A Study on the Estimation of Continuous Blood Pressure using PTT and Biometric Parameters

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Abstract

In this paper, we propose a subject-independent regression model to estimate systolic blood pressures (SBP) conveniently and continuously. There have been several researches on estimating SBP with pulse transit time (PTT) and they showed promising results. However, previous studies used only PTT as the estimation parameter, and their models were generated with just one person's PTT data which is not applicable to estimating other person's SBP. Therefore, we collected several additional biometric parameters with 202 healthy subjects. After statistical analysis of measured biometric parameters with SBP, we chose final estimating parameters including PTT to generate a multiple linear regression model for estimating SBP. Comparing the results of our study with approvable standards of automated sphygmomanometers developed by Association for the Advancement of Medical Instrumentation and approved by American National Standards Institute (ANSI/AAMI) indicates that our proposed method for continuously blood pressures monitoring gives an acceptable error.

Key words : blood pressure, continuous, pulse transit time, noninvasive, cuffless

I. INTRODUCTION

The measurement of systolic blood pressure (SBP) helps a physician to determine the functional integrity of a patient's cardiovascular system. Invasive or noninvasive methods to measure BP are commonly used in clinical environments [1-2].

The invasive method has the advantage of obtaining blood pressure (BP) continuously and accurately, but it also has the disadvantages of contamination and side effects arising from inserting the catheter-tip into a patient's blood vessel. Typical noninvasive methods to measure SBP are the mercury sphygmomanometer and oscillometry. Conventional mercury sphygmomanometers were first introduced in the early 20th century and are still regarded as the gold standard for arterial BP measurement a century later. Automatic BP meters were later developed based on oscillometric method and give objective BP readings [3].

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However, noninvasive BP measurement techniques are inappropriate to monitor and estimate continuous SBP due to the periodic inflation and deflation of the cuff attached to a patient's arm. Frequent occlusion of the artery can cause inaccurate measurements. Therefore, continuous SBP measurement using pulse transit time (PTT) has been used extensively in the past few decades [4-6].

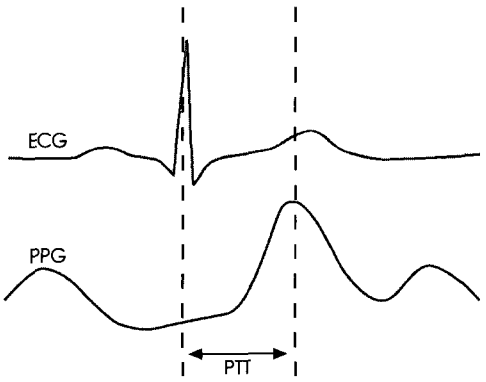

Fig. 1. PTT from R-wave of ECG and peak of PPG.

PTT is the time interval for the arterial pulse pressure wave from the aortic valve to a peripheral site. It is widely accepted that PTT varies inversely with SBP changes and can be used for cuffless and continuous estimation of SBP [7]. In this

study, PTT is measured as the time interval between the R-peak of electrocardiogram (ECG) and the peak of a peripheral pulse [8]. The peripheral pulses are recorded at the fingertip using photoplethysmography (PPG) (Fig. 1).

SBP can be determined using the pulse wave velocity (PWV). PWV is the inverse of PTT using the Bramwell and Hill's equation,

$$c^2 = \Delta pV/\Delta v\rho,$$

where c = PWV[m/s], Δp = change in pressure, Δv = change in volume, V = initial volume and ρ = density of fluid [9]. This means a higher BP corresponds to a shorter PTT interval (Fig. 2).

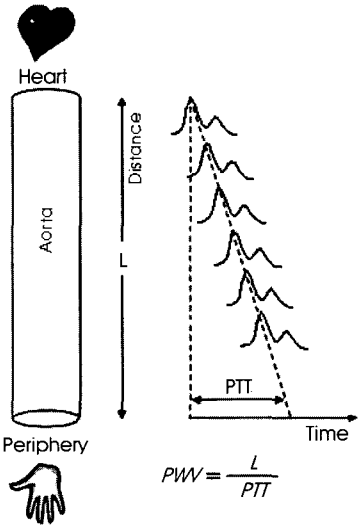

Fig. 2. PTT represents the time that it takes for the pressure pulse wave to propagate through a length of the arterial tree.

In our previous research, the method for estimating BP using only PTT had been studied [10]. It was necessary for the initial calibration of each subject. After the initial calibration, a regression model was obtained for each subject. This model formed a linear function between BP and PTT. However, the method was not appropriate for others.

