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# Contactless Recording of Photoplethysmogram on a Sleeping Bed

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*Abstract*—**This paper reports a novel contactless monitoring method to record reflective mode photoplethysmogram (PPG) on a sleeping bed for heart rate (HR) estimation. The electrocardiogram (ECG) and pulse transit time (PTT) were also measured in this study. ECG was measured from subjects' limbs whilst PPG was obtained from their right index fingers and their backs with and without direct contact between the PPG sensor and the subjects' skin respectively. Clear PPG waveforms were obtained from the subjects' backs even though the sensor was not directly attached to their skin. Beat-to-beat HRs derived from the back PPGs were closely correlated with those measured from the finger PPGs and ECGs. Thus we found that contactless PPG could be captured from the subjects' backs to determine HR accurately.**

## I. Introduction

Population aging is a significant demographic problem in both developed and developing countries throughout the world [1]. The increasing aging population has profound impact on the economy, social conditions and public health. Since prolonging longevity of the elderly typically concurs with chronic diseases [2, 3], improved home healthcare would help to ease the burden on hospital health services.

The monitoring of cuffless blood pressure [4], electrocardiogram (ECG) [5-7], heart rate (HR) [5-7] and photoplethysmogram (PPG) [8-9] in home appliances and wearable belongings is becoming the state of art technology for home healthcare. Among these physiological sensors, the ECG [5-7] and PPG [8-10] sensors do not contact the subjects' skin during measurement. In this study, we proposed the non-contact monitoring of reflective mode PPG on subjects sleeping on a bed and examined its application for HR and pulse transit time (PTT) measurements.

## II. Materials and Methods

Figure 1 shows the placement of electrodes and PPG sensors. The electrodes for ECG measurement were placed on the subject's left and right forearms. The reflective mode PPG sensors (an infra-red light emitting diode [λ=850nm, SFH 4250Z, OSRAM Opto Semiconductor, Regensburg, Germany] and a photodetector [SFH 320 FA-2/4, OSRAM Opto Semiconductor, Regensburg, Germany]) were embedded in the mattress underneath the white sheet and in the finger clip respectively. The dimensions of light emitting diode (LED) and photodetector were 3.4x3.0x1.2 and 3.4x3.0x1.4 $mm^3$ respectively. The PPG sensor in the finger clip contacted the skin of the subject's right index finger directly. The sheet and clothing separated the PPG sensor in the mattress from the subject's skin approximately 1-2 mm. The LED in the mattress was 8 mm away from the photodetector. ECG and PPG were detected by in-house-designed circuits. The same circuits were used for capturing the back and finger PPGs, except that the voltage gain in the circuit connecting to the PPG sensor in the mattress (758 V/V) was larger than that in finger clip (30 V/V).

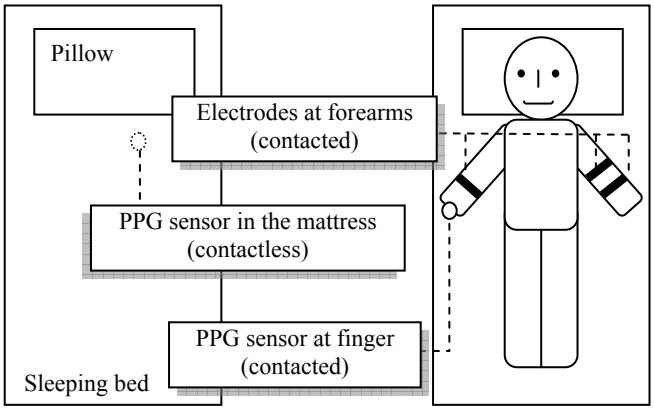


Figure 1. An illustration of the placement of (a) PPG sensor in the mattress and (b) PPG sensor and electrodes on the subject lying on the bed. The sheet covers the PPG sensor in the mattress.

Subjects were requested to remove their jumpers, jackets and coats, such that they were only wearing their thin clothes, such as a T-shirt, shirt or vest in the experiments. The materials of their clothes included wool, cotton and polyester. The PPG sensor in the mattress was located under the trapezius muscles.

### *1. Experiment A*

Experiment A was conducted on fourteen subjects, including five males, aged 27±5 years (from 23 to 38 years). The subjects laid and rested on the bed. ECG and finger and back PPGs were sampled at 166 Hz by an A-D converter (Model DI-220, DATAQ Instrument WINDAQ, USA) and recorded simultaneously for two minutes.

