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New Model to estimate Mean Blood Pressure by Heart Rate with Stroke Volume changing influence

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***Abstract*—Mean Blood Pressure (MBP) has high correlation with Heart Rate (HR), but such e relationship between them is ambiguous and nonlinear. This paper investigates establishing an accurate mathematical model to estimate MBP that is considering the influence of the stroke volume changing. Twenty three cases of MIMIC database [1] are employed; 12 cases for training and 11 cases for verification. The mean and standard deviation for all cases are calculated and compared with real results. Our suggested mathematical model achieved an encouragement results.**

I. Introduction

BLOOD pressure (BP) is vital measurement, which is used by the physicians for diagnosing patients health and saving them from critical diseases or situations such as Hypertension, Hypotension, Artery stiffness, Coma or Heart attack. Many methods has used to measure blood pressure; these methods including *cannulation*, which used catheter, *auscultatory*, which used sphygmomanometer, and the *cuff-less and real time measurement*; also known as *photo-plethysmography* (PPG), which used PPG sensor that utilizing infrared diode and optical diode.

The *cannulation* and *auscultatory* methods are most common methods have used to measure blood pressure. The *cannulation* method measures blood pressure directly and it is very accurate, but it is invasive, while *auscultatory* method is using cuff, interpreted, and time consuming for cuff inflation and deflation. *The cuff-less and real time measurement* are non-invasive and continuous methods since the PPG sensors extracted the PPG signal from subject's finger by infrared diode and optical diode.

PPG methods estimate blood pressure by using PPG signal through mathematical models depend on the relationship between BP and PPG signal's features; such as heart rate which is equal the frequency of the PPG signals.

The BP and PPG signal's features relationship are complex and dynamic [2]. This relation has been studied; Yan and Zhang stated that the normalized hormonic area of a discrete period transform of PPG signal has high correlation with BP [3].Moreover, the time interval between peak of electrocardiograph (ECG) and the front foot of PPG signal, also known as the PTT_f; has high correlation with BP variability [4].

Furthermore, a model has been found to estimate BP by using a weighed PTT (PTT_w); this feature is dependent on the subject. PTT_w depends on calibrating measurements of systolic and diastolic BP [5].

Some works on PPG based methods have established correlation between PPG signal and BP [6]. This correlation improved by adding constant factors to increase the accuracy of the measurements, while some of these factors are not constant in reality. One of these changeable constant factors is stroke volume.

This paper investigates the relationship between MBP and PPG signal. A new mathematical model has developed depending on HR and stroke volume changing. This new mathematical model will be discussed in next section.

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II. Methodology

The relationship of MBP and HR is specified by Ganong [6], through these equations:

$MBP = CO \times TPR$ and $CO = HR \times SV$.

$\therefore MBP = HR \times SV \times TPR$

Where MBP is mean blood pressure

- CO cardiac output
- HR number of heart beats/ minute.
- TPR resistance of blood vessels against blood flow.
- SV stroke volume of the heart.

The MBP can be estimated when HR is variable, SV and TPR are constants. But in reality, SV is changed according to heart rate [7]; Therefore, the equation:

$MBP = HR \times SV \times TPR$ can be written as:

$MBP = HR \times (SVo + A \times SVo \times HR) \times TPR$

$MBP = SVo \times TPR \times HR \times (A \times HR+1)$

where SVo constant stroke volume of the heart.

A coefficient of changing percentage.

For calculating the coefficient A; twenty three cases, chosen randomly of MIMIC database, has been analyzed. The MIMIC database is obtained from Physio-bank database [1]; which includes continuous recorded from intensive care unit (ICU) every second over than 10 hours; that means 36000 records for each case, at least. In addition, the database of each case includes signals and interrupted measurements such as HR, MBP, Systolic BP and Diastolic BP. These measurements obtained from a bedside monitor and clinical database extracted from the patient's medical record.

The following procedure has been followed to produce the coefficient A:

Firstly; The HR and MBP have been extracted from twenty three cases of MIMIC database to investigate the relationship between them. The coefficient of changing percentage (A) was generated by using a fit function for twelve cases which is found equivalent to -0.0026. The developed formula is:

MPB = SVo *x* TPR *x* HR *x* (A *x* HR+1)

Secondly; The MBP was estimated for all cases' records by above created formula.

Thirdly; for comparison, we used the published formula that mentioned in [6], to estimate MBP for all cases' records, where TPR and SV are constant, through this equation:

MBP = HR *x* SV *x* TPR

Where TPR = 0.018 mmHg.min/ml [8].

