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Variance Analysis of Photoplethysmography for Blood Pressure Measurement

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***Abstract*—The emergence of photoplethysmography for blood pressure estimation is offering a more convenient method. The elements of photoplethysmography waveform is crucial for blood pressure measurement. Several photoplethysmography elements are still not completely understood. The purpose of this study was to investigated corelation of photoplethysmography elements with blood pressure using statistical approach. Analysis of variance test (ANOVA) was conducted to see if there are any correlation between elements of photoplethysmography with blood pressure. This study used 10 volunteers without an ethical clearance. Photoplethysmography waveform and blood pressure measurements were taken through the patient monitor equipment Datascope™. As the result, value factor from the arithmetic is 35.67 and value factor from the table is 3.14. The value of $F_{arithmetic}$ (35.67) > F_{table} (3.14). The correlation of diastolic time (Td) is negative with systolic arterial pressure (SAP) and the correlation of systolic amplitude (As) is positive with diastolic arterial pressure (DAP). The results showed elements of photoplethysmography can be used to estimation blood pressure.**

Keywords—continuous blood pressure, noninvasive blood pressure, phoptoplethysmography, pulse wave analysis

I. INTRODUCTION

Blood pressure is an essential parameter for early detections cardiac diseases because it can detect hypertension or hypotension symptom. Hypertension mentions to arterial pressure being unusually high, as opposite to hypotension, when it is unusually low. Blood pressure measurement is a measure on how much power comes from the heart pump given to the arterial wall and circulates throughout the body. Blood pressure generally consists of three features, namely diastolic arterial pressure (DAP), systolic arterial pressure (SAP), mean arterial pressure (MAP) and measured in millimeters of mercury (mmHg) [1]. The features are not stable depend physiological change during the day.

There are two methods for measuring blood pressure, namely invasive method and non-invasive method. Although, invasive method have been well-known to estimate blood pressure continuously and precisely but is very uncomfortable to implement and can trigger infection to the patients. The commonly used non-invasive methods are using cuff technolog but also not very convenient to apply particularly for wounded people, overweight people and newborns [2].

To simplify the measurement process and then to obtain accurate continuous data several methods have been developed. The methods are non-invasive cuff-less continuous blood pressure such as ballistocardiography (BCG) [3], electronic bioimpedance (EBI) [4], tonometry [5], and photoplethysmography (PPG) .

Photoplethysmography is also known to carry useful information regarding other important physiological parameter as shown in Fig.1. Measurement of photoplethysmography based non-invasive continuous blood pressure methods becomes popular among researchers and a plenty of work has already been done in this subject. R.Chawla et al [10] had studied to use photoplethysmography to measure systolic blood pressure in 1992 after that several studies have been reported to check the feasibility of blood pressure through photoplethysmography. X. F. Teng [13] using the optimum elements photoplethysmography for estimating blood pressure and four elements of photoplethysmography signals were examined. R. Samria et al [15] were analyzed three elements of photoplethysmography signals, such as systolic time, diastolic time and the time interval between the systolic and diastolic tops.

The objective of this study was to examined relationship of photoplethysmography elements with blood pressure using statistic approach. Analysis of variance test (ANOVA) was used to verify whether there were significant difference in photoplethysmography elements that may relation for any variations in blood pressure. The p-value to judge the significance of the effect is $p < 0.05$.

We begin in section II by describing the methodology. We discuss the outcomes of this study in section III. After all, in section IV concludes this paper.

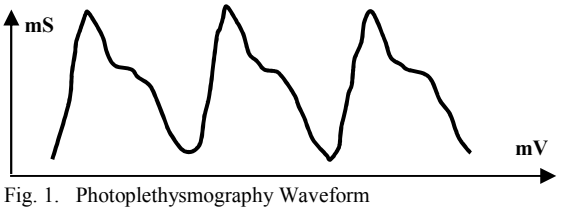

Fig. 1. Photoplethysmography Waveform

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TABLE I CATAGORIES OF HYPERTENSION [2]

Clasiffication	Systolic Arterial Pressure (mmHg)	Diastolic Arterial Pressure (mmHg)
Normal	120	80
Prehypertension	120-139	80-89
Stage-1 hypertension	140-159	90-99
Satge-2 hypertension	≥ 160	≥ 100

II. METHODOLOGY

A. Data summary

We have measured features of a photopletysmography waveform and blood pressure with 10 volunteers (15 – 45 years old) without an ethical clearance.The measurement is repeated 3 times and runs in random order. Photoplethysmography waveform and blood pressure measurements were taken through the Datascope™ patient monitor equipment.

Blood pressure was measured using noninvasive (NIBP) methods and divided into four categories based on category's hypertension as figured out in Table I. Photoplethysmography was recorded at left index finger for 5 minutes. In request to find an optimum element for measueremnt blood pressure, four elements of photoplethysmography signals were investigated as shown in Fig. 2, such as, diastolic time (Td), systolic time (Ts), systolic amplitude (As), diastolic amplitude (Ad). After collected the data, a table of measures results can be made as shown in Table II.

