

Non-intrusive measurement of pulse arrival time and Estimation of Systolic Blood Pressure

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무구속적 맥파 전달 시간의 측정을 통한 혈압 추정

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Abstract

¹Even though the blood pressure is one of the most widely used index for the healthcare monitoring of hypertensive and normotensive persons, there is no non-intrusive measurement method which is commercialized until now. Pulse Arrival Time (PAT) is known that it has close relation with the systolic blood pressure (SBP) and arterial stiffness. In this study, SBP estimation methods by non-intrusive measurement of PAT are suggested. For the unconstrained measurement of PAT, the first method used the electrically non contact electrocardiogram (ENC-ECG) technique and the reflective type of Photoplethysmography (PPG) sensor on the computer mouse. In the second method, ENC-ECG and the air pressure sensor in the seat cushion on a chair were measured. The third method used ECG electrodes and PPG sensors on the toilet seat cover. The validation and regression analysis of the relationship of PAT and SBP are summarized. These methods have considerable errors to be used for all people. But these can be applied for each subject after the parameter customization within acceptable error. So, it is feasible for suggested methods to be used for monitoring of SBP in daily life in non-intrusive way when there is personal identification system of each subject.

Keywords—blood pressure, non-intrusive monitoring, pulse arrival time

I. INTRODUCTION

There are many trials to measure the physiological signals for ubiquitous healthcare, home healthcare, or mobile healthcare in many countries. Even though the blood pressure is one of the most widely used healthcare parameter, there is no convenient, accurate, and economic device to measure blood pressure (BP) in non-intrusive way. The non-intrusive

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monitoring is more strict condition than non-invasive monitoring in the sense that there should be no disturbance like sensors or harness on the subject's body surface in daily life. Home device to measure BP are mainly using the oscillometric technique and cuff system which is not convenient for daily monitoring. For unawareness monitoring, and non-intrusive monitoring, and long term monitoring, there should be proper measurement device. For this purpose, Sameshima [1] and Kim-Gau Ng [2] introduced new concepts but they are not proper for daily life monitoring. Bases on the special condition of pressure measurement, it is very difficult to design new device to measure BP directly without interrupting daily life for monitoring.

There have been many studies on the relationship between pulse arrival time (PAT) and BP [3-6]. PAT is also closely related with pulse wave velocity (PWV). These indexes get influence from arterial stiffness and blood pressure. Since arterial stiffness changes in long term, daily changes of PAT gets major influence from BP. Blood pressure have been changed by various stimulation experiments [4-5], and correlation between PAT and BP is considerable. Even though most of the techniques used pressure-sensing catheter, Photoplethysmography (PPG) can detect the volume change in many places of human body which has direct relationship with

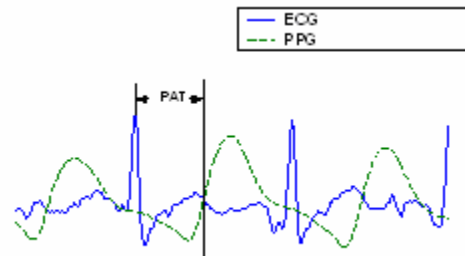


Fig. 1. PAT is defined the time interval between R peak in ECG and certain feature point in PPG.

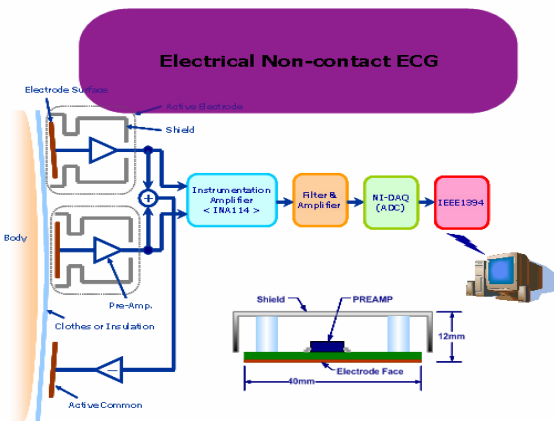


Fig. 2. The schematic diagram of Electrically Non-Contact Electrocardiogram (ENC ECG)

pressure.

In this paper, three methods that can measure PAT in non-intrusive way are suggested. Through the regression analysis of the PAT data in various situations is performed to check whether these methods can be used for the estimation of systolic blood pressure (SBP) with acceptable range of accuracy and convenience.