SV = 70 ml [8].

The comparison between both models is illustrated in Results section by tables and figures.

RESULTS

The database records for each case is too many, so the mean of estimated MBP of both models has been taken,

Our model: MBP = SVo *x* TPR *x* HR *x* (A *x* HR+1)... (1)

Second model: MBP = HR *x* SV *x* TPR ……… (2)

The results of both models have been compared with mean of real MBP for each case record. The difference of mean of both models and mean of real MBP for all cases is illustrated in table (1).

From table (1), the difference of mean between estimated MBP in our method is closer to zero than the difference of mean of the other method; as illustrated in Fig. 1, hence; our method, where stroke volume changing has been considered (Mean 1), is better than the other method; where stroke volume has been fixed (Mean 2), and this support the fact of the effect of the stroke volume change on MBP estimation.

Standard deviation has obtained, for more inspection of our model reliability, through finding the standard deviation of each case for both methods as shown in Fig. 2, the standard deviation of our new method (STD1) where stroke volume changing has been considered, is better than the other method (STD2) where stroke volume has been fixed.

In addition, the sample of two case over 100 seconds for the real mean blood pressure, the estimated MBP by our model; where stroke volume changing has been considered (MBP1), and other method; where stroke volume has been fixed (MBP2) has compared in Fig. 3.

From two graphs in Fig. 3, it is clear that our model (MBP1) is better than the other model (MBP2); since the calculated MBP of our model is closer to real MBP than the calculated MBP of second model.

Table (1) The mean and Standard Devotion for models and real reading

Case	MPB = SVo *x* TPR *x* HR *x* (A *x* HR+1)		MBP = HR *x* SV *x* TPR	
	Mean1	Std1	Mean2	Std2
1	19.7	15.068	-2.4719	14.121
2	-9.4927	3.3214	-30.533	4.1829
3	0.40713	4.7569	-26.804	7.1712
4	12.245	7.9457	-1.9611	7.7208
5	12.478	8.684	-5.1428	10.064
6	1.8051	8.5257	-17.901	9.451
7	-2.6774	7.4635	-28.549	9.5374
8	20.022	4.9878	1.8481	5.593
9	24.082	12.465	13.736	12.846
10	2.4781	15	-18.586	17.453
11	13.634	9.54	-2.6757	9.8445
12	8.0994	8.1175	-9.159	10.827
13	0.78268	9.5236	-23.667	10.605
14	-3.4284	4.5737	-28.616	6.4983
15	4.657	7.6563	-15.746	8.4812
16	1.7982	11.619	-25.488	14.313
17	0.2105	11.6	-23.109	14.18
18	6.916	7.8818	-8.1457	7.2153
19	2.0743	7.4491	-16.667	10.028
20	-8.9361	6.8042	-35.144	7.9888
21	-11.831	6.8298	-40.689	8.4006
22	10.184	8.2482	-12.238	9.7905
23	-3.3689	4.7629	-26.908	6.063

Mean is the difference between mean of real MBP and mean of estimated MBP and **Std** is the standard deviation of difference between real MBP and estimated MBP for both models.

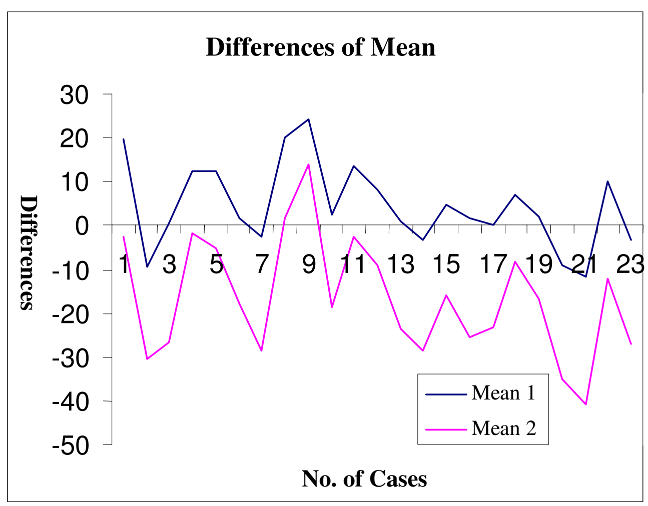


Fig. 1. The Difference between mean real MBP and estimated MBP of each mathematical model for all cases

