34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

A Clip-free Eyeglasses-based Wearable Monitoring Device for Measuring Photoplethysmograhic Signals

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***Abstract*— An eyeglasses-based device has been developed in this work to acquire photoplethysmogram (PPG) from the nose bridge. This device is aimed to provide wearable physiological monitoring without uncomfortable clips frequently used in PPG measurement from finger and ear. Switching control is applied on the LED and photo detector for power saving. An experiment involving postural change and treadmill jogging among 10 healthy young subjects was carried out to evaluate the performance of the device. Electrocardiogram (ECG) and PPG from finger, ear and nose were simultaneously recorded, from which heart rate (HR) and pulse transit time (PTT) were calculated. The results show that PPG measured from nose and ear are more resistant to motion than signal from finger during exercise. In addition, the difference between PTT measured from ear and nose indicates that local vasomotor activities may exist on ear and/or nose channel, and suggests that PPG from different sites should be used for cuff-less PTT-based BP estimation. We conclude that this wearable device has great potential to be used in the healthcare management in the future.**

I. INTRODUCTION

Wearable monitoring technology has been considered as one of the great challenges of health informatics to practice advancing healthcare management featured by low cost, high efficiency and high quality [1]. Photoplethysmography is a very popular and low-cost optical technique to detect the blood volume changes of the microvascular bed of tissue in a wearable manner [2]. This technique has been applied in many clinical areas in physiological monitoring, such as cuff-less and noninvasive BP estimation [3, 4], heart rate monitoring [5], blood oxygen saturation (SpO_2) monitoring [6], and clinical assessment of some vascular diseases [7], autonomic regulatory function [8].

Due to the portable nature of wearable monitoring devices, two major issues which need to be considered in the design of photoplethysmogram (PPG) measurement device are motion artifacts and power consumption of the device. Motion artifact is the major problem which constrains the practical application of PPG measurement and many efforts have been made to overcome this problem, such as adopting advanced signal processing techniques [6, 9] and optimizing the mechanical design [10]. However, motion artifact is still considered as one of the major challenges [11]. According to the knowledge of the author, the regular sites from which the PPG signal is measured include finger, earlobe and toe [12, 13]. Few studies have considered the PPG signal from nose bridge.

In this work, an eyeglasses-based PPG measurement device is developed, which aims to provide stable, accurate and comfortable monitoring of the physiological states of the subject. The sensing components are mounted on the frame of the eyeglasses and contact with the skin of the nose bridge. To evaluate the performance of the device, an experiment involving postural change and treadmill exercise was carried out in this study.

II. SYSTEM DEVELOPMENT

A. System Architecture

The eyeglasses-based PPG measurement device contains the following parts: optical sensor, sample-and-hold (S/H) circuit, filter, micro-controller unit (MCU, ATmega 8), bluetooth module (WT12) and cell phone or PC. The photo of the eyeglasses-based device and the block diagram of the device are shown in Fig. 1.

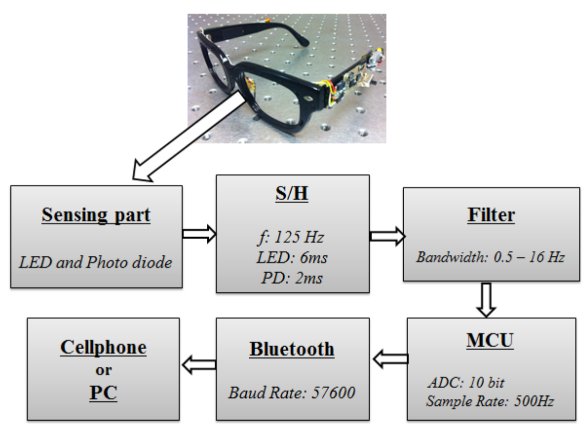

Figure 1. The eyeglasses-based PPG measurement device and the block diagram of the device

The PPG signal from nose is detected in reflective mode in this device. The sensing components consist of a near-infrared LED emitter and a photo diode (PD), which are surface-mounted onto the nose bridge of the eyeglasses with a distance of 6 mm. The wavelength of the detected optical signal by the PD ranges from 800 nm to 850 nm.

Manuscript received April 23, 2012. This work was supported by the Hong Kong Innovation and Technology Commission (ITS/159/11), the 973 Project Fund (2010CB732606), and the Guangdong LCHT Innovation Research Team Fund in China.

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Since the LED emitter is responsible for a great portion of total power consumption of the device, switching signal is applied on the LED and PD to reduce power. The switching frequency is designed to be 125 Hz and the pulse width of switching signals for the LED and PD are 6ms and 2ms, respectively, as shown in Fig. 2.

