

Construction of Blood Pressure Monitor Using Photoplethysmography Calibrating with Upper-arm Blood Pressure Monitor

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Abstract. A photoplethysmography (PPG) is one of an alternative technique for monitoring personal health with the advantages of non-invasive, inexpensive, and easy to use. In this work, PPG is used to estimate blood pressure with the aim to construct a prototype of blood pressure monitor by photoplethysmography and calibrate with upper-arm blood pressure monitor. The NIR LED light source and detector is used to obtain PPG signals. The PPG signals from blood pressure prototype are recorded with band pass filter and used for calibration with upper-arm blood pressure monitor in 10 volunteers. It is found that the maximum and minimum values of PPG signals show linear dependence of systolic and diastolic blood pressure from the commercial blood pressure monitor with $R^2=0.72$. The obtained linear relation is applied to calibrate the measured PPG signals and to test with 12 volunteers. From the test, the precision of systolic and diastolic blood pressure from the prototype are 8 mmHg and 6 mmHg respectively and the accuracy is equal to ± 10 mmHg compared with that of commercial blood pressure monitor of ± 3 mmHg. Thus, the prototype of blood pressure shows less accuracy than that of commercial blood pressure monitor and may not medically use for health monitoring. However, the prototype maybe practically use as a screening tool for monitoring blood pressure due to easy to use and fast measurement.

Keyword: Photoplethysmography, blood pressure, blood pressure monitor

1. Introduction

The patients of hypertension (high-blood pressure) have approximately 5.6 million people in Thailand and keep increasing [1]. High blood pressure is a “silent killer” because there are no obvious symptoms. Normally, upper-arm blood pressure monitor is used to measure and monitor a blood pressure. But there are some drawbacks such as too many steps for measuring (make it difficult to measure by ourselves especially for elderly people), and sometimes leave a bruise on your arm skin due to the inflation especially for high-blood pressure people. To overcome these drawbacks, a prototype of blood pressure monitor by photoplethysmography (PPG) is constructed and developed. The photoplethysmography which is commonly used to measure a heart rate and oxygen in artery blood is applied as an alternative

technique to detect the blood pressure for monitoring personal health with the advantages of non-invasive, inexpensive, and easy to use. In this work, PPG is used to estimate blood pressure with the aim to construct a prototype of blood pressure monitor and calibrate with upper-arm blood pressure monitor. The NIR LED light source and detector is used to obtain PPG signal.

2. Experimental

2.1. Design and construction of the blood pressure prototype

The design of the prototype consists of two main components: (1) near infrared (NIR) light source (890 nm) with photo detector and (2) Arduino pro micro for data processing. The arduino pro micro is used to process a PPG signals with band pass filter [2], transmit PPG in spreadsheet software (Microsoft excel), and display the values of blood pressure on organic light emitting diode (OLED). The band pass filter is performed by exponential moving average (EMA) [3]. A prototype case is designed with Auto Desk Fusion 360 program and printed by 3D printer using polylactide (PLA) filament. The final assembly of the prototype is shown in figure 1.

2.2. Calibration and testing for the prototype of blood pressure monitor

The prototype is calibrated with upper-arm blood pressure monitor (Citizen CHU503) as shown in figure 2. The calibration is performed by comparing between PPG signals measured from 10 volunteers using the prototype of blood pressure with the blood pressure values obtained from the upper-arm blood pressure monitor. The maximum and minimum values of PPG signals are used to find linear relation and applied this linear relation to calibrate the measured PPG signals from the prototype. After the calibration, the prototype is tested with 12 volunteers and compared again with upper-arm blood pressure monitor in order to find the precision and accuracy of this prototype.



Figure 1. The prototype of blood pressure monitor.

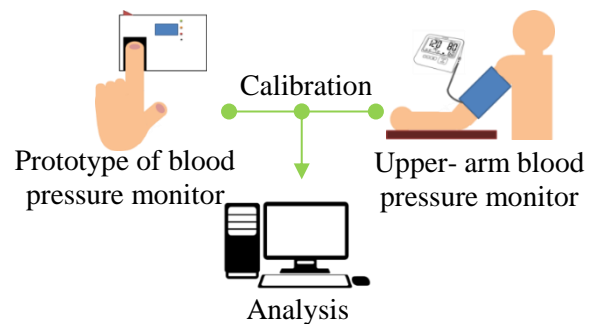


Figure 2. Calibration of PPG signals and blood pressures.

