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Research Article

Towards Fully Automated Cuffless Calibration for Tonoarteriography Using 3-Axis Accelerometer

G Iyappan[1], N Ji[1], ZJ Liu[2], T Xiang[2] and YT Zhang[1,2]*

[1]Hong Kong Center for Cerebro-Cardiovascular Health Engineering (COCHE), Hong Kong SAR, China

[2]Department of Biomedical Engineering at City University of Hong Kong (CityU), Hong Kong SAR, China

N Ji, co-first author who contributed equally to the work

***Corresponding author:** Y.T. Zhang is with COCHE and CityU, Hong Kong SAR, China.

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Abstract

Tonoarteriography (TAG), the cuffless and continuous arterial blood pressure measurement technology, is essential for the monitoring of cardiovascular diseases and hypertension. In this work, a method using a 3-axis accelerometer for TAG calibration is explored based on the hydrostatic effect of the peripheral artery. The accelerometer linked with a finger-based blood pressure probe, an analogue processing unit, and a real-time output display were set up in our lab for the TAG measurement. With the arms raised above, at or below the heart level, the effects of hydrostatic pressure on the TAG signals were examined using the accelerometer's X, Y, and Z axises as references. The preliminary results of this study showed a corresponding variation in TAG signals to hydrostatic changes. Thus, the accelerometer for automatic cuffless calibration, combined with a peripheral-mounted BP sensor configuration, could be potentially used for unobtrusive and continuous BP/TAG measurement.

Keywords: Accelerometer; Angle positions; Cuffless BP/TAG; Height measurement; Hydrostatic pressure; Wearable biosensor

Introduction

Cardiovascular disease is a severe illness that can lead to sudden death if vigorous physical activity is performed [1-2]. Blood pressure (BP) is a commonly used parameter which carries essential information for appraising the condition of the cardiovascular system. Tonoarteriogram signal (TAG) is a graphical record of the continuous arterial blood pressure signal as a function of time. The TAG signal can be acquired by an unobtrusive, wearable or cuffless continuous arterial blood pressure measurement device [3-4]. Recently, Hongwei Yuan et al. discussed using an accelerometer coupled with a photoplethysmography sensor to measure blood pressure based on the height difference and reported an experimental study of the effects of external physiological parameters in the context of local blood pressure (hydrostatic pressure changes) [5]. According to Y.M. Wong et al., exercise impacts the link between pulse transit time (PTT) and arterial blood pressure; they also addressed how to estimate blood pressure using the PTT method following a series of exercises [1]. James E Sharman et al. reported automated "oscillometric" blood pressure measuring devices: how they work and what they measure [6]. Another early research (Yinbo Liu et al.) showed a model-based calibration method utilizing hydrostatic pressure for BP estimation and revealed the possibility for a preferable range of heights used for hydrostatic calibration [7]. Hundreds of BP measuring devices/BP estimation algorithms are available today, but almost all of them, require frequent calibration to maintain accuracy. Although many researchers studied blood pressure monitoring under different situations [8-9], a suitable experimental investigation on the fully automated cuffless calibration method for cuffless BP/TAG signal, based on the hydrostatic information, has not yet been carried out. Furthermore, there is no report on the effect of continuous hydrostatic pressure changes on the peripheral TAG signals. Therefore, a method that can automatically calibrate the models for TAG estimation by arm movements, for better accuracy performance of BP monitoring, especially during daily strenuous activities, is essential. This study proposes an automated cuffless BP/TAG signal calibration method based on the hydrostatic effect, employing a 3-axis accelerometer to gauge the height difference of the peripheral measuring site relative to the heart level. Additionally, the findings in this study offer some evidence to support the peripheral blood pressure fluctuations that occur when elevating the arm above the heart level. The suggested sensor module is automated, wearable, small, light, and with less energy consumption.

