A Preliminary Study of Non-intrusive Blood Pressure Monitoring using Portable Device

Hanbyul Kim[1], Hongji Lee[1], Hyunjae Baek[1], Wonkyu Lee[1], Jungsu Lee[1] and Kwangsuk Park[2]
[1]*Interdisciplinary Program of Bioengineering, College of Engineering, Seoul National University, Seoul, Republic of Korea*
[2]*Department of Biomedical Engineering, College of Medicine, Seoul National University Hospital, Seoul, Republic of Korea*

Keywords: Non-intrusive Monitoring, Blood Pressure (BP), Electrocardiogram (ECG), Photoplethysmogram (PPG), Pulse Arrival Time (PAT), Portable Device.

Abstract: Novel blood pressure (BP) monitoring device focused on portability was studied preliminarily. Electrocardiogram (ECG) and photoplethysmogram (PPG) was measured and pulse arrival time (PAT) was computed from these signals. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) showed a clear correlation with PAT. BP estimation model was constructed based on this result and verified by means of leave-one-out cross-validation (LOOCV). Estimated SBP, DBP were involved in two standards of means of original data. This device is expected to be useful to the people who want to monitor BP at any time and space.

1 INTRODUCTION

Blood pressure (BP) is significant biological signal which indicates cardiovascular diseases. They are one of the leading reasons of death worldwide and even cause sudden death (Murray et al., 1996). Monitoring BP becomes important issue to the people who have risk of heart attack.

On the one hand, the concept of ubiquitous healthcare has been promising as communication and medical technology advances rapidly. It gradually changes conventional notion of medical treatment. Non-intrusive physiological monitoring is a typical example. It allows medical care without consciousness as well as seeing a doctor in person.

There also has been many developments to monitor BP to fit this fashion. Mercury sphygmomanometer has been used to measure BP and considered “gold standard” for a long time. However, sphygmomanometer was inconvenient since it is obstructive and had a difficulty with continuous monitoring, so several non-constrained methods began to appear.

Among them, pulse waveform analysis based on the facts that pulse arrival time (PAT) correlates BP is now engaging much thought. Kim developed a system using toilet seat which can sense ECG and PPG (Kim et al., 2006) and also suggested system for computer users with a chair and a mouse (Kim et al., 2007). The cuff-less measurements of BP using pulse transit time was also investigated (Poon and Zhang, 2006).

However, these studies had limits since they didn’t focus on the portability of device. The results aren’t suitable for users who engage in outdoor activities mainly. To resolve this problem, we designed a necklace-type monitoring system which is convenient to carry. It measures ECG and PPG signals simultaneously and extracts PAT from them to estimate BP using built-in algorithm.

In this study, a similar but wired system was developed and examined for verification of portable device. The correlations between PAT and SBP, PAT and DBP was observed to ensure connections between these parameters. BP estimation model was constructed on each subject and validated by statistical methods afterwards.

2 METHODS

2.1 Data Acquisition System

Figure 1 shows expected goal of our improved BP monitoring system. The front side consists of PPG sensor, ECG electrode, and display to show the results of analysis. The backside has the other ECG electrode and driven electrode. Before we start to develope, we conducted preliminary experiment to explore the possibility of this device.

Kim H., Lee H., Baek H., Lee W., Lee J. and Park K..
A Preliminary Study of Non-intrusive Blood Pressure Monitoring using Portable Device.
DOI: 10.5220/0004247101630167
In *Proceedings of the International Conference on Biomedical Electronics and Devices* (BIODEVICES-2013), pages 163-167
ISBN: 978-989-8565-34-1

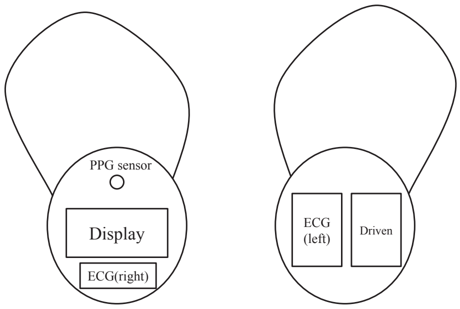


Figure 1: A schematic diagram of portable blood pressure monitoring system. The left and right one denotes frontside and backside of the system. Frontside contains display for output, PPG sensor, ECG sensor (left). Backside has two electrodes to measure ECG (right, driven).