3. Results and discussion

3.1. Data processing with filtering process

The PPG signals from photo sensor before and after filtering process as a function of time are plotted in figure 3. It can be seen that before filtering signals are noisy and difficult for analysis and interpretation. The noise can be attributed to a signal of respiration [4]. Thus, band pass filter using EMA is applied for filtering process and the better PPG signals with clear periodic cycle (as seen in top graph of figure 3) can be obtained for a further analysis. A characteristic of PPG signals after filtering looks similar to common PPG signal that consists of a major peak (the maximum amplitude) and a minor peak (the local amplitude) in the wave platform. Typically, the frequency of the PPG signals can be related to the heart rate (beat per minute). In addition, the amplitude maybe relates to blood pressure value. Therefore, the maximum and minimum of PPG signals are used for calibration.

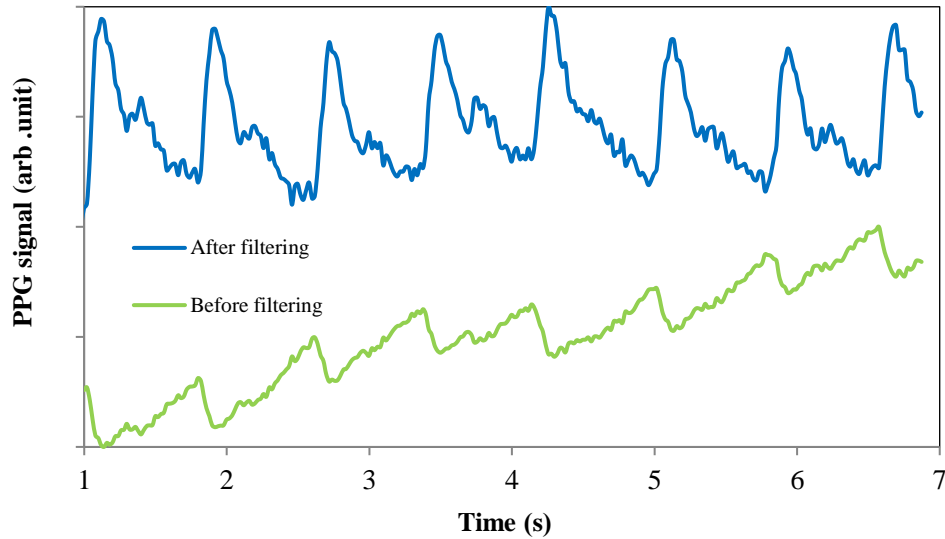


Figure 3. Normalized PPG signal before filtering (green line) and normalized PPG signal after filtering as in the times (blue line).

3.2. Calibration of the prototype of blood pressure monitor

The maximum and minimum value of PPG signals are respectively plotted with systolic and diastolic blood pressure from the commercial blood pressure monitor in 10 volunteers as shown in figure 4. It can be clearly seen that the maximum and minimum value of PPG signals exhibit linear relation with systolic and diastolic blood pressure from the commercial blood pressure monitor. By using least mean square method, the linear equation is obtained as $BP = 0.154 \times PPG - 66.149$ and $R^2 = 0.72$.