Experimental Setup

During the experiments, the unique finger-mounted BP monitoring probe (CNAP Monitor- Bio PAC Systems) was coupled with the 3-axis accelerometer (Wit-Motion HWT-9052-485) for blood pressure and height measurements. The low- power, 3-axis capacitive HWT9052-485 accelerometer is a multi- sensor device that measures acceleration, angular velocity, angle, and magnetic field. It measures the static acceleration of gravity in tilt-sensing applications (for standard gravity, 1 g _ 9.81 m/s2) and dynamic acceleration resulting from motion and shock. There are five components of proposed measurement unit, including, a distinct finger-mounted blood pressure sensor, an acceleration unit, a processing unit, a real-time output display, and data storage. BP finger probe-based sensing unit measures the matching TAG signals during arm swinging. At the same time, an accelerometer records the motion when elevating the arm higher than the heart level (corresponding to X, Y, and Z axis). The normal orientation of the BP finger probe is defined to be such that the positive side of the accelerometer references the Z-axis points in the upper direction. The Y-axis points along the finger, and the X-axis is orthogonal to the Y-axis in the horizontal plane. The experiment was conducted under the condition that the subject sat upright and with their shoulders back for at least five minutes before the test was administered. The BP finger probe unit and accelerometer were attached to the subject using adhesive tape to avoid the miscarriage of the accelerometer during experiments. BP finger probe and accelerometer were placed on the left-hand index and middle finger in the same position while repeating the experiments. TAG signals and acceleration data were simultaneously captured for the experimental data analysis. The subject had no known cardiovascular illnesses, and the room temperature was maintained during the tests. A digital signal processing software package (AcqKnowledge Data Acquisition and Analysis Software - BIOPAC) was used to compute the collected signal parameters, such as TAG signal and accelerometer coefficients. TAG signal was potentially increased, decreased, and strongly affected by height variations of the arm relative to the heart level. The schematic representation for the experimental set-up is displayed in Figure 1.

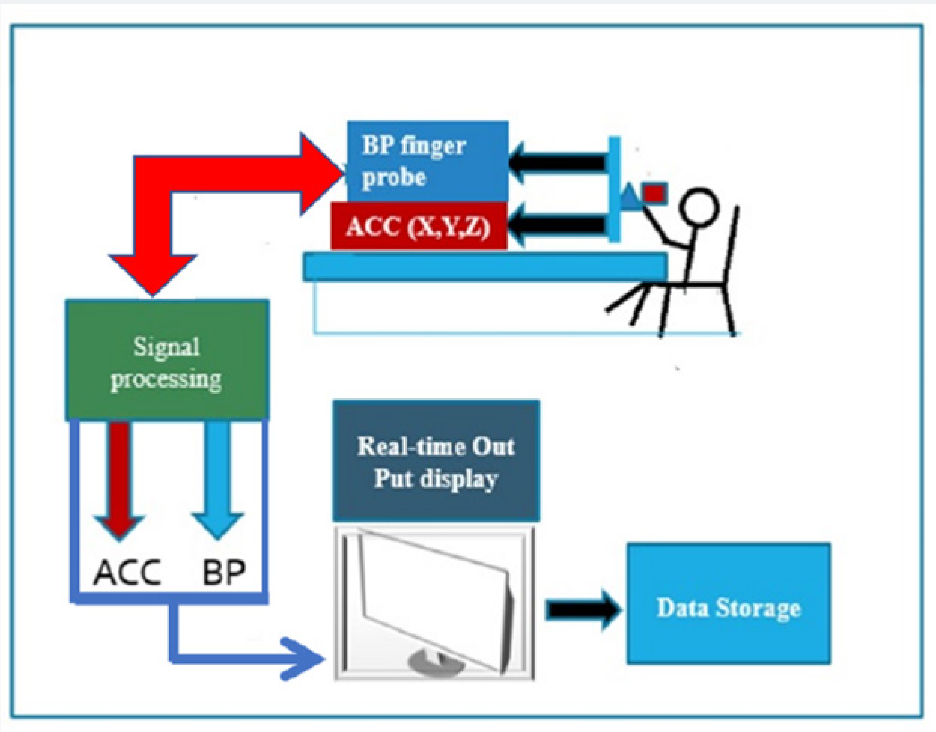

Figure 1: The schematic representation for the experimental set-up system.

