.5 years without known cardiovascular abnormalities, participated in this study. Electrocardiogram (ECG) and Pulse Plethysmogram (PPG) of each subject were recorded for around 5-10 mins with an interval of 3 mins, during which the blood pressure of subjects measured by finger blood pressure cuff for calibrating the continuous monitor.

The recorded data then analyzed for estimation of HR, PTT, PTV and eventually Systolic Blood Pressure (SBP) using National instrument LabVIEW.

2.2 Signal Processing

First of all, the signals from ECG, PPG and ABP channels were truncated with the same time intervals and same time frame to exclude the discontinuous segments, which were caused by alteration of channels.

The recorded signals were processed by a sliding window of window length 3 sec. The data segment then detrended by a wavelet detrend for removing baseline wandering of signals. The trend threshold frequency can be obtained by below equation:

$$Trend\ Level = \frac{\log_2 2t}{\log_2 N}$$

where, t = sampling duration, and
N = Number of samples

The sampling frequency of the system is 1kHz. Thus, sampling duration and number of samples can be easily calculated by measuring collected array size and dividing it by 1000.

Then after, characteristic points, i.e. peak of R-wave and peak of PPG pulse were located by wavelet based peak detection algorithms, having variable threshold of each window as 70% of the value of maximum value found throughout the window. This method is acceptable because none of the signal is having any feature over that threshold except R-

wave peak and PPG peak respectively. Correlation analysis was carried out on the variability in R-R interval and PTT calculation as shown in figure-1.

Heart rate is calculated from the R-R interval from below formula:

$$HR\ (bpm) = \frac{60}{RRI\ (sec\ )} \tag{1}$$

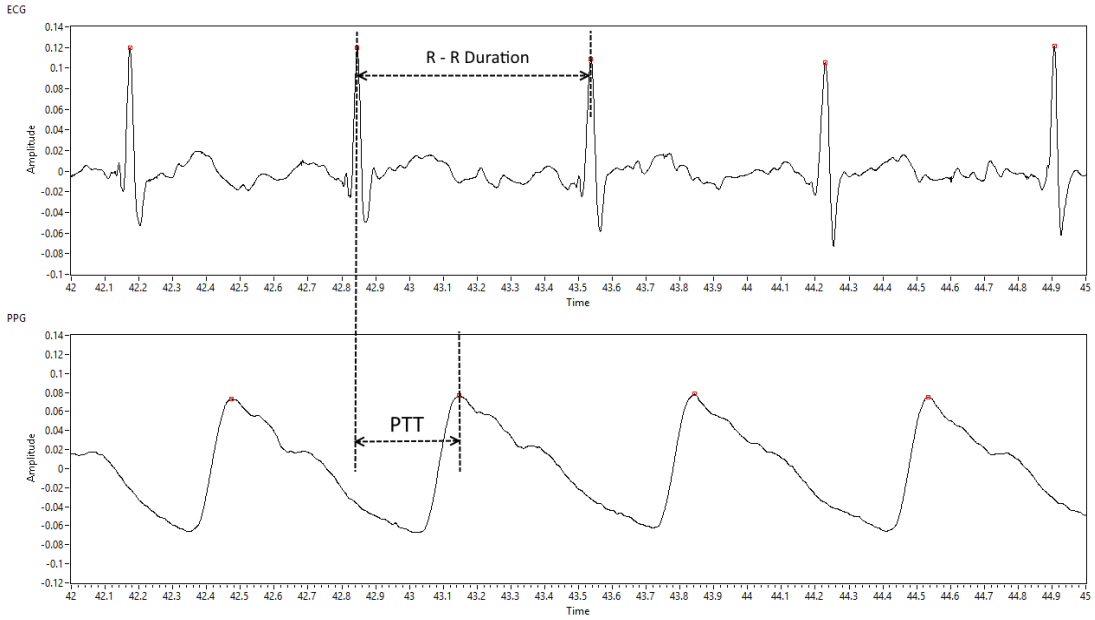

Fig-1 *PTT derived from location of R-wave peak from ECG (upper trace) and next consecutive peak derived from PPG (lower trace). Heart rate can be derived by calculating R-R interval.*

2.3 Determination of Pulse Transient Velocity

The velocity of a longitudinal pressure wave is related to the elasticity of the arterial vessel and to the vessel dimension by the equation of Moens and Korteweg. PTV depends both on the arterial pressure and the intrinsic elastic properties of the arterial wall. In practice, it is difficult to estimate how well PTV reflects BP and in how far severe age-dependent or disease-related changes (e.g., atherosclerosis) influence the arterial wall stiffness. In fact, investigations in a larger number of subjects showed that age, BP, gender, and cardiovascular risk factors significantly influence PTV. These results suggest that PTV can only be used for measurement of relative BP changes as it has been shown by a number of studies in human beings and animals[1].