B. Statistical analysis.

Analysis of variance (ANOVA) was implemented to ensure if elements of photoplethysmography can be used to estimation blood pressure. There are two hypotheses in ANOVA namely; H_0 if there is no significant difference between variabels and H_1 if there is a significant difference at least one variabel. Where, F is ANOVA coefficient, if the value of $F_{arithmetic} > F_{table}$, then reject hypothesis H_0 because of not enough evidence to accept hypothesis H_0. ANOVA statistical calculations were obtained using a confidence level of 95% and the p-value to judge the significance of the effect is $p < 0.05$. The small p-value indicates the excellent evidence against the H_0.

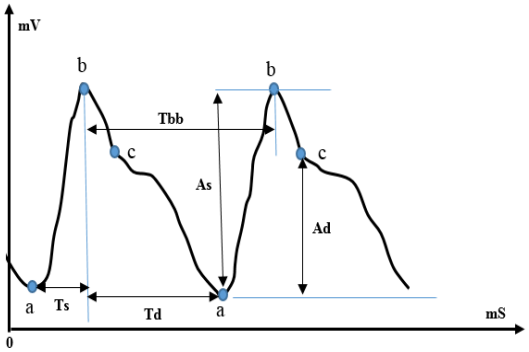

Fig. 2. Photoplethysmography elements, where Ts is a systolic time, Td is diastolic time, As is systolic amplitude, and Ad is diastolic amplitude

TABLE II TABLE OF MEASURES

PPG Elements	Valunteers						Total	Mean
	1	2	3	4	5	n		
Ts	T_{1S}	T_{2S}	T_{3S}	T_{4S}	T_{5S}	T_{nS}	Tst	$\bar{Y}$ts
T_d	T_{1d}	T_{2d}	T_{3d}	T_{4d}	T_{5d}	T_{nd}	Tdt	$\bar{Y}$td
A_S	A_{1S}	A_{2S}	A_{3S}	A_{4S}	A_{5S}	A_{nS}	Ast	$\bar{Y}$as
A_d	A_{1d}	A_{2d}	A_{3d}	A_{4d}	A_{5d}	A_{nd}	Adt	$\bar{Y}$ad

The outcomes of the ANOVA are described in an ANOVA table, which has columns identified Sum of Squares, degrees of freedom, mean of square, and F for F-ratio as shown in Table III. ANOVA has the following test statistics ;

$$F = \frac{\text{MStreatment}}{\text{MSerror}} \quad (1)$$

Where, MStreatment is mean of squares for treatment and MSerror is mean of squares for error [19]

$$\text{SSt} = \sum \text{n}(\text{y} - \bar{\text{y}})^2 \quad (2)$$

$$\text{MStreatment} = \frac{\text{SSt}}{\text{p} - 1} \quad (3)$$

Where, SSt is sum of squares for treatment, p is total number of populations, and n is total number of samples in a population [19] .

$$\text{SSe} = \sum(\text{n}-1)\text{S}^2 \quad (4)$$

$$\text{MSerror} = \frac{\text{SSe}}{\text{N} - \text{p}} \quad (5)$$

Where, SSe is sum of squares for error, S is standard deviation of the samples, and N is total number of observations [19].

TABLE III THE ANOVA RESULTS TABLE

Source of difference	Sum of square	Degrres of freedom	Mean of square	F
SSt (treatments)	$\sum \text{n}(\text{y} - \bar{\text{y}})^2$	$p - 1$	$\frac{SSt}{p-1}$	$\frac{\text{MStreatment}}{\text{MSerror}}$
SSe (error)	$\sum(\text{n}-1)S^2$	$N - p$	$\frac{SSe}{N-p}$	
Total				

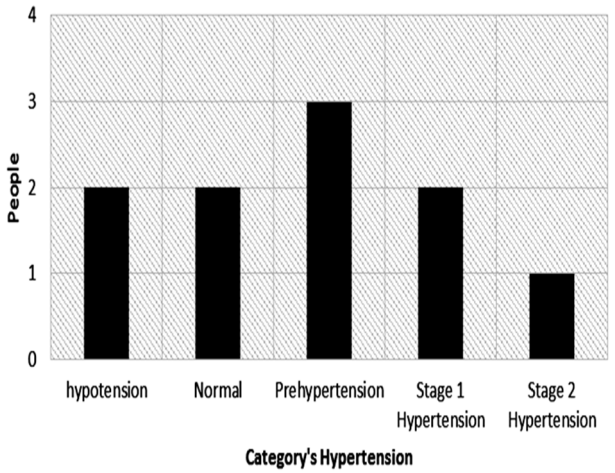

Fig. 3. Data of volunteers

This study used 10 volunteers by dividing it into category hypertension. The result of blood pressures of volunteers representing all categories as shown in Fig 3. There were differences of morphology PPG at diastolic time (Td) in systolic blood pressure subjects as shown in Fig. 4. Diastolic time (Td) in high systolic value, more longer than in low systolic value.