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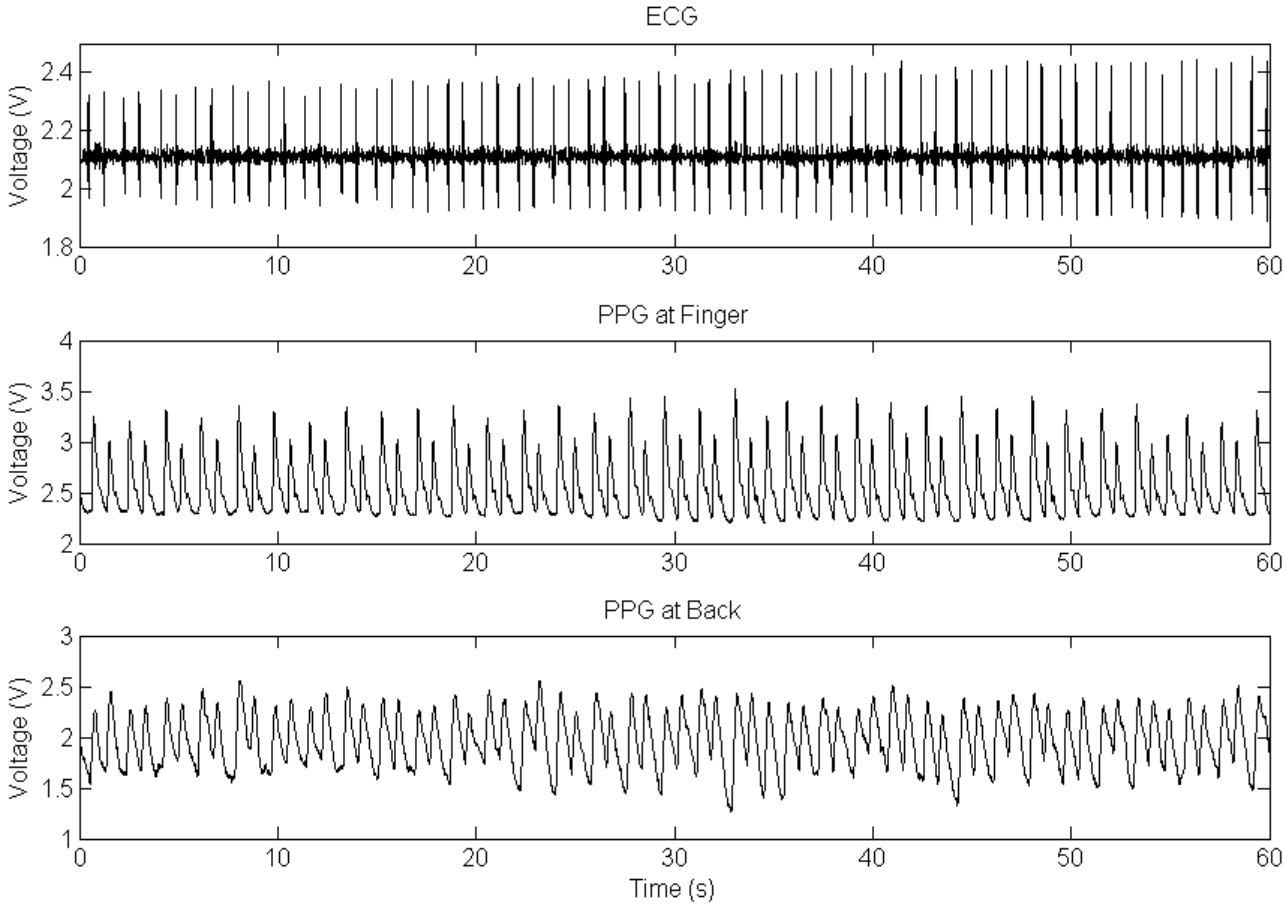

Figure 2. The simultaneous captions of ECG and finger and back PPGs from one female subject in Experiment A.

*2. Experiment B*

Experiment B was conducted on fifteen subjects (10 joined in Experiment A), including six males, aged 26±5 years (from 23 to 38 years) and weighed 59±14 kg (from 43 to 86 kg). ECG and two PPGs were sampled at 1000 Hz by the A-D converter. The subjects laid on the bed such that ECG and finger and back PPGs were recorded simultaneously for six minutes. Afterwards, they sat upright for one-minute (no signals were recorded) to provoke changes in their cardiovascular systems. Then they laid on the bed and ECG and two PPGs were recorded simultaneously again for the next four minutes.