Determination of the individual PTV–BP correlation and calibration of the system would allow the measurement of the absolute BP using the indirect method using PTT. This procedure is time consuming and not feasible in most of the situations. Therefore, we developed a one-point calibration of the PTV–BP correlation, which needs only one measurement of BP using a cuff based reference method.

The aim of the present study was to develop a PTV–BP function on the basis of the physiological properties of arterial walls and to test if a one-point calibration of the PTV–BP correlation offers an adequate measure of the absolute SBP.

The PTV can be calculated using the following equation:

$$PTV\left(\frac{cm}{ms}\right) = \frac{BCF \times height\ (cm)}{PTT\ (ms)} \tag{2}$$

Where, BCF = Body Correlation Factor, and height = body length. BCF is taken as 0.5 for adult when taken the finger for detection of the peripheral pulse wave as used in the present study[1]. While in case of earlobe measurement BCF can be taken as 0.1 considering the anatomy[2]. PTV values calculated from the above formula were used in order to estimate the SBP.

2.4 Correlation Model for estimation of SBP

The correlation function consists of three terms: (1) an exponential term, (2) a second non-linear term, and (3) a correction constant, which is calculated by Heart Rate Variability (HRV). This model still lacks correction corresponds to a one-point calibration and shifts the curve to the reference BP measured by cuff. The following function was obtained:

$$BP_{EST} = p_1 \times PTV \times e^{p_2 \times PTV} + p_3 \times PTV^{p_4} - \frac{p_5}{HR_i} \tag{3}$$

Where, the values of constant p1- p5 are derived by least square fitting of the function to the data of 35 subjects.

In order to evaluate the relationship factor between the SBP and PTT signal, the scatter plot and the correlation r is applied. There are two types of correlations: Positive and Negative. Since the PTT is decreasing with the increase of SBP, the correlation between this two signals should be negative. The formula to calculate correlation coefficient between two sets of data points is depicted in below equation:

$$r = \frac{\sum xy - \sum x \sum y / n}{\sqrt{\left[\sum x^2 - \frac{(\sum x)^2}{n}\right]\left[\sum y^2 - \frac{(\sum y)^2}{n}\right]}} \quad (4)$$

Where x and y represents the SBP data points and the PTT data points, respectively. n is the length of the data window and the value of correlation coefficient r should be in the range from -1 to 0. When the value of r is smaller than -0.8, it can be decided that the two sets of data points have strong correlation[3].