In this paper, we propose a subject-independent regression model to continuously monitor and estimate SBP using PTT and biometric parameters that influence BP. Many studies assert that height, leg length, age, and gender are associated with BP [13-14]. We selected biometric parameters of: Sex, Age[yr], Arm length[cm], Height[cm], Weight[kg], Body fat percentage [%] and Body fat mass[kg].

II. METHODOLOGY

A. Data Collection

Experiments were conducted on 202 healthy male and female subjects, aged 19~83, and we excluded subjects with a history of peripheral vascular disease or diabetes mellitus. All experimental procedures were approved by the Institutional Review Board (IRB) of Hanyang University Medical Center.

The ECG and PPG signals of 202 subjects were collected from the Family Medicine of Hanyang University Medical Center for an eight week period. Throughout the signal recording, the subjects were seated in a temperature controlled environment (24±3℃) and were asked to relax [11-12]. The ECG and PPG signals were recorded for 40 seconds at a sampling rate of 1 kHzwith PPG100C, ECG100C and TSD200 (BIOPAC System Inc., USA). BP was measured by an experienced registered nurse using the auscultation technique on a conventional mercury sphyg- momanometer attached to the upper left arm. The ECG was monitored by the standard lead I. The PPG was recorded by a reflectance probe on the right hand index finger (Fig. 3).

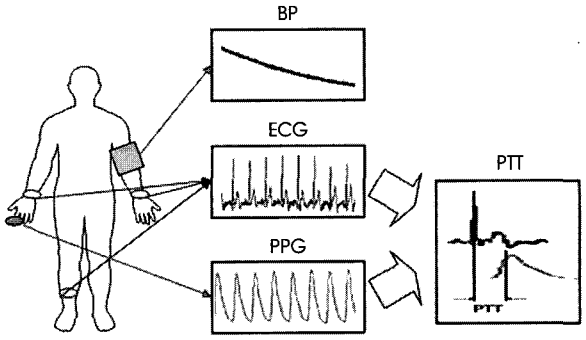

Fig. 3. The experimental setup.

Every data was collected on the same day of each subject's participation. The experimental procedure was as follows: (1) Making the subject relax for about 10 minutes; (2) Measuring the target BP using the mercury sphygmomanometer; (3) Acquiring ECG and PPG signals from the subject for 40 seconds; (4) Measuring the target BP again; and (5) Measuring the biometric parameters.

Each subject repeated the trial three times. Since BP can change between beats, we used the average PTT value of 40 seconds, and the average SBP of the previously mentioned measurements [15]. Table 1 shows the distribution of each biometric parameter.

B. Data Analysis

In this study, we performed multiple linear regression analysis for estimating BP. We used the SPSS 12.0 (SPSS Inc., USA) to derive the multiple linear regression models. Multiple

linear regression analysis is the statistical method that evaluates and predicts a relation between two or more independent variables and one dependent variable [16-17].

Before the multiple linear regression analysis, we performed statistical analysis to determine whether each independent variable is appropriate as predictors. First, we examined correlation analysis to search correlativity among variables, and t value and F value of each biometric parameter to test the significance of the regression model coefficients [16-17]. Next, we performed multiple linear regression analysis using selected variables and 5-fold cross validation as model evaluation method [17]. The data set is divided into 5 subsets. One of the 5subsets is used as the test set and the other 4 subsets are put together to form a training set. Then the average error across all 5 trials is computed. Lastly, we compared errors between target and estimated BP values.

III. RESULTS

Table 2 shows the results of correlation analysis. In this table, we can see high correlation values among Sex, Height, Body fat percentage, Arm length and Weight (except a correlation value between Body fat percentage and Weight), and also a high correlation value between Body fat percentage and Body fat mass.

Table 3 shows the t value and F value of each biometric parameter. The t and F value are used to test the significance of the regression model coefficients. Since $t^2 = F$, if the F of a parameter is higher than 1, the parameter is significant [16-17]. In this table, every variable (except Sex, Height and Arm length) is statistically significant.

Table 3. The test value and F value of each biometric parameter

	t	$F(t^2)$
Sex	0.906	0.821
Age [yr]	4.401	19.369
PTT [ms]	-2.429	5.900
Height [cm]	-0.720	0.518
Weight [kg]	1.316	1.732
Arm length [cm]	-0.567	0.321
Body fat percentage [%]	-2.825	7.981
Body fat mass [kg]	1.490	2.220

On the basis of Table 3, we selected Age, Weight, Body fat percentage, Body fat mass and PTT which have the highest correlation coefficient with BP as input variables. Therefore, we performed the multiple linear regression analysis with Age, Weight, Body fat percentage, Body fat mass and PTT.

