Estimation of Blood Pressure Using Photoplethysmography on the Wrist

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Abstract

Blood pressure measuring method using PPG signal is the one of many non-invasive blood pressure methods. In this study, we have studied a new method that estimates the blood pressure using wrist cuff and wrist PPG (Photoplethysmograph) signal.

During the deflation of the wrist cuff pressure, the PPG pulse appears at certain point that is similar to Korotkoff sound. After the pulse appeared, the morphology of PPG pulses was changed into the certain shape. So, we use these points to estimate the blood pressure. For validation, the reference SBP and DBP are measured by auscultatory method at the left upper arm.

Subjects were 13 non cardiac disease of man in their twenties. The result of this study, the mean difference of SBP and DBP, between auscultatory method and PPG analysis is 2.08 ± 5.07mmHg and 1.38 ± 7.86mmHg respectively.

1. Introduction

U-healthcare is a technique that provides healthcare service anywhere. For this reason, U-healthcare is applied in various situations, allowing the detection of emergency situations, the treatment of chronic infections, treatment of diets, and other sorts of clinical problems that require ubiquitous healthcare.

Currently, the bio signals that used in u-healthcare are electrocardiogram, blood pressure, respiration and activity level. But in daily life, it is ideal for vital signs monitoring system to have minimum size in order to offer enhanced comfort for users to carry it around for a long time. Blood pressure is one of the most basic vital signs, but the current home blood pressure monitoring devices in the market are rather uncomfortable, since the cuff must be placed on the brachial arms. Furthermore, the measuring devices are somewhat inaccurate. In that regard, a portable and accurate wrist blood pressure monitoring devices are emerging as a solution to aforementioned limits in portable blood pressure measurement devices.

In this study, a new method that derives blood pressure via estimation of SBP (systolic blood pressure) and DBP (diastolic blood pressure) is presented. This new method detects the changes in morphology of the PPG signal measured from the radial artery. Based on the detection of the changes in morphology of the PPG signal, SBP and DBP can be estimated.

2. Methods

2.1. Measuring environment

The hardware system for blood pressure measurement device consist of the wrist cuff, PPG array sensor and main control system based on MSP430 (TI inc., USA) like figure 1. PPG array sensor has the four IR LEDs on each corner and one photo transistor on center. Main control system has two modules — a PPG signal processing module and pressure pump and valve control module.

2.2. Measuring methods

PPG signal was measured that the cuff and PPG sensor on the wrist as shown in figure 2. For validation of

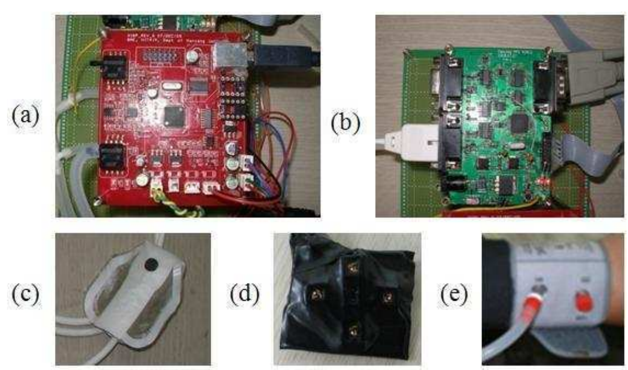

Figure 1. The hardware system configuration for blood pressure measurement. NIBP module (a), PPG module (b), Finger PPG sensor (c), wrist PPG sensor array (d) and wrist cuff (e).

Figure 2. Wrist cuff and wrist PPG sensor array was put on the wrist.

estimated blood pressure value using PPG signal, the gold standard method, which is measuring korotkoff sound using the sphygmomanometer and stethoscope, was conducted simultaneously with PPG signal measurement. The reference blood pressure at the left upper arm is measured by two observers who were trained by the BHS (British hypertension society) program. Thirteen men in their twenties who do not have cardiac disease were tested as subjects. During the measurement, the subjects sat on chairs in comfortable positions, with their arm placed on desks at their respective heart level [1].