ID	Sex	Age (yrs)	Height (cm)	Weight (kg)	HR (bpm)	PTT (ms)	PTV (cm/ms)	BP_{CUFF} (mmhg)	BP_{EST} (mmhg)	CF (r)	Error
					mean ± variance						
1	F	22	168	52	73±6	267±4	0.31±0.03	122±5.23	128±4.27	-0.82	±5.11
2	F	22	157	53	78±5	289±5	0.27±0.01	117±2.65	115±3.29	-0.79	±2.44
3	F	21	155	52	71±8	234±6	0.33±0.03	121±4.12	119±5.23	-0.85	±3.42
4	F	21	167	52	75±3	312±8	0.27±0.01	131±5.98	130±7.76	-0.91	±2.71
5	F	20	162	52	81±7	342±8	0.24±0.04	135±3.24	132±1.24	-0.90	±3.48
6	F	20	157	49	73±2	371±8	0.21±0.02	126±8.23	127±3.12	-0.83	±1.51
7	F	20	156	54	68±3	319±4	0.24±0.01	124±6.41	117±10.23	-0.88	±7.76
8	F	19	164	49	83±8	316±7	0.26±0.03	116±4.09	115±4.87	-0.94	±1.63
9	F	19	153	47	65±7	267±8	0.29±0.04	114±5.29	112±2.23	-0.84	±2.89
10	F	19	160	54	80±6	311±11	0.26±0.05	125±7.54	126±6.24	-0.86	±1.69
11	M	23	186	76	90±5	340±10	0.28±0.01	118±4.51	121±6.21	-0.87	±2.80
12	M	27	175	80	92±5	242±7	0.36±0.01	132±6.24	138±3.85	-0.84	±3.47
13	M	23	166	56	76±6	275±6	0.30±0.02	125±5.37	127±5.23	-0.86	±3.27
14	M	22	167	58	79±3	274±12	0.30±0.06	133±4.31	131±8.03	-0.89	±2.65
15	M	21	173	76	87±6	298±10	0.29±0.06	127±3.19	126±4.90	-0.91	±1.93
16	M	20	163	56	72±9	314±12	0.26±0.05	129±5.24	134±6.25	-0.89	±5.79
17	M	22	171	64	84±6	276±11	0.31±0.06	118±4.31	120±7.20	-0.87	±2.33
18	M	20	174	70	91±6	279±5	0.31±0.05	120±6.23	119±3.27	-0.92	±1.93
19	M	20	175	65	93±8	256±7	0.34±0.02	122±4.87	124±4.23	-0.91	±2.51
20	M	19	175	75	89±7	284±12	0.31±0.03	129±6.34	135±7.30	-0.86	±6.97
21	M	22	170	62	87±9	291±5	0.29±0.06	135±3.23	127±6.53	-0.88	±8.36
22	M	21	174	45	64±8	332±3	0.26±0.01	137±6.82	139±9.91	-0.84	±2.72
23	M	19	162	47	65±4	376±1	0.22±0.01	118±4.31	117±3.76	-0.86	±1.86
24	M	21	172	63	78±6	279±6	0.31±0.03	114±5.32	115±4.79	-0.87	±1.92
25	M	20	168	58	67±2	306±8	0.27±0.04	131±7.86	126±5.53	-0.88	±6.27
26	M	23	169	65	76±4	381±11	0.22±0.05	121±2.76	122±2.37	-0.89	±1.20
27	M	23	172	63	79±9	325±4	0.26±0.02	132±6.43	127±5.32	-0.86	±5.48
28	M	23	173	70	84±4	353±2	0.25±0.01	129±6.74	134±6.52	-0.82	±5.62
29	M	23	179	79	89±7	274±7	0.33±0.03	125±6.49	122±3.37	-0.90	±3.84
30	M	20	169	68	74±6	292±3	0.29±0.01	128±5.27	129±3.61	-0.89	±1.51
31	M	22	178	73	86±3	268±5	0.33±0.03	130±6.83	136±7.59	-0.91	±6.90
32	M	22	182	79	87±5	269±4	0.34±0.02	132±8.27	130±2.28	-0.86	±2.72
33	M	21	165	54	65±6	316±3	0.26±0.01	120±9.36	124±4.43	-0.87	±4.97
34	M	20	169	58	76±3	320±4	0.26±0.02	127±4.23	129±6.44	-0.85	±2.41
35	M	19	157	48	78±4	312±6	0.25±0.03	136±7.28	137±8.82	-0.89	±1.73

Table-1 Data collected and analyzed of 35 volunteers

III. RESULTS

The variability signal for each individual parameter was constructed as a data series along the beat index, as shown by the examples in Fig-2. Cross-correlation function was applied on pairs of the variability parameters to quantify not only the degree of correlation, represented by the correlation coefficient, but also the phase relationship, characterized by the corresponding beat shift for specified correlation coefficient. For each pair of variability parameters, the maximum correlation coefficient and its corresponding beat shift were selected to characterize the relationship between them, as summarized in Table-1.