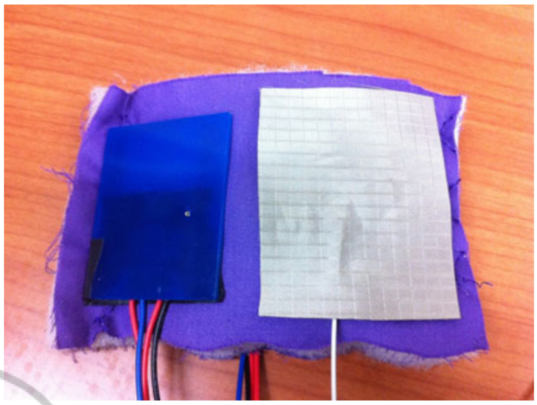
Figure 2 is the sensing part designed for this preliminary study. ECG measurement system followed convention of driven-right-leg (DRL) circuit design (Winter and Webster, 1983). Two active electrodes developed by Lim were used to measure ECG (Lim et al., 2006). These can be reused semi-permanently since they are dry electrodes. The one ($5cm \times 4cm$) was placed on the chest between nipples. The other one ($3cm \times 2cm$) was on the palm of right hand. Driven electrode was employed to cancel common noise of the body. It was located next to the electrode on chest. Frequency bands of the ECG signal were 0.5-35Hz.

A ring-type sensor (RP320, Laxtha, South Korea) was chosen to monitor PPG. PPG signal was collected from the index finger of right hand. Frequency bands of the PPG signal were 0.5-35Hz. Finometer® PRO (Finapres Medical Systems, Netherlands) was used to measure beat-to-beat BP measurement. The finger-type sensor was worn on the left middle finger. All analog ECG, PPG and BP waves were digitized at a sampling rate of 500Hz using BIOPAC acquisition system (MP150 and UIM100C, BIOPAC Inc., USA).

2.2 Experiments

A total of three male subjects who had no history of heart-related disorders participated in the experiment. They were 24, 24 and 30 years old and weighed 67, 73 and 65kg respectively.

After all sensors attached as previously described, they rested quietly for 2 minutes at first. The Valsalva maneuvers for BP increase were performed for about 15 seconds. Five minutes of rest was necessary for BP to reach resting state. The maneuver and relaxation repeated 4 times.



(a)

(b)

Figure 2: A preliminary sensing part of portable blood pressure monitoring system. (a) blue one: active electrode placed on the chest, grey one: driven electrode. (b) blue one: active electrode on the palm of right hand, black ring: PPG sensor.

2.3 Data Analysis

Decreasing BP section right after Valsalva maneuver was selected for the analysis. We could cover a wide range of BP and remove many BP data around mean blood pressure by doing that. The worst data due to motion artifact was excluded from the analysis.

PAT is defined as the time difference between ECG R-peak and the characteristic point of PPG signal. Various characteristic points have been chosen in many studies. But Chiu showed first derivative point method provided consistent results (Chiu et al., 1991). So we calculated PAT by subtracting time of R-peak of ECG from that of maximum first derivative point of PPG in this study (Figure 3).

The hypothesis that PAT and BP correlate were verified at first. PAT was compared with corresponding systolic blood pressure (SBP) and diastolic blood pressure (DBP) values.