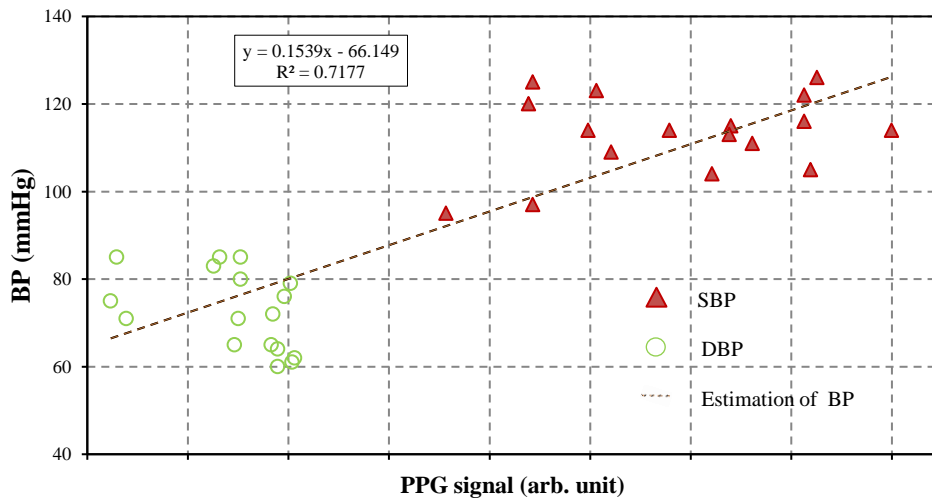






Figure 4. Relationship between photoplethysmogram signals and Blood pressure.

3.3. Sampling test of prototype of blood pressure monitor

The obtained linear relation from figure 4 is applied to calibrate the measured PPG signals and to test with upper-arm blood pressure monitor in 12 volunteers. The test data are show on table 1 with error and accuracy of the blood pressure prototype.

Table 1. Blood pressure values measured from upper-arm blood pressure monitor compared to the prototype of blood pressure monitor in 12 volunteers with error and accuracy.

Volunteers	 Upper-arm blood pressure monitor		 Prototype of blood pressure monitor		 Error		 Accuracy	
	SBP (mmHg)	DBP (mmHg)	SBP (mmHg)	DBP (mmHg)	SBP (mmHg)	DBP (mmHg)	SBP (%)	DBP (%)
1	134	87	131	69	4	18	97	79
2	117	68	104	70	17	4	85	95
3	92	61	108	67	16	6	82	89
4	126	60	123	62	6	4	94	93
5	118	60	108	62	10	6	92	90
6	92	63	93	75	3	12	96	82
7	114	64	106	74	11	11	90	83
8	100	72	109	65	9	7	92	91
9	117	70	102	62	7	8	94	88
10	118	71	112	63	8	9	93	88
11	92	72	110	68	18	4	80	94
12	115	61	106	67	15	9	87	85

The error in mmHg is calculated from the percent error multiply by blood pressure value (real value) of upper-arm blood pressure monitor (percent error equal to an absolute value of difference between the real value and the prototype value divided by the real value and multiply by 100). While accuracy is equal to 100 minus the percent error. The average percent accuracy of systolic and diastolic blood pressure in prototype of blood pressure monitor is 90 % and 88 %. In addition, the precision (obtained from average standard deviation) of systolic and diastolic blood pressure measured from the prototype are 8 mmHg and 6 mmHg. Normally, the error in mmHg can be sometimes defined as the accuracy of the commercial blood pressure monitor. In our case, the accuracy of upper-arm blood pressure monitor is ± 3 mmHg comparing to the average accuracy of the prototype about ± 10 mmHg for SBP and ± 8 mmHg for DBP. It should be noted that the range of accuracy is ± 3 mmHg to ± 18 mmHg for the prototype. Thus, the prototype of blood pressure shows less accuracy than that of commercial blood pressure monitor and may not medically use for health monitoring. However, the prototype maybe practically uses as a screening tool for monitoring blood pressure due to easy to use and fast measurement.

4. Conclusion

The prototype of blood pressure monitor by photoplethysmography is successfully constructed and calibrated with upper-arm blood pressure monitor. It is found that the maximum and minimum values of PPG signals from the prototype show linear dependence of systolic and diastolic blood pressure from the commercial blood pressure monitor with $R^2=0.72$. Moreover, the prototype with calibration relation is successfully tested with 12 volunteers and found the precision of systolic and diastolic blood pressure from the prototype are 8 mmHg and 6 mmHg, respectively with the accuracy of ± 10 mmHg compared to that of commercial blood pressure monitor of ± 3 mmHg. Therefore, the prototype of blood pressure monitor maybe practically use as a screening tool for monitoring blood pressure due to easy to use and fast measurement and may not medically use for health monitoring.

5. References

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