Beat-by-Beat Monitoring of Systolic Blood Pressure based on an ASIC and a Mobile Phone for Ambulatory Application

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Abstract: This paper describes an ambulatory monitor for beat-by-beat monitoring of systolic blood pressure (SBP) based on an ASIC chip and a mobile phone. The ASIC is able to measure electrocardiogram (ECG), photoelectric plethysmogram (PPG), and has a peripheral interface to control an air pump and valve for inflating and deflating a sphygmomanometer cuff in conventional blood pressure measurement. Algorithms for signal processing, characteristic point detection and SBP estimation are implemented on a mobile phone. Pulse arrival time (PAT) is derived from the apex of QRS complex to the maximum slope of PPG, and is used to estimate a rapid change component in SBP beat-by-beat. An oscillometric sphygmomanometer with a cuff is used to determine SBP intermittently for calibration purpose. Data communication between a mobile phone and the ambulatory monitor is conducted via a Bluetooth wireless connection. Performance of the prototype is examined by data from five healthy college students. The results show that 65.9% of estimated SBP fall into ±5% relative error, 96.6% in ±10% and 99.7% in ±15%. This prototype is a pilot study aiming at integrating an innovative sphygmomanometry into a mobile phone for continuous blood pressure monitoring. We expect to find potential applications in ambulatory monitoring and daily healthcare.

1 INTRODUCTION

Ambulatory monitoring of multiple vital signs attracts more and more attention in daily healthcare domain. Monitoring devices with smaller size and lighter weight are desirable. With dramatic advancement in information technologies, a mobile phone is nowadays not only a communication tool, but also provides a universal platform with versatile interfaces, large amount of computational power and high capacity of data communication. Widespread utilization of mobile phones in daily life makes it practical and acceptable to extend their applications in ambulatory healthcare by integrating advanced biomedical sensors and functionalities.

Ambulatory applications based on mobile phones have been widely explored in various aspects such as diagnosis, monitoring and health management.

Without requiring any additional accessories, a built-in camera can be used to monitor breath rate and pulse rate simultaneously by analyzing chest movement during breathing and chromatic tone change due to blood flush during heartbeating in a series of images (Philips, 2011).

More professionally, an external device with specific function is connected to a mobile phone via wired or wireless means to turn a mobile phone into a significantly efficient medical checkup equipment.

For example, an electrode pad is attached to an iPhone or Android smartphones to monitor ECG and detect heart rate in real-time mode without directly contacting the electrodes to the body surface (AliveCor, 2011). Although it does not serve to diagnose acute myocadial infarction, an ambulatory ECG can mark cardiac events in emergency situation conveniently.

A B-mode ultrasound imaging device based on a mobile phone was developed to offer an imaging tool for kidney, liver, eye and uterine screenings (Richard and Zar, 2009). It is realized by simply connecting a portable ultrasound probe to a mobile phone via a USB cable. A mobile phone implements

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algorithms for signal processing and image reconstruction, and serves as a GUI display.

Peripherals applicable to mobile phones include an electronic stethoscope for cardiac auscultation (Bentley, 2011), a sphygmomanometer cuff for blood pressure measurement (Withings, 2011), an acousticon-type device for multiple vital signs monitoring (CIM, 2008), and many others (Liu and Liu, 2011).

Our study aims at developing an ASIC for mobile phone application, and exploring the possibility of ambulatorily monitoring systolic blood pressure beat-by-beat based on the ASIC and a mobile phone.

In this paper, we describe implementation of a prototype using the ASIC for monitoring electrocardiogram (ECG) and photoelectric plethysmogram (PPG) continuously, and estimating systolic blood pressure (SBP) beat-by-beat by using pulse arrival time (PAT) and intermittent calibration method proposed by (Chen et al., 2000). We examined five subjects to assess the performance of the prototype by comparing the estimated SBP with reference from a tonometer beat-by-beat.

2 METHOD

This prototype consists of three parts: a conventional sphygmomanometer with a cuff, an ambulatory unit and a mobile phone, as showed in figure 1.