II. METHOD

A. Measurement Principle

PAT in this paper is defined as the time difference between R peak in ECG and certain feature point in PPG waveform as shown in Fig. 1. This time difference is composed of pre-ejection period and pulse wave traveling time through arteries. In many studies, the pulse transit time (PTT) becomes shorter as BP increases and arterial stiffness increases. To measure PAT in non-intrusive way, there should be the method to measure ECG and PPG in non-intrusive method in daily life.

Electrically Non-Contact Electrocardiogram (ENC ECG) was developed that has no electrode or harness contact with the subject.[7] The Capacitive electrodes with very high impedance delivers the electric signal through the clothes to pre-amplifier as shown in Fig. 2. To enhance CMRR, active common ground sheet was placed on the chair. This technology can be applied to bed for sleep monitoring and chair for monitoring in daily life.

For the measurement of PPG signal, the reflective type PPG sensor (NONIN finger clip 8000K2, USA) was mounted on the computer mouse and toilet seat cover where the measurement is required and feasible. The detailed measurement configurations for suggested methods are followings.

B. Measurement Method I: PAT for computer user

As shown in Fig. 3, to measure PAT in non-intrusive way while using computer, ENC ECG was installed on the chair and PPG sensor on the mouse (computer pointing device). The reflective type of PPG sensor picks up the pulses on the inner side of thumb. Through this configuration, we can measure ECG and PPG signal without notice of computer users. Through signal processing, we can calculate the PAT of the computer user.

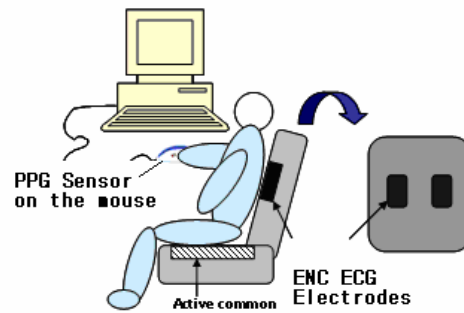


Fig. 3. The measurement configuration of method I for computer user

C. Measurement Method II: PAT on the chair

To measure the PAT in non-intrusive way on the chair, ENC ECG technique was applied as Method I. In method II, instead of using PPG sensor, high sensitive air mattress and air pressure sensor were used. When there is no body movement, by the beating of the heart, very small pressure changes are detected on the air cushion on a chair. This signal contains the information of mechanical force of heart beating. To increase the sensitivity of the pressure changes, the air mattress sensor system with balancing tube with reference air cell was used [8]. Typical waveform with this method II is shown in FIG. 7.

D. Measurement Method III: PAT on the toilet seat cover

As shown in Fig. 5, to measure PAT in non-intrusive way on toilet seat cover, ECG electrode and reflective type of PPG sensor were placed on toilet seat cover. Three pieces of copper place contact the thigh while seating, it can detect R-Peak in ECG. Also reflective PPG sensor detects the pulse on the femoral artery. By calculating PAT from this configuration, we could estimate the blood pressure.

E. Experimental Setup

Analogue ECG signal were filtered between 0.5 Hz and 200Hz, and PPG signal between 0.5 to 35 Hz. After filtering, the signal was digitized at 12 bits per sample and sampled at 2 kHz with Bio Pac and NI-DAQ 6070E. 3 male subjects (age: 25-31, weight: 61-75kg) who has no history of cardiovascular

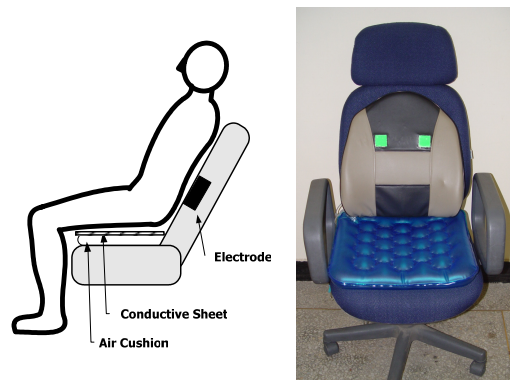


Fig. 4. The measurement configuration of method II for chair and its implemented form