The Korotkoff sound blood pressure at the brachial arm was first measured, and around two to three minutes later, blood pressure was measured at the wrist with PPG signal. After two to three minutes passed again, the Korotkoff sound was measured at the left brachial arm. Wrist blood pressure, which was estimated by analyzing PPG signals measured, was compared with average blood pressure value derived from the results of two-time

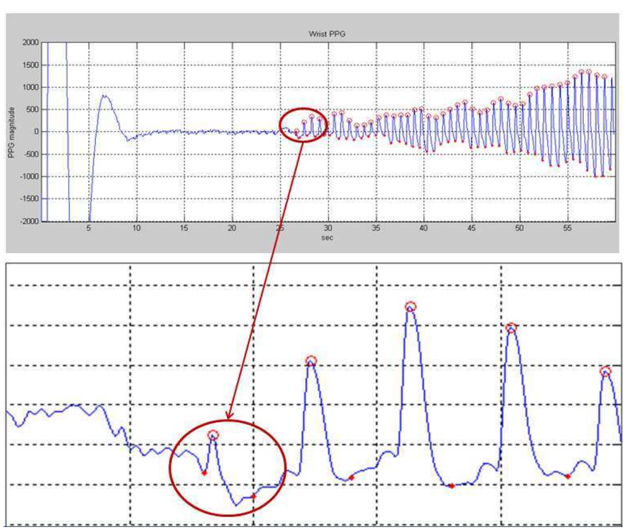

Figure 3. One typical example of PPG signal when the cuff pressure is decompressed.

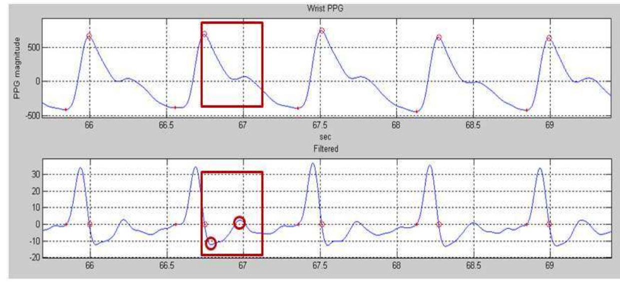

Figure 4. PPG signal waveform (upper figure) and the differentiated PPG signal waveform (lower figure).

Korotkoff sound measurement.

2.3. PPG signal analysis

When air is injected into the wrist cuff, blood vessel is eventually blocked by the increasing pressure of the cuff. PPG pulse, which is measured on the wrist by the PPG sensor, gradually becomes too weak for the sensor to pick up its signal.

Upon the disappearance of the PPG signal, let the wirst cuff pressure be decompressed gradually. Then, the PPG pulse re-appears at a certain point that is similar to Korotkoff sound as shown in figure 3; this point can be related to SBP [2, 3]. After reappearance of the pulse, the morphology of PPG pulses changes; the point at which this change is detected can be related to DBP.

Conventionally, SBP is defined as a certain point in cuff pressure at which sound is detected as according to Korotkoff sound measurement via auscultatory method. However, the method of blood pressure measurement discussed in this paper is different from auscultatory method; this research measures blood pressure at the wrist radial artery, whereas conventional auscultatory methods measure blood pressure at the brachial artery. Blood pressure at the distal artery is higher than that at the proximal artery [4]. Since SBP at the wrist radial artery is higher than the SBP at the brachial artery, we determined the SBP by comparing two methods of SBP

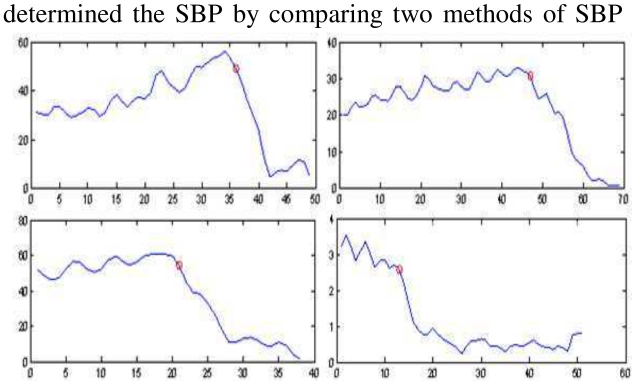

Figure 5. The slope of reflection wave of each pulse of which indicates from last value to first one.

determination.