Figure 1: Three main parts of the monitor. A conventional sphygmomanometer (ABS box) with a cuff (deep blue) in the left; a mobile phone in the right; an ambulatory unit making use of a mouse crust above the ABS box.

The sphygmomanometer is used to measure SBP intermittently, for example once a day, as initial value for calibration of estimated beat-by-beat SBP. It is not necessary to be portable. The size is 110×196×37mm^3.

The ambulatory unit embeds the ASIC and other peripheral circuits into a mouse crust. This unit is small to be portable and used to measure ECG and PPG, and therefore to derive PAT beat-by-beat for estimation of SBP.

A mobile phone is used to implement various algorithms, such as signal processing, characteristic point detection for ECG and PPG, and SBP estimation. It also serves as a GUI terminal for data visualization and transmission.

All communications for data and commands among the sphygmomanometer, the ambulatory unit and a mobile phone are available via a Bluetooth connection. Daily results can be transmitted to a specific database server via mobile network and be accumulated for further data mining.

2.1 Sphygmomanometer

The sphygmomanometer with a built-in air pump and valve can inflate and deflate the cuff by UART commands from a mobile phone wirelessly. Pressure change in the cuff can be monitored in real-time and transmitted to a mobile phone.

Figure 2 shows pressure profiles in the cuff during inflation and deflation. The cuff is firstly inflated to approximately 150 mmHg and then deflated gradually as showed by the pink trace (DC). At the same time, the oscillation component in the cuff is amplified as showed by the blue trace (AC). The AC signal is used to determine SBP and mean BP by the oscillometric method.

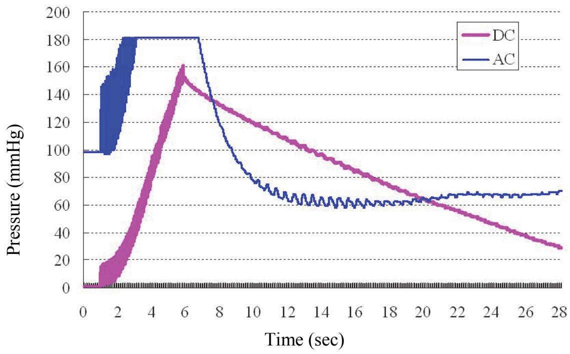

Figure 2: Cuff pressure profiles during inflation and deflation procedures. Pink trace indicates a direct component (DC) in the pressure signal. Blue trace is the alternating component (AC).

2.2 Ambulatory Unit

The ambulatory unit utilizes a mouse crust to mount the electronic circuit board, including the ASIC, for measurements of Lead I ECG and two wavelengths of PPG.

The ASIC is customized to integrate several functional blocks with analogue and digital mixed circuits, such as front-end amplifiers, poor contact detector, auto gain controller, filters and other logic circuits. The ASIC is fabricated by UMC 0.18um mixed-mode process with 1.8V and 3.3V dual power supplies (United Microelectronics Corp., Taiwan).

Measured analogue signals are digitized by 12-bit AD converters and transmitted to a mobile phone as showed in figure 3 (right). Two Ag/AgCl film electrodes are attached on two sides of the mouse crust contacted by left hand. Another electrode surrounding the light hole is touched by right hand. Photo diode and detector are deployed in the hole of the mouse. In this way, the ambulatory unit can measure ECG and PPG simultaneously by two hands as showed in figure 3 (left).