Table 4 shows the tolerances of Age, Weight, Body fat percentage, Body fat mass and PTT. Tolerances can be used to diagnose collinearity (or muticollinearity). Collinearity means that within the set of independent variables, some of the independent variables are nearly predicted by the other independent variables. Small values of tolerance (close to zero) are not

Table 1. 202 Subject's data distribution of each biometric parameter

	Range	Mean ± SD
Sex	Male: 94 / Female: 108	-
Age [yr]	19 ~ 83	52.96 ± 13.41
Height [cm]	139 ~ 186	160.28 ± 9.70
Weight [kg]	41 ~ 109	63.71 ± 11.80
Arm length [cm]	60 ~ 83	72.36 ± 4.76
Body fat percentage [%]	14.6 ~ 42.1	29.92 ± 7.68
Body fat mass [kg]	12.1 ~ 32.5	19.48 ± 5.36
Systolic blood pressure [mmHg]	103.25 ~ 167.75	127.85 ± 16.29
PTT [ms]	185.024 ~ 267.021	205.229 ± 18.014

Table 2. The correlation analysis of each biometric parameter
BFP: Body fat percentage, AL: Arm length, BFM: Body fat mass

	Sex	Height	BFP	AL	Weight	BFM	Age	PTT
Sex	1	-0.776*	0.790*	-0.669*	-0.575*	0.376	0.234	0.017
Height	-0.776*	1	-0.700*	0.870*	0.664*	-0.262	-0.426	0.076
BFP	0.790*	-0.700*	1	-0.585*	-0.190	0.769*	0.323	0.029
AL	-0.669*	0.870*	-0.585*	1	0.598*	-0.182	-0.274	0.069
Weight	-0.575*	0.664*	-0.190	0.598*	1	0.402	-0.202	0.054
BFM	0.376	-0.262	0.769*	-0.182	0.402	1	0.190	-0.025
Age	0.234	-0.426	0.323	-0.274	-0.202	0.190	1	-0.062
PTT	0.017	0.076	0.029	0.069	0.054	-0.025	-0.062	1

(*: High correlation value)

desirable [16-17]. So, we exclude the Body fat percentage and the Body fat mass. We performed the multiple linear regression analysis, again. Consequently, the multiple linear regression model using PTT and valid biometric parameters for estimating any subject's SBP is

$$Systolic\ blood\ pressure = 114.495 - 0.149PTT[ms] + 0.370Age[yr] + 0.383Weight[Kg] \quad (1)$$

We also performed the multiple linear regression analysis using only PTT for estimating any subject's SBP.

$$Systolic\ blood\ pressure = 165.388 - 0.179PTT[ms] \quad (2)$$

Since the P value of the above regression model (1) and (2) is $P<0.05$, it is significant. Table 5 shows the comparison between the errors of each multiple linear regression model.

Table 4. The tolerances of biometric parameters

	Tolerances
Age [yr]	0.868
Weight [kg]	0.723
Body fat percentage [%]	0.111
Body fat mass [kg]	0.096
PTT [ms]	0.986

Table 5. The error of multiple linear regression model (1) and (2)

	Mean [mmHg]	SD [mmHg]	Sig.
Error of model (1)	5.13	4.26	$P < 0.05$
Error of model (2)	7.66	5.73	$P < 0.05$

The approvable standards of automated sphygmomanometers in American National Standards Institute and Association for the Advancement of Medical Instrumentation (ANSI/AAMI) recommend that maximal mean difference and standard deviation of noninvasive arterial BP, obtained from at least 85 patients, should not exceed 5±8mmHg from a reference method [18]. According to Table 7 and the standards of ANSI/AAMI, it is more appropriate that the multiple linear regression model (1) using PTT and valid biometric parameters for estimating any people's SBP.

IV. DISCUSSION AND CONCLUSION

Continuous monitoring of SBP is very important for the prediction and diagnosis of hypertension and cardiovascular disease. However, existing BP measurement methods are difficult to continuously measure BP.

Our study shows that the PTT and the use of several biometric parameters can be used for the continuous estimation of SBP. The method using PTT alone is adequate to estimate SBP for personal use. However, it is inadequate for the use of the general population because it exceeds allowable error of ANSI/AAMI standard. The PTT method of measuring SBP can yield more accurate results when combined with specific biometric parameters such as weight and age. Although the regression model using the PTT and valid biometric parameters gives encouraging results, it requires more study to increase its accuracy and capabilities.

We are now in a position to develop an embedded system based on ARM 9 core and WinCE.net for the continuous monitoring of biomedical signals. Many of these technologies have been demonstrated to work extremely well under controlled environmental conditions in a hospital. However, when they are applied in living environment, the results are unsatisfactory. One of the most important focuses of future development will no doubt be the improvement of these devices by the reduction of ambient noise and motion artifacts.

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