The collected ECG and PPGs were analyzed offline using Matlab (MathWorks, USA). The background noise in ECG and two PPGs was removed by low-pass filters. HR was determined from the ECG and two PPGs. It was calculated as the reciprocal of the successive time intervals between the peaks of ECG (HR-ecg), finger PPG (HR-finger) and back PPG (HR-back) separately. PTT was measured from the peak of ECG R wave to the peaks of the first derivative of PPG obtained from the fingers (PTT-finger) and from the backs (PTT-back) respectively. In Experiment A, the averages of the parameters were calculated for the correlation study. The beat-to-beat values were used for the correlation study in Experiment B.

## III. RESULTS

*1. Experiment A*

Figure 2 depicts the simultaneous measurements of ECG and back and finger PPGs from one female subject in Experiment A. The dicrotic notch was clearly shown on the PPG measurement from finger but not from the back. Compared to finger PPG, back PPG was relatively sensitive to the respiration so that its baseline was shifting during recording.

Table 1 summarizes the average correlation coefficients between the studied parameters in Experiment A. HR measured from ECG was closely correlated with HR measured from the finger ($r$=0.999) and back PPGs ($r$=0.999). The two HRs calculated from the contacted (finger) or contactless (back) PPG measurements were also closely correlated ($r$=0.960). However, PTT-finger was less correlated with PTT-back ($r$=0.464).

Table 1
The average correlation coefficients between the studied parameters over all subjects in Experiment A.

| HR-ecg Vs HR-finger | HR-ecg Vs HR-back | HR-finger Vs HR-back | PTT-finger Vs PTT-back |
|---|---|---|---|
| 0.999 | 0.999 | 0.960 | 0.464 |

*2. Experiment B*

Table 2 shows the average correlation coefficients between the studied parameters in Experiment B. There were 4980 and 2599 beats of data collected before (Dataset 1) and after (Dataset 2) the 1-minute sitting session. In Dataset 1, the correlation between HR-ecg and HR-back was very high ($r$=0.896) though the correlation coefficient was smaller than that between HR-ecg and HR-finger ($r$=0.997). HRs calculated from the contacted (finger) or contactless (back) PPG measurements were also closely correlated ($r$=0.896). In Dataset 2, HR-back was closely correlated with HR-ecg ($r$=0.888) and HR-finger ($r$=0.885). However, PTT-finger was less correlated with PTT-back ($r$=0.126 in Dataset 1 and $r$=0.117 in Dataset 2). This was probably due to the wide range of PTT-back induced by the respiration effects.

Table 2
The average correlation coefficients between the studied parameters over all subjects in Experiment B.

| Datasets (no. of beats) | HR-ecg Vs HR-finger | HR-ecg Vs HR-back | HR-finger Vs HR-back | PTT-finger Vs PTT-back |
|---|---|---|---|---|
| 1 ($n$= 4980) | 0.997 | 0.896 | 0.896 | 0.126 |
| 2 ($n$= 2599) | 0.996 | 0.888 | 0.885 | 0.117 |

Figure 3 illustrates the scatter plot of beat-to-beat PTT-back versus PTT-finger of two subjects. It can be seen that PTT-back increased with PTT-finger in these subjects. The PTT-back of male subjects varies in a wider range compared to PTT-finger. Moreover, the values of PTT-back were different from those of PTT-finger. This was probably due to the different arterial distance of the measuring site from the heart.

## IV. Discussion and Conclusion

In this study, we demonstrated the contactless reflective mode PPG measurement from the subjects' backs. The results revealed that the contactless PPG measurement could provide accurate HR measurement. However, further examination of contactless PPG for beat-to-beat PTT measurement is necessary in the future.

Compared to the contact PPG measurement from the finger, the contactless monitoring of PPG at the back was strongly affected by the respiration (as shown in Figure 2). Significant respiratory features could also be observed in the direct PPG measurement at the back [11]. Thus, the respiration-induced variation was associated with the location of measurement. When the PPG sensor was located at the subjects' backs, the respiration could induce up and down movement when in a lying-down posture. The change of contact force between the PPG sensor and measuring site could be one of the important factors to affect the monitoring of PTT: the variation of PTT increased with contact force [12]. This respiration-induced variation of the contact force caused large variation of the PTT-back measurement and resulted in poor correlation between PTT-finger and PTT-back. It should be noted that the signal of non-contact PPG measurement at the back was relatively weak and induced measurement errors. Therefore, the inclusion of simultaneous monitoring of contact force and respiration and direct PPG measurement at the back in future studies will help to account for the poor PTT-back. Moreover, the filtering for removing respiration component from PPG-back measurement should be further investigated to improve beat-to-beat PTT measurement at subjects' backs.