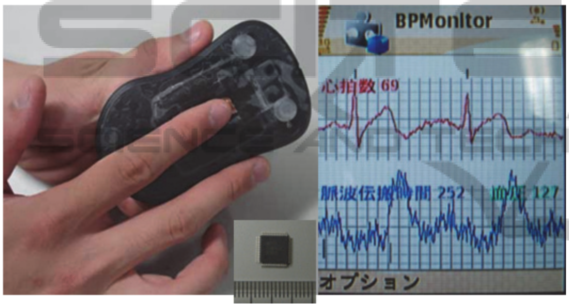

Figure 3: Left: Measurement of ECG and PPG using the ambulatory unit. Two fingers of left hand touch one electrode and right forefinger touches another to measure Lead I ECG. At the same time, right forefinger is also used to measure PPG. Right: Sample snapshot on a mobile phone display captured by a camera. Upper trace indicates ECG and heart rate (69). Lower trace indicates PPG and the corresponding PAT (252) and estimated SBP (127). The ASIC chip (middle lower) inside the mouse crust is 7×7mm^2 in size.

2.3 Estimation of SBP Beat-by-Beat

SBP is estimated beat-by-beat through PAT based on the algorithm described in (Chen et al., 2000). Definition of PAT varies on different studies. Beat-by-beat PAT is usually defined as a time interval from apex of an ECG's QRS complex to the following nadir or the maximum slope of PPG in the corresponding heartbeat. Because the maximum slope is more distinguishable than the nadir, we choose the former to derive PAT in this study.

Estimated SBP is obtained by two steps: intermittent calibration and beat-by-beat estimation. Once an initial SBP calibration value is attained by using a conventional sphygmomanometry method, change in beat-by-beat SBP is tracked by summation of the calibrated SBP value and the filtered PAT value. This procedure is illustrated in figure 4.

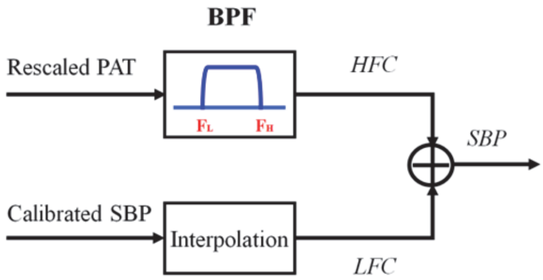

Figure 4: SBP is estimated by summation of higher frequency component (HFC) from filtered PAT and lower frequency component (LFC) from measured SBP using a sphygmomanometer intermittently. The PAT is rescaled to a regular interval of 1 sec before passing through a narrow band-pass filter, which had a low cut-off frequency F_L= 0.00053 Hz, and high cut-off frequency F_H = 0.004 Hz.

3 RESULTS

Five college students at their twenties were involved in measurement and performance evaluation. Data were collected from each subject for about ten minutes. Blood pressure was elevated through cold water immersion test. Estimated SBP was compared with SBP measured simultaneously by a noninvasive continuous blood pressure monitor (Jentow-7700, Nihon Colin, Aichi, Japan), which measures radial arterial pressure by the tonometry method.

The performance was evaluated by relative error between the reference and the estimation. Table 1 summarizes the probability distribution of relative error in five subjects. With a wide range of SBP from 108 to 163 mmHg, nearly 100% of estimations fall within the range of ±15% relative error.

Table 1: Summary of probability distribution of relative error in five subjects with different SBP range during cold water immersion test.

No.	Probability and Relative Error (%)			Range of SBP (mmHg)	Data Length (min)
	±15	±10	±5		
1	100	97.3	49.8	120-163	7
2	100	96.1	71.4	115-147	10
3	100	96.7	62.5	108-139	10
4	100	95.8	68.4	124-156	10
5	98.6	97.0	77.2	116-152	11
Avg	99.7	96.6	65.9		9.6
Std	0.6	0.6	10.4		1.5

Figure 5 shows the continuous profiles of subject

No. 1 in Table 1. Figure 6 shows the histogram of relative error distribution of the same subject.