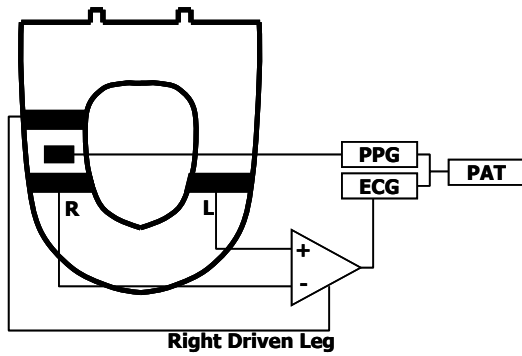


Fig. 5 The measurement configuration of method III for toilet seat cover

disease participated to collect data. To make the variation in BP within short time, various stimulation were applied like Valsalva Maneuver, static exercise (horse riding posture for 5 minutes), and cold pressor (put his leg into iced cold water for 1 minute). For the reference measurement of blood pressure Tonometer (CBM 7000, Colin) was used.

III. RESULTS

A. Measurement Method I: PAT for computer user

Fig. 6 shows the result of one subject. PAT was measured by the method I and SBP was measured by Tonometer. Linear regression model was applied to find the relationship between PAT and SBP. With three kinds of stimulation that changes blood pressure temporarily, it has the close relation and SBP can be estimated. In table I, Pearson Correlation Coefficients were shown for each subject. When we consider the data of 3 subject altogether, based on the differences of many parameters of each person like height, weight, age and other physiological parameters, the correlation coefficient decreases so much. It is not feasible to find the one linear regression parameter value which can be applied to all of the subjects. So the parameter should be customized for each person.

TABLE I Correlation Coefficients and the Linear Regression of 3 Subjects ($p < 0.001$)

	Correlation	Regression model
Subject1	-0.7868	SBP=-0.48PAT+243.59
Subject2	-0.8933	SBP=-0.97PAT+379.95
Subject3	-0.6930	SBP=-0.59PAT+289.78

B. Measurement Method II: PAT on the chair

As we did in section III.A, the correlation between PAT by

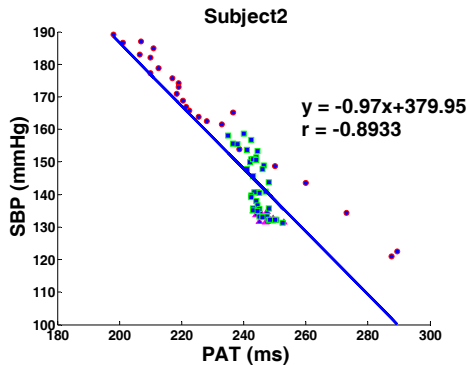


Fig. 6. The plot of SBP and PAT (method I)

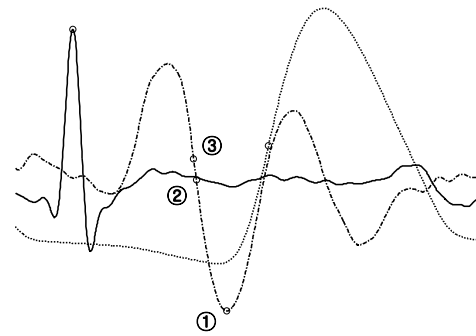


Fig. 7. One-interval waveforms of electrically non-contact ECG (2), pressure pulse of air cushion (3) and PPG on toe (1).

method II and SBP by Tonometer was analyzed. The correlation was somewhat low($r=0.65$) because the localization of feature point in the waveform of air pressure is not so stable. After averaging of 5 beats and 10 beat according to the R-peak of ENC ECG, the correlation is increased. To peak up the heart beating signal on the air cushion, the sensitive of the pressure sensor should be very high. Even the respiration movement can make the variance of the sensor system. Averaging of the waveform can eliminate these artifacts. Fig.7 shows one cycle of ENC ECG and air pressure changes by heart beating and PPG signal on the toe. Table II shows the enhancement of correlation coefficients. As known in prior researches, the correlation with diastolic BP(DBP) and pulse pressure(PP) is lower than that of SBP.

TABLE II The correlation coefficients of PAT using method II and SBP/DBP/PP when the pressure waveforms were averaged by 5 beats and 10 beats.