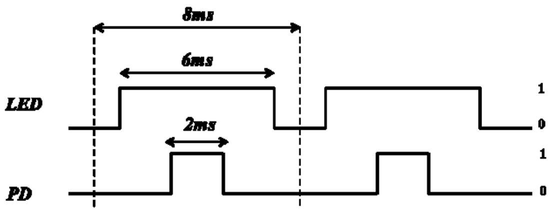

Figure 2. The switching signals for LED and photo diode

The pass band of the analog band-pass filters applied on the PPG signal is from 0.5 to 15 Hz. ECG and PPG from ear and finger are acquired by another in-house-designed circuitry which is not shown here. The same type of sensor was used for measuring PPG at the three sites.

All the acquired signals are then output to the MCU to perform analog-to-digital conversion with 500 Hz sampling rate and 10-bit resolution. After processing by the MCU, the signals are sent to cell phones or computers via the Bluetooth module with baud rate of 57600 Bd. All signals are received and stored in the computer or cellphone for further processing.

III. Experiment

A. Experiment Procedure

The experiment was conducted in a quiet room at an ambient temperature of 25°C. 10 healthy young subjects aged 27 ± 4 years old participated in the experiment. Upon arrival, the subject was instructed to fill the form with enquiries of age, gender, weight, height, disease history and medication in recent days.

Before data recording, each subject was asked to rest for at least 5 min. The subject was firstly asked to maintain sitting and standing postures each, for 2 minutes, and then was instructed to jog on the treadmill (C956, Precor, USA) for 1 min at the speed of around 1.2 km/h. After the mild exercise, the subject was asked to sit down to recover for 2 min. PPG from right index finger, right earlobe and nose bridge were recorded simultaneously together with ECG throughout the experiment.

B. Data Analysis

The acquired ECG and all PPGs were filtered by low-pass filter with cutoff frequency at 30 Hz and 16 Hz, respectively. The R-peak of ECG and the peak of the first derivative of PPG (dPPG) were detected. The beat-to-beat heart rate (HR) was calculated according to the detected feature points. Pulse transit time (PTT) which has been considered as a potential surrogate of cuff-less and noninvasive measurement of blood pressure [3] was computed beat by beat as the time interval from R-peak of ECG to the peak of dPPG. Distorted PPG waveform due to motion artifacts was manually removed and the corresponding HR and PTT values were excluded from the analysis. The beat-to-beat HR and PTT were then both resampled at 1 Hz for further processing.

The difference between PTT (ΔPTT) measured from the finger and other two sites, i.e., $\Delta PTT_{Finger\text{-}ear}$ and $\Delta PTT_{Finger\text{-}nose}$, were also calculated. The respiration-related high frequency components (>0.15Hz) of ΔPTT were removed to focus on the low frequency variability, which is commonly understand as the frequency band related to vasomotion.

IV. Results

Excluding the Bluetooth module, the power consumption of the eyeglasses-based device is about 40 mW.

A. Finger, ear and nose PPG during jogging

It was found that for all subjects, the waveform of PPG measured from the finger was corrupted severely during jogging, while PPG measured from the earlobe and nose bridge were relatively stable. Segment of PPG from the three sites and ECG of one subject during jogging were shown in Fig. 3. The red stars indicated the detected feature points.

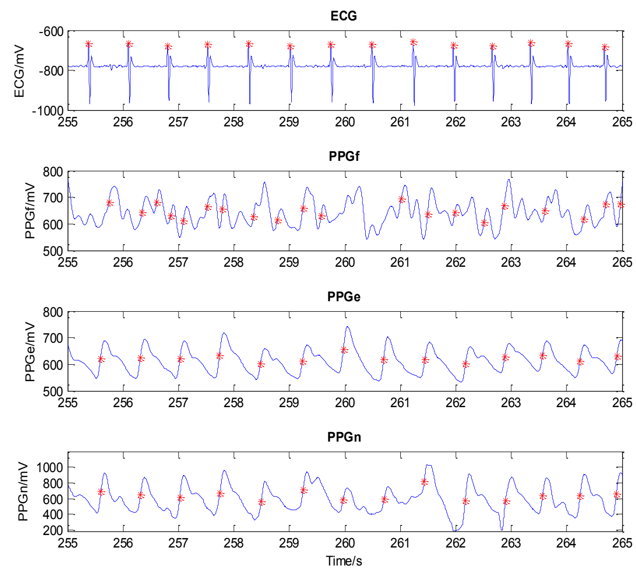

Figure 3. Typical data segment of one subject during jogging, where PPGf, PPGe, PPGn are PPG measured from finger, ear and nose, respectively

B. HR, PTT and ΔPTT during four states

Fig. 4 and Fig. 5 present the averaged HR and PTT among 10 subjects throughout the experiment, respectively. It is shown that HR and PTT can be calculated from PPGs measured from earlobe and nose bridge throughout the experiment. Compared with HR and PTT measured from earlobe and nose bridge, HR and PTT obtained from finger were only available when the subjects were stable.