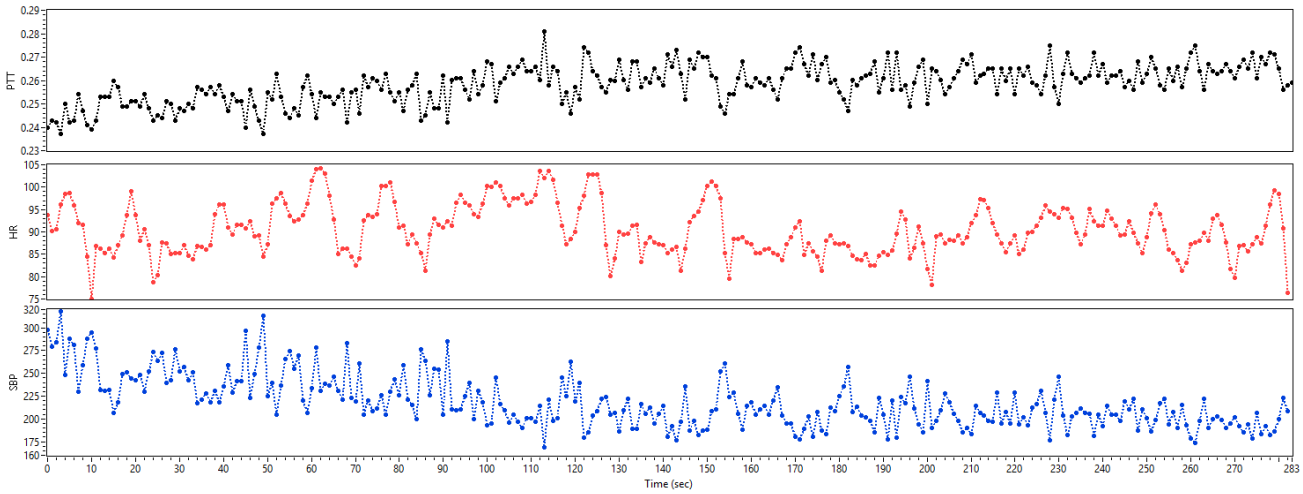

Fig-2 *Variability in different cardiovascular parameters for 5mins of period (a) PTT (b) HR (c) SBP*

The correlation between PTT and SBP is shown in Figure-3 (a), where correlation coefficient calculated by Equation (4) is calculated -0.87 ± 0.04 for all subjects. The correlation between HR and SBP is having r= 0.49 ± 0.08 is shown in Figure3 (b).

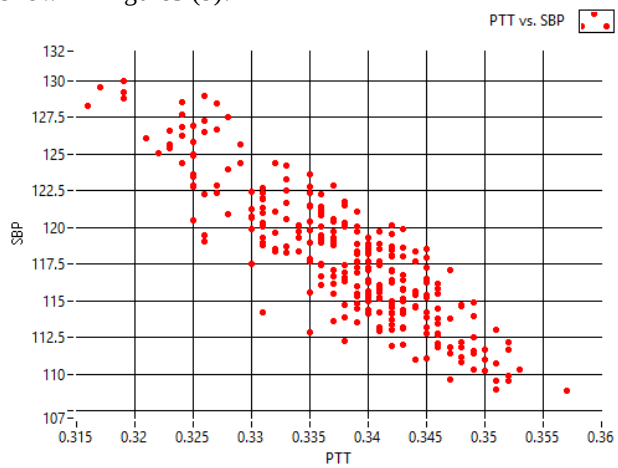

Fig-3 *(a) Correlation of PTT and SBP with correlation coefficient r=-0.87*

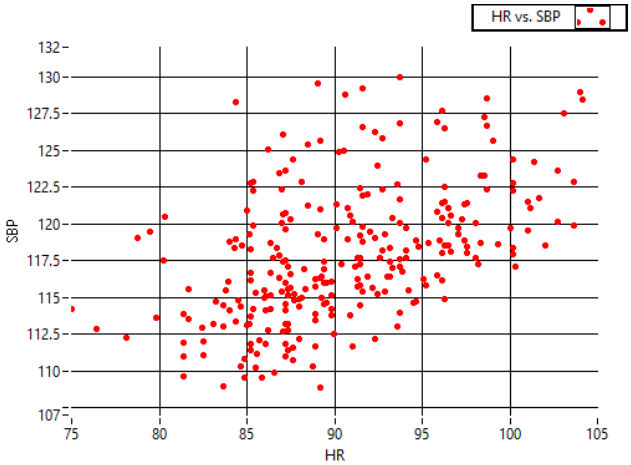

Fig-3 *(b) Correlation of HR and SBP with correlation coefficient r= 0.49*

IV. DISCUSSION

The extended model between SBP and PTT clearly shows significantly validated correlation over a range of subjects with specific age group. Although, suggested method has to be validated for other age groups with wide range of blood pressure and known cardiovascular abnormalities to identify the limitations of applied method.

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