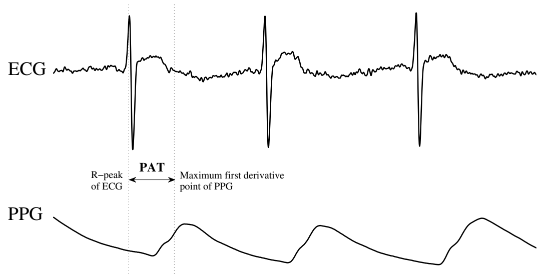


Figure 3: ECG and PPG waveforms measured from experiment. PAT is defined as the time difference between R-peak of ECG and maximum first derivative point of PPG.

Blood pressure estimation model can be constructed according to this result. Previous study (Yoon et al., 2009) showed total calibration using all the data of subjects made estimation errors bigger, so we only performed individual calibration.

This model was assessed by means of cross-validation study. Leave-one-out cross-validation (LOOCV) was selected out of various cross-validation methods. LOOCV uses a single observation data as the validation data and remaining data as the training data (Kohavi, 1995). The correlation coefficient between BP and estimated BP and root mean square error (RMSE) were computed to evaluate estimation.

Parameter calculations, correlation and cross validation analysis were performed using Matlab software (MathWorks, USA).

3 RESULTS

Figure 4 shows the correlations between PAT and BP. The scatterplot of PAT and SBP (DBP) on each subject were drawn on a single graph. The correlation coefficients for each subject were also given in figure 4. SBP had a considerable correlation with PAT but DBP showed lower linearity than SBP did.

Figure 5 summarizes the results of estimation of SBP and DBP from PAT obtained by LOOCV. It indicates estimated SBP and DBP correlated well with the measured ones. Most estimated BPs don't deviate from the two standard of mean BP.

4 DISCUSSION

The relationships between PAT and BP were examined for three subjects in this study. The correlation of our study showed better results compared with that of system using a chair and computer mouse (Kim et al., 2007) and BP monitoring device (Yoon et al., 2009). A device of toilet seat type showed a high correlation between SBP and PAT but there was a lower relationship in DBP and PAT (Kim et al., 2006).

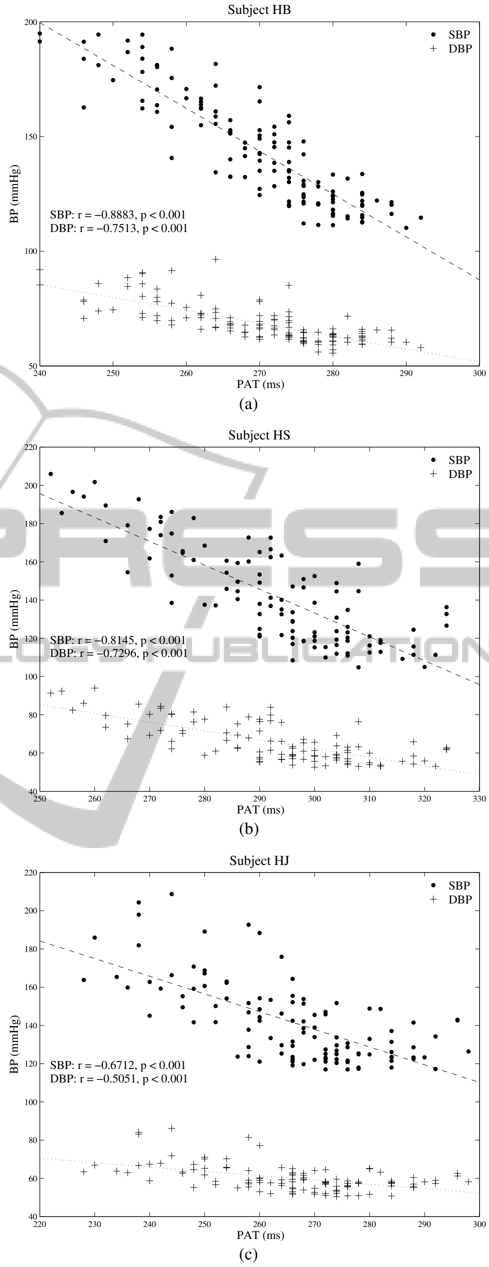


Figure 4: Relationship between blood pressure (SBP, DBP) and PAT observed for (a) Subject HB (SBP: -0.8883, DBP: -0.7513). (b) Subject HS (SBP: -0.8145, DBP: -0.7196). (c) Subject HJ (SBP: -0.6712, DBP: -0.5051).