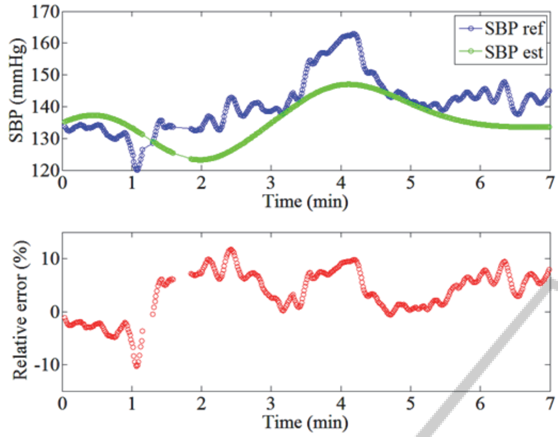

Figure 5: Comparison of the measured SBP and the estimated SBP. Blue trace is the measured SBP by the tonometer and green trace is the estimated SBP by our prototype in the upper plot. Red trace in the lower plot indicates the relative error between reference SBP and estimated SBP.

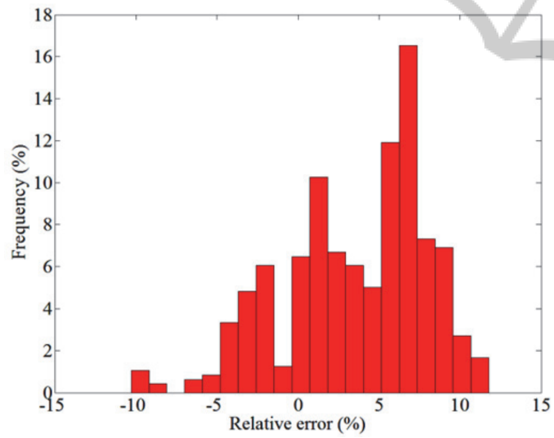

Figure 6: Relative error distribution. About half of the estimations have ±5% relative error. 97.3% of the estimations fall into ±10% range of relative error. All of the estimations are within ±15%.

4 DISCUSSION

Because mobile phones are becoming more powerful than ever before, more algorithms are able to be implemented within the mobile phone platform in real-time processing mode; more information can be bundled into the ambulatory monitor. Location-based and personalized services are possible to be provided in various scenarios.

However, a mobile phone with smaller size brings about severe electromagnetic interference which leads to difficulty in designing the ASIC. Improving SNR in the ASIC is a big challenge, especially in a compact volume of space embracing a wide range of working spectral band.

Discrepancies between the reference and the estimated SBP beat-by-beat are relatively low and practical in daily use if we consider ±15% relative error acceptable. Nevertheless, there is still a vacancy to improve estimation accuracies if higher SNR can be achieved.

5 CONCLUSIONS

We developed an ASIC-based ambulatory monitor for measurement of ECG and PPG, and evaluated its performance in estimation of beat-by-beat SBP on a mobile phone platform. It is confirmed that the ambulatory monitor based on the ASIC and a mobile phone is promising in daily healthcare application.

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REFERENCES

AliveCor, 2011, *Mobile-powered devices*. Available from: http://alivecor.com/. [8 Nov. 2012].

Bentley, P., 2011, *iStethoscope Pro*. Available from: http://www.peterjbentley.com/. [8 Nov. 2012].

Chen, W., Kobayashi, T., Ichikawa, S., Takeuchi, Y., Togawa, T., 2000. Continuous Estimation of Systolic Blood Pressure Using the Pulse Arrival Time and Intermittent Calibration. *Med. & Bio. Eng. & Comp.*, 38(5), pp. 569-574.

CIM, 2008, *Care In Motion*. Available from: http://cim-t.net/. [8 Nov. 2012].

Liu, L. and Liu, J., 2011. Biomedical sensor technologies on the platform of mobile phones, *Frontiers of Mechanical Engineering*, 6(2), pp. 160-175.

Philips, 2011, *Philips launches personal App to measure heart rate and breathing rate*. Available from: http://www.newscenter.philips.com/. [8 Nov. 2012].

Richard, W. and Zar, D., 2009, *Ultrasound imaging now possible with a smartphone*. Available from: http://news.wustl.edu/. [8 Nov. 2012].

Withings, 2011, *Smart Blood Pressure Monitor*. Available from: http://www.withings.com/. [8 Nov. 2012].