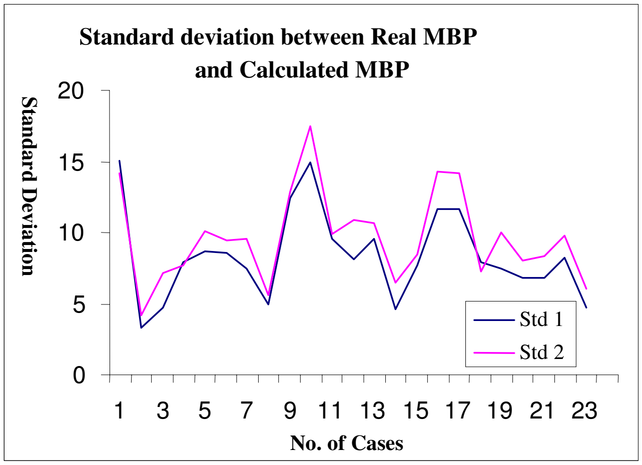
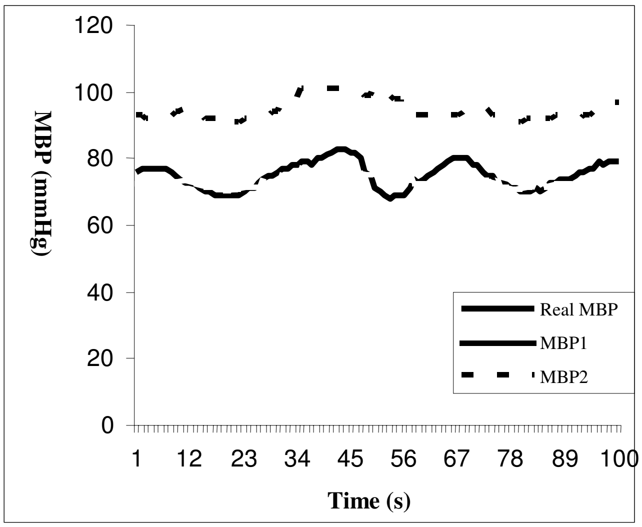
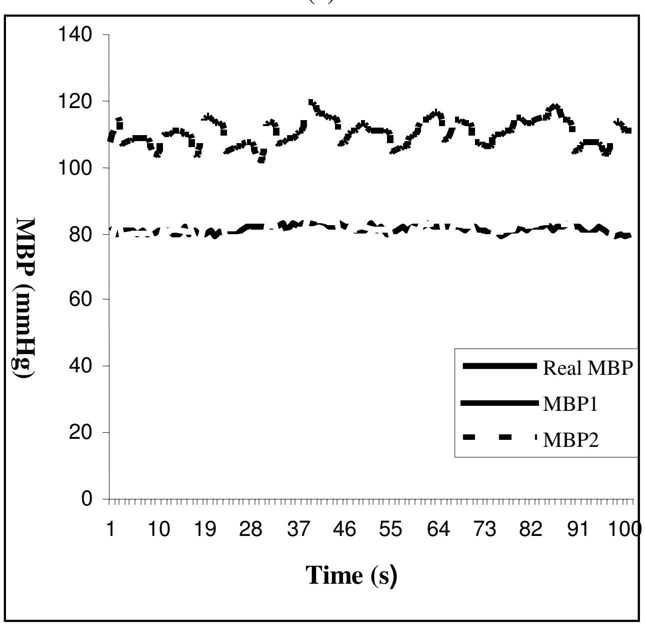


Fig .2. Standard deviation between Real MBP and Estimated MBP of both models for each case



(a)



(b)

Fig.3. The real MBP, calculated MBP by First model (MBP1) and calculated MBP by Second model (MBP2)

III. Conclusion

The relationship between heart rate (HR) and mean blood pressure (MBP) is nonlinear. A lot of efforts have done to simplify this relation; one model had added many constants factors to estimate the Mean blood pressure. One the common model assuming constant factors for the stoke volume while it is changeable in reality depend on the heart rate. This paper investigated the effect of the stroke volume and found out the relationship between MBP and HR is: MBP = SVo x TPR x HR x (A x HR + 1); where the stroke volume (SV) changing is considered. This new model results are more accurate and closer to real cases' records as that shown in the mean of difference, standard deviation, and sample of comparison figures and table. In future work, the coefficient of changing (A) will be investigated to achieve high accuracy by testing more cases to finding the best fit function and by using the physiological clarification of this phenomenon.

The work of this paper is part of our project to develop the Cardiovascular Parameters Long Term Monitoring System (CPLTMS).

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