Subject HJ showed lower correlation in both SBP and DBP than the others did. It gave better results when Valsalva maneuver section were separated from

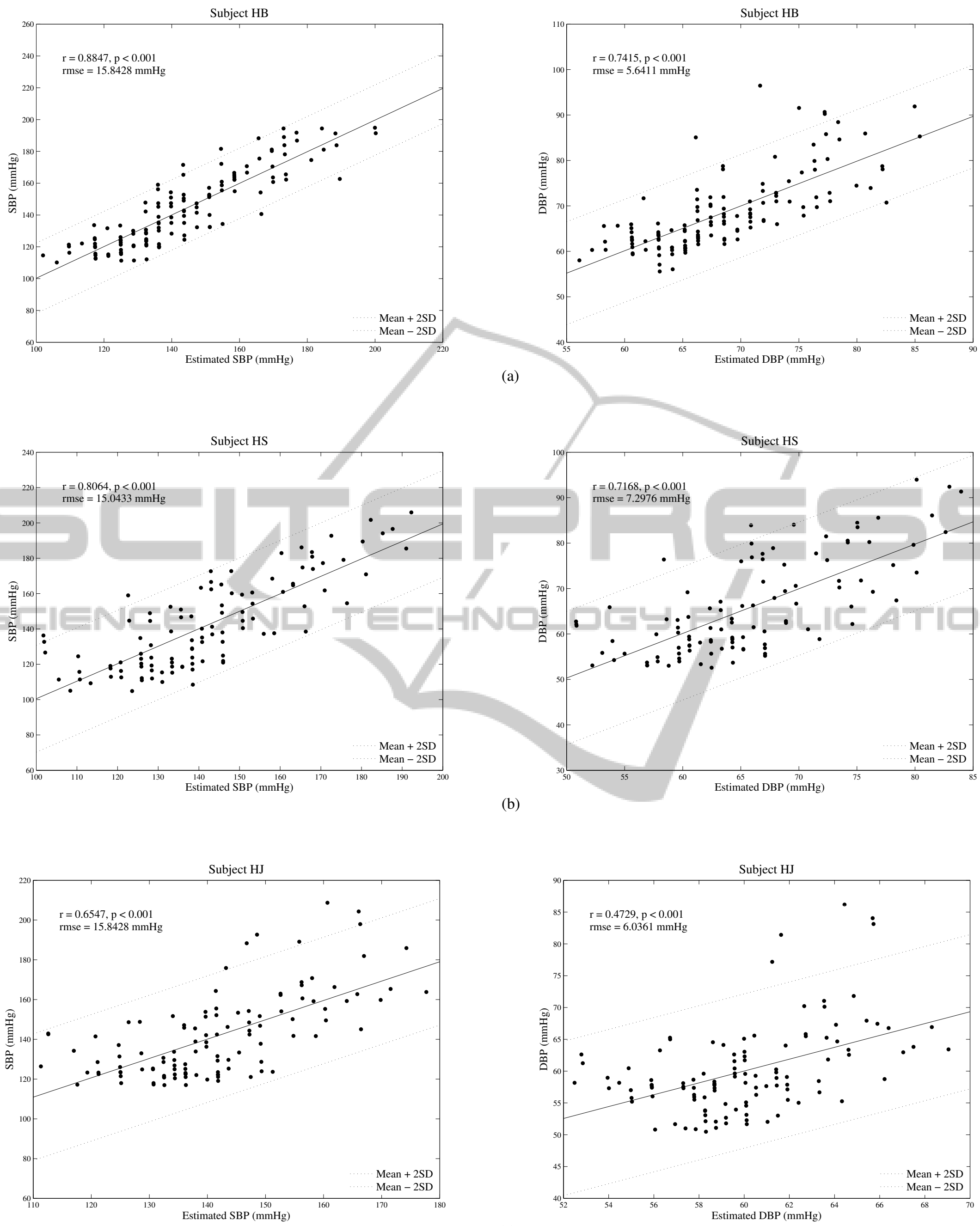


Figure 5: Correlation between SBP (DBP) and estimated SBP (DBP) (a) Subject HB. (b) Subject HS. (c) Subject HJ.

all data (-0.7796, -0.8282, -0.7213 respectively). It can be infered from this result that accumulation of data doesn't always make better outcome.

All correlation coefficients between PAT and DBP were lower than that of PAT and SBP. Most previous studies had a trouble finding relation between PAT and DBP. Kim showed this could be improved by multiple linear regression method (Kim et al., 2008). So parameters like heart rate should be introduced to estimate DBP.

The results of BP estimation was validated by using LOOCV method. As a result, we found that the RMSE between SBP and estimated SBP was about 15mmHg. Cross-validation analysis in DBP showed that PAT couldn't estimate DBP well but it had a lower RMSE that SBP did. The fact that the range of DBP is narrower than that of SBP is assumed to the main reason of this result.

Several additional works are planned to proceed this project. More subjects should be employed to demonstrate generality of this model. Experiments will be performed to verify if this estimation is applicable to long-term monitoring. The data measured in a few days from same subject can be collected for this purpose.

5 CONCLUSIONS

The potential of portable BP monitoring system was explored. Several experimental results showed PAT which was measured non-intrusively had an obvious correlation with both SBP and DBP. So it could be used as parameter for the estimation of BP. Further work with more subjects is needed to assert the accuracy of prediction. People can monitor BP in daily life easily with no limitations of time and space with this portable system.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government(MEST) (No. 2012010714).