The correlation systolic blood pressure to diastolic time (Td) and systolic amplitude (As) were showed in graphical form in Fig. 5 and Fig. 6. From that figures, it is clearly seen that the correlation of diastolic time (Td) is negative and systolic amplitude (As) is positive with the blood pressure. That means the value of blood pressure is inverse with the dias

The hypothesis; there is the significant change in systolic time (Td) on PPG that may account for any variations in systolic arterial pressure (SAP). One way analysis of variance (ANOVA) test is perform to see if there is any significant defference between diastolic time (Td) on PPG parameter with systolic arterial pressure (SAP).

We used analysis of variance (ANOVA) to prove the effect of PPG features on blood pressure in statistical approach. One way ANOVA was performed to compare the photoplethysmography feature on blood pressure. ANOVA test results are as follows ; the sum of squares due to error (SSE) is 0.21, the mean sum of squares due to treatment (SST) is 1.89, and the ANOVA coefficient, is 35.67, as shown in Tabel IV.

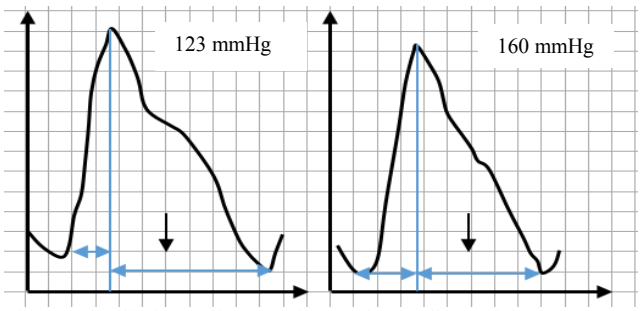

Fig. 4. Diatolic time (Td) comparison with systolic arterial pressure (SAD)

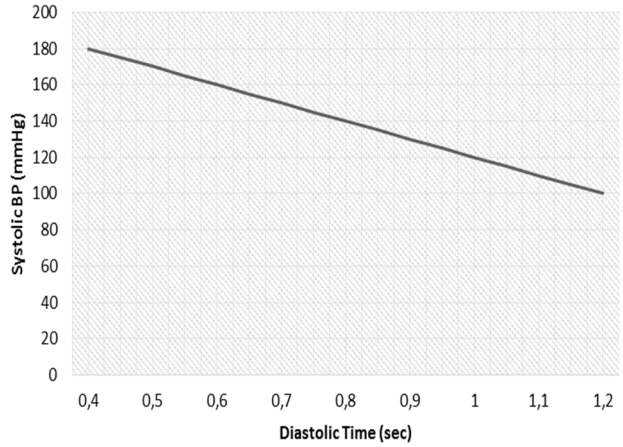

Fig. 5. Diastolic time comparison of sytolic arterial pressure

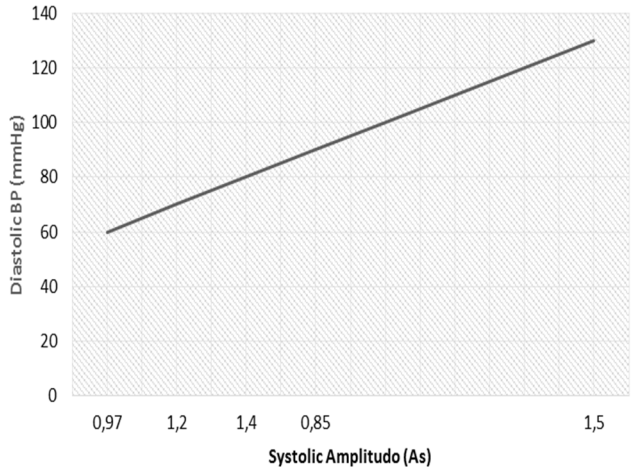

Fig. 6. Systolic amplitude comparison of sytolic arterial pressure

The ANOVA factor from the F table statistic is 3.14. The value of $F_{arithmetic}$ (35.67) > F_{table} (3.14), then reject hypothesis H_0 because of not enough evidence to accept hypothesis H_0. The results showed elements of photoplethysmography can be used to estimation blood pressure.

TABLE IV ANOVA RESULTS

Source of variation	Sum of square	df	Mean of square	F
Treatments	1.89	3	0.63	35.67
Error	0.21	12	0.02	
Total	2.09	15		

IV. Conclusion

A single photoplethysmography sensor as the only input for a device that measures blood pressure is promising because it offers ease of use for the patient. This study was to use analysis of variance to prove the effect of photoplethysmography features on blood pressure. So as to discover an optimum elements for blood pressure measurement, four elements of photoplethysmography signals were examined such as, diastolic time (Td), systolic time (Ts), systolic amplitude (As), diastolic amplitude (Ad). The value of F arithmetic > F table showed that there are statistically provide evidence features of photoplethysmography can be used to estimation blood pressure. The correlation of diastolic time (Td) is negative and systolic amplitude (As) is positive with the blood pressure. That means the value of blood pressure is inverse with the diastolic time (Td) but linear with systolic amplitude (As). The future work may contain validating with additional individual test subjects and refining the elements of photoplethysmography to achieve a better precision.

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