Fig. 4 shows that HR from ear and nose demonstrate very similar changing trend with HR from ECG during four states. It increased instantly at the onset of standing and jogging, and then returned back rapidly to baseline level at the beginning of recovery.

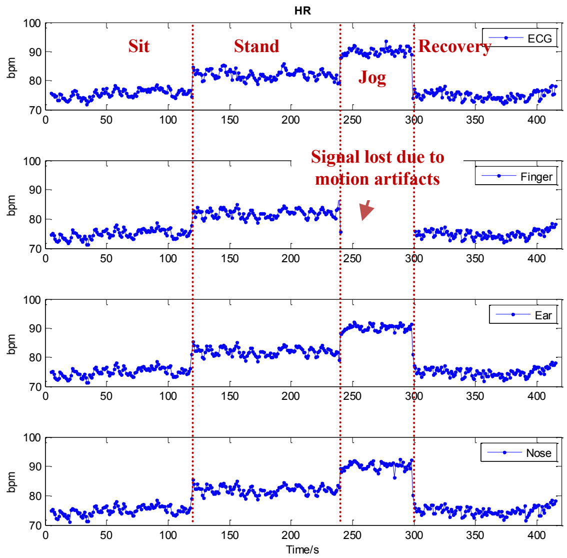

Figure 4. The averaged HR calculated from ECG and PPG measured from three sites among 10 subjects

As shown in Fig. 5, PTT measured from earlobe and nose bridge showed consistent changing trend throughout the experiment, where it decreased suddenly at the beginning of standing, gradually went back to baseline level during the first 30 sec during standing (*Stand1*), and maintained at a level comparable to the baseline for the remaining one and a half minute of standing (*Stand2*). PTT decreased acutely when start jogging and returned to baseline during recovery.

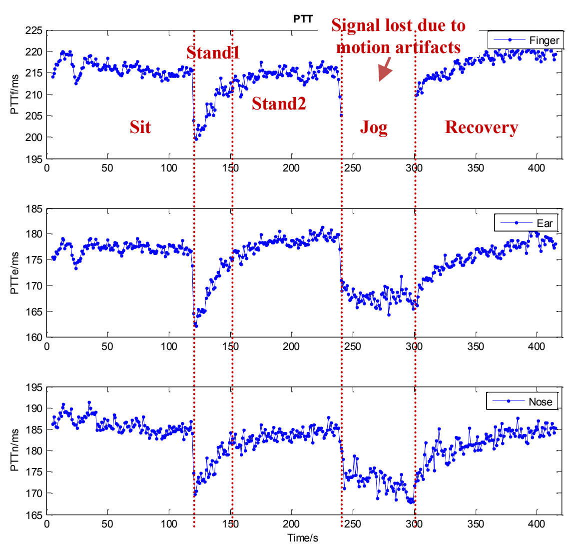

Figure 5. The averaged PTT calculated from ECG and PPG measured from three sites among 10 subjects

Table I summarizes the statistics of the HR and PTT during each state among 10 subjects. The results of the study showed that the statistics of HR from PPG of different sites are comparable to that measured from ECG.

On the other hand, the absolute values of PTT from three sites are different due to the different pulse transmission length. Compared with baseline, PTT from three sites showed similar changing trend: significantly decreased during *Stand1* and jogging, while no significant change during *Stand2* and recovery ($p<0.05$).

TABLE I. MEANS AND STANDARD DEVIATIONS OF HEART RATE AND PULSE TRANSIT TIME OF 10 SUBJECTS AT DIFFERENT STATES

		ECG	Finger	Ear	Nose
HR (bpm)	***Sit***	75 ± 4	75 ± 4	75 ± 4	75 ±4
	Stand	82 ± 5	82 ± 5	82 ± 4	82 ± 4
	Jog	90 ± 5	--	90 ± 4	90 ± 4
	Rec	75 ± 4	75 ± 5	75 ± 4	75 ± 5
PTT (ms)	***Sit***	--	216 ± 5	177 ± 4	186 ± 5
	Stand1	--	*207 ± 6	*170 ± 5	*177 ± 6
	Stand2	--	214 ± 5	178 ± 4	184 ± 5
	Jog	--	--	*168 ± 5	*173 ± 8
	Rec	--	217 ± 5	176 ± 5	182 ± 7

All data are presented as mean ± SD. * Student's t-test compared to the baseline level ($p<0.05$ is considered as significance).