REFERENCES

Chiu, Y., Arand, P., Shroff, S., Feldman, T., and Carroll, J. (1991). Determination of pulse wave velocities with computerized algorithms. *American heart journal*, 121(5):1460–1470.

Kim, J., Chee, Y., Park, J., Choi, J., and Park, K. (2006). A new approach for non-intrusive monitoring of blood pressure on a toilet seat. *Physiological measurement*, 27:203.

Kim, J., Kim, K., Baek, H., and Park, K. (2008). Effect of confounding factors on blood pressure estimation using pulse arrival time. *Physiological Measurement*, 29:615.

Kim, J., Park, J., Kim, K., Chee, Y., Lim, Y., and Park, K. (2007). Development of a nonintrusive blood pressure estimation system for computer users. *Telemedicine and e-Health*, 13(1):57–64.

Kohavi, R. (1995). *A Study of Cross-Validation and Bootstrap for Accuracy Estimation and Model Selection*. Morgan Kaufmann.

Lim, Y., Kim, K., and Park, S. (2006). Ecg measurement on a chair without conductive contact. *Biomedical Engineering, IEEE Transactions on*, 53(5):956–959.

Murray, C., Lopez, A., et al. (1996). The global burden of disease. *Geneva: WHO*, 270.

Poon, C. and Zhang, Y. (2006). Cuff-less and noninvasive measurements of arterial blood pressure by pulse transit time. In *Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. 27th Annual International Conference of the*, pages 5877–5880. IEEE.

Winter, B. and Webster, J. (1983). Driven-right-leg circuit design. *Biomedical Engineering, IEEE Transactions on*, pages 62–66.

Yoon, Y., Cho, J., and Yoon, G. (2009). Non-constrained blood pressure monitoring using ecg and ppg for personal healthcare. *Journal of medical systems*, 33(4):261–266.