PAT vs.	Correlation Coefficients		
	1	5 beats	10 beats
SBP	-0.6484	-0.8397	-0.8584
DBP	-0.2214	-0.3056	-0.3293
PP	-0.6792	-0.8701	-0.8885

C. Measurement Method III: PAT on the toilet seat cover

Fig. 8 shows the relationship of PAT on the toilet seat cover and SBP with Tonometer. With different stimuli, the SBP changes from 100 ~ 160 mmHg and PAT changes 230 to 300 ms. Also when we plot and analyze the regression performance of 3 subjects together, the correlation was too low to be used in general. But intra-subject correlation between SBP and PAT (method III) was high enough to estimate SBP with PAT. Table III shows that SBP has the higher correlation with PAT than DBP and PP.

TABLE 3 Correlation coefficients between SBP, DBP, and PP and PAT of Method III ($p < 0.001$)

	Subject 1	Subject 2
SBP	R=-0.9453	R=-0.9013
DBP	R=0.1208	R=-0.2326
PP	R=-0.7378	R=-0.5779

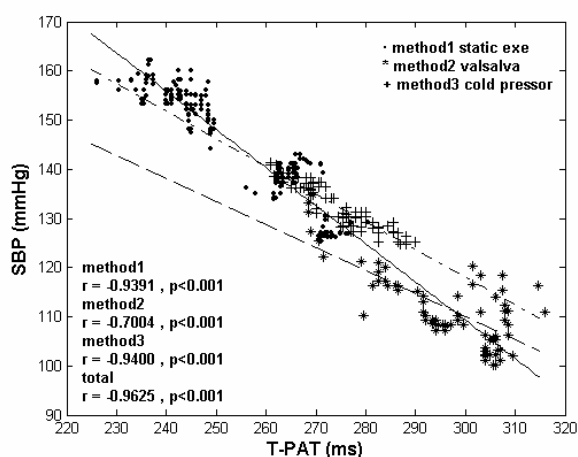


Fig. 8. Plot of PAT (method III) and SBP in one subject. Three kinds of stimulations was applied to make the changes of BP. Considering all stimuli, the correlation coefficient was -0.9625

IV. DISCUSSION

As shown in previous section, the suggested methods can measure the PAT that contains the information of BP. It is well known that PAT also varies with arterial stiffness. It may make some error in estimation of BP with PAT. But the time scale of changing arterial stiffness is quite long compared with BP. So PAT can be used for the estimation of BP. From SBP, DBP, and PP, SBP has the highest correlation with PAT, as was confirmed by prior researches [4] [9-10]. So the suggested method is suit for the estimation of SBP.

To estimate SBP with PAT using linear regression model, the sample data can make big difference of the regression line. So it is almost impossible to get unique value that can be applied for all subjects. Within a subject, with prior test and data analysis, the regression results can be used even in different date. It might be needed for a subject to calibrate periodically, e.g., once a year.

In method 2, the averaging of 5 to 10 beats shows good result. Based on the very sensitive pressure sensor system, small movement like respiration may makes the deformation of the wave form. As a result, it leads the error to find the feature point in pressure curve.

The Fig. 9 shows one example of the future application. For long term monitoring of SBP may be helpful to find the trend of his cardiovascular performance. In the Fig. 9, the SBP estimation in method III and reference measurement of SBP with oscillometric method was compared for 15 days. For home healthcare monitoring, the customized system for one subject, and relative changes in long term can have valuable information on his health changes.

V. CONCLUSION

The pulse arrival time were measured in non-intrusive ways using electrically non-contact ECG and mounting PPG sensor on the computer mouse and toilet seat cover. To estimate systolic blood pressure, linear regression method was used for the data of each subject. With this method, SBP can be estimated in unconstrained method. These technologies can be

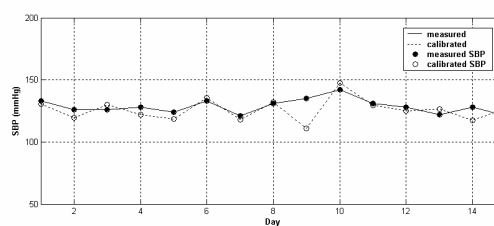


Fig. 9. Individual original tracing of SBP and estimated SBP from T-PAT. This data were obtained from JS subject every morning for 15 days.

used for long term monitoring, non-intrusive monitoring of the blood pressure for ubiquitous healthcare system and home healthcare system in the future.

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