DBP is established at a certain point in cuff pressure where Korotkoff sound has disappeared in auscultatory method. After the SBP, the morphology of PPG pulses started to form a certain shape. Afterwards, the reflection wave of PPG pulses appeared rapidly and appeared continuously from that specific point. The point where the slope of reflection wave changed rapidly was detected, and this point can be related to DBP. This point was compared with the reference DBP for validation. Figure 4 shows differentiated PPG signal for measuring the slope of reflection waves. X-axis shows time (seconds), and Y-axis refers to the size of the signal. Figure 5 shows each pulse's slope from the back for 4 subjects.

3. Results

From the result of this method, the pressure at the point that PPG pulse appeared was 14mmHg (mean value of differences) higher than the reference SBP, and the pressure at the point that slope of reflection wave changed rapidly was 18mmHg (mean value of differences) higher than the reference DBP. So SBP and DBP of PPG pulse were defined as the values that were subtracted by two difference values. In conclusion, the mean difference of the blood pressure, SBP and DBP, between auscultatory method and PPG analysis was 2.08 ± 5.07 mmHg and 1.38 ± 7.86mmHg, respectively. Table 1 shows the differences between two methods.

Table 1. The differences between two methods, auscaltatory method and PPG analysis.

	Korotkoff Sound (KS)		PPG		SBP (PPG – KS)	DBP (PPG – KS)
	SBP	DBP	SBP	DBP		
01	122	92	121	88	-1	-4
02	112	75	116	80	4	5
03	110	76	109	76	-1	0
04	120	71	132	71	12	0
05	101	69	102	67	1	-2
06	110	66	107	67	-3	1
07	95	53	90	55	-5	2
08	102	59	105	62	3	3
09	125	85	125	80	0	-5
10	96	52	102	50	6	-2
11	123	72	122	74	-1	2
12	107	43	108	68	1	25
13	111	80	122	73	11	-7

4. Discussion and conclusions

The results from the proposed method satisfy the recommended error boundary as defined by the Association for the Advancement of Medical Instruments (AAMI), which is 5mmHg ± 8mmHg. As for subjects that display large boundaries of error, this seems to have been a result from the distortion of motion artifact's distortion; this is the hardest problem to solve in non-invasive blood pressure measurement. It is suspected that some results which have comparatively big differences are caused by distortion of signals.

PPG sensor position and fixing intensity are important factors. If the PPG sensor is positioned apart from the radial artery, wrong determination can be resulted because of the distortion of PPG pulses reflection wave. In addition, if the PPG sensor is fixed on the wrist sensing weak intensity, it brings about the distortion of PPG signal caused by skin movement from cuff deflation. Thus, when estimating the blood pressure using the PPG signal, the distortion of signal is an important factor to consider.

The research which estimates the DBP using the morphology of PPG signal has hardly existed, even though there have been many cases of the research of SBP estimation. In that regard, this study suggests the efficient method that improves the accuracy of blood pressure estimation by using the method that estimates DBP by using the change of morphology in PPG signal without the amplitude information.

In future, a research to improve accuracy of blood pressure measurement by using more diverse pool of subjects and thereby improving the clinical relevance of the results is to be conducted. Furthermore, continuous blood pressure measurement is necessary, and this is to be done by measuring the PTT (pulse transit time) from wrist to finger PPG signal for continuous blood pressure measurement.

Acknowledgements

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