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Results and Discussion

The TAG signals and accelerometer's 3-axis orientation signals from the subject were collected for three times without changing the positions for repeating the experiments. Figure 2 shows the TAG waveform and corresponding 3-axis acceleration (ACC) signals in the process of swinging the arm up and down by rotation at the shoulder in 60 seconds. It could be observed that the range of acceleration during the arm elevation is from ~0 to 1g, which is consistent with the previous work [10]. The TAG results suggest that the peripheral BP decreases as the arm/measuring site is raised above the heart level. And the peripheral BP increases as the arm/measuring site is lowered to the heart level. Therefore, it is evident that arm movements above the heart level significantly impact the peripheral TAG signals. According to the accumulated experimental data, variations in hydrostatic pressure and height measurements cause considerable changes in waveform morphology. Also, the averaged systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse pressure (PP), and mean arterial blood pressure (MBP) were calculated with different arm positions and tabulated in table 1. Table 1 shows the averaged SBP, DBP, and MBP values, except for PP, all vary significantly with the hand movements at the heart level and above the heart level (Figure 2, Table 1).

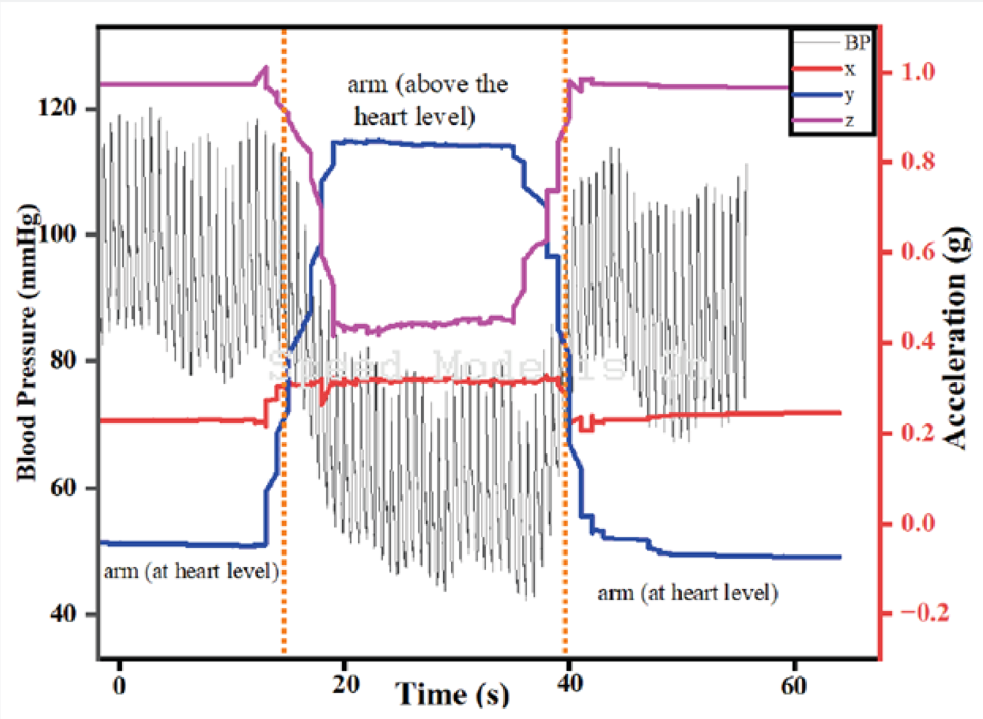

Figure 2: TAG signal waveform and accelerometer outputs at different heart levels.

Table 1: The averaged SBP, DBP, PP, and MBP.

Arm Position	Avg SBP	Avg DBP	Avg PP	Avg MAP
At heart level	116	83	33	94
Above heart level	76	47	29	57
Back to heart level	108	75	33	86

Unit (mmHg)

The blood pressure monitor needs an accurate measurement of the subject's arm height in order to calibrate the blood pressure reading depending on height (arm elevation to the heart). Most current methods use video motion tracking or fluid-filled tubes, both of which can be cumbersome or unworkable. A 3-axis accelerometer angle-based approach for the height measurement could be implemented to fulfil this need. The distance from the shoulder to the measuring site could be measured, together with the angle on the respective outputs of the accelerometer, are the key to the height measurement.

Conclusion

A method using a 3-axis accelerometer for BP/TAG calibration is proposed based on the hydrostatic effect of peripheral artery. It has been demonstrated experimentally that the measured continuous blood pressure/TAG signal is significantly influenced by hydrostatic pressure. This study provides a promising automated cuffless calibration method by simply arm motion, which could possibly be further implemented in BP/TAG devices for unobtrusive monitoring of cardiovascular diseases.

Acknowledgements

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Conflict of Interest

No conflict of interest.

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