The averaged $\Delta PTT_{Finger\text{-}ear}$ and $\Delta PTT_{Finger\text{-}nose}$ among 10 subjects during the experiment are shown in Fig. 6. It can be seen that the trend of $\Delta PTT_{Finger\text{-}ear}$ was different from that of $\Delta PTT_{Finger\text{-}nose}$.

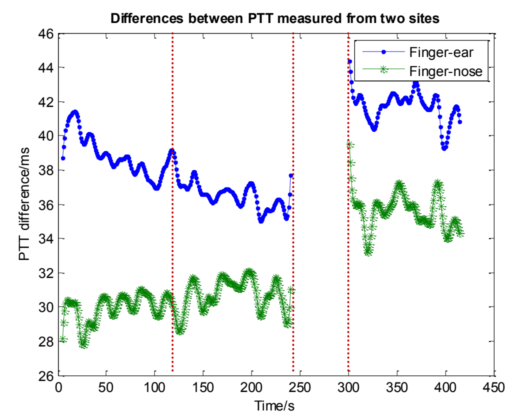

Figure 6. The averaged ΔPTT between finger and other two sites among 10 subjects

V. DISCUSSION

Changes of PTT are often regarded as indicators of BP; however, during postural change, the redistribution of blood can also affect the measurement of PTT, which has to be confirmed by further studies. The results of Fig. 4, Fig. 5 and Table I showed that PPG measured from the nose bridge by the proposed eyeglasses-based device showed better performance than PPG from finger and the same performance as PPG from ear in terms of HR and PTT monitoring. Therefore, this PPG measurement device has great potential to be developed into wearable devices for physiological monitoring during daily activities in the future. Most importantly, compared with typical PPG measurement devices developed in the past, the eyeglasses-based PPG measurement device in our study is more comfortable and convenient for daily use, since it mounts the sensors on the eyeglasses and does not need to introduce additional clips.

The signal quality of PPG measured from the nose bridge may be affected by the following factors: 1) vibration of the treadmill's motor. We observed that the signal quality decreased during jogging when the motor was on; and 2) slipping of the eyeglasses. Unlike the clip used in PPG measurement from ear where the sensor has very stable contact with the skin, the eyeglasses on the nose may slip down and cause artifacts, especially during exercise. This can be corrected by adding a belt to fasten the eyeglasses.

As aforementioned, in addition to the monitoring of HR and PTT, another important potential application of PPG measurement is for continuous, noninvasive and cuff-less BP estimation, which has been reported in a number of studies [13, 14]. The accuracy of beat-to-beat BP estimation based on PTT is still the great challenge in this area, especially during dynamic states, and many efforts have been made to address this challenge. Some studies pointed out that the effect of cardiac pre-ejection period (PEP) should be removed from PTT for BP estimation [15]. As an approximation, ear PTT was subtracted from finger PTT to represent the vascular transit time along the peripheral vessels [16]. However, the results as shown in Fig. 6 indicated that the differences between $\Delta PTT_{Finger\text{-}ear}$ and $\Delta PTT_{Finger\text{-}nose}$ were probably affected by local vasomotor activities exist in the blood vessels of the ear and/or nose. Since ΔPTT is different from site to site, ΔPTT calculated from either ear or nose branch should be used with care for accurate central BP estimation and multiple peripheral branches would be necessary for accurate estimation. Further studies are needed to explore the method by making use of the multichannel information to improve the accuracy of BP estimation.

VI. CONCLUSION

This work presented a novel eyeglasses-based device which can measure PPG from the nose bridge. This device is suitable for daily use as no clips are needed. The results showed its ability of providing stable and accurate monitoring of HR and PTT during mild exercise. In addition, the different results in difference between PTT measured from two sites indicate that local vasomotor activities may exist in the peripheral channels and suggest that PPG from multiple sites should be made use of in PTT-based BP estimation. Therefore, this device is promising to be used in physiological monitoring for modern healthcare management.

The subjects recruited in this study are young, healthy subjects and therefore further studies are needed to confirm whether the results obtained here still stand among older subjects. In addition, a much lighter pair of eyeglasses will be designed in the future to reduce the motion artifacts resulted from the slipping of the eyeglasses on the nose bridge. Furthermore, the underlying relationship between central BP and the different vascular transit time measured from different peripheral branches will be further studied to explore solutions to improve the accuracy of BP estimation.

ACKNOWLEDGMENT

The authors are thankful to Y.P. Liang at JCBME for his contribution on developing the software for signal displaying and storage in the computer.

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