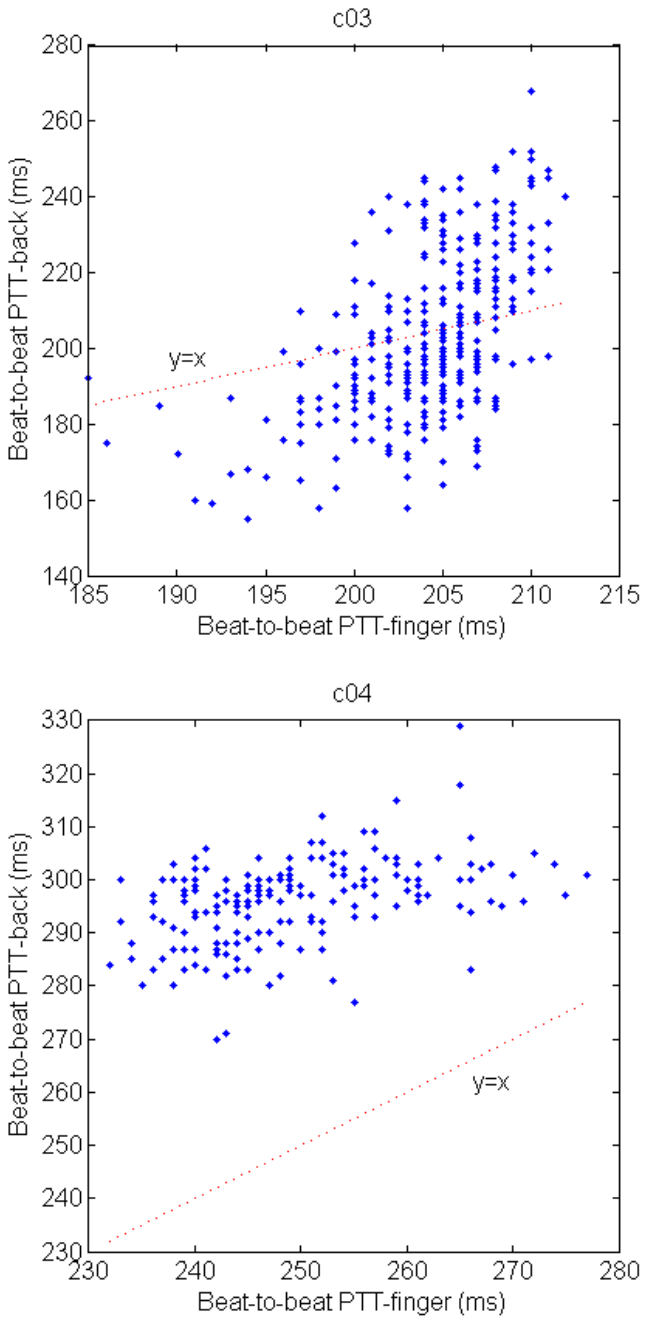


Figure 3. The scatter plot of beat-to-beat PTT-back versus PTT-finger of one (top) male and (bottom) female subjects. Dotted line indicating y=x is given as reference.

In this study, the PPG sensor embedded in the mattress emitted the infra-red and it was able to pass through the sheet, clothing, skin and tissue to the peripheral arteries at the backs

of subjects. Since there were more layers between the photodetector and the peripherals and the relative thicker skin at the back compared to the contact measurement at the fingertip, it was not surprising that the PPG measurement at the back required larger voltage amplification in this experiment. As one of the layers between PPG sensor and skin surface, the material, thickness and colour of clothing and sheet could also affect the non-contact detection of PPG. Noisy and small PPG data were collected from the subjects who wore wool and dark coloured clothes. The effects of material, thickness and colour of garments on the contactless monitoring of reflective mode PPG at the back should be further investigated in the future. This helps to improve the signal quality of back PPG measurement.

The contactless measurement of PPG while subjects are asleep on our novel bed means that other physiological parameters, such as blood oxygen saturation and respiration rate (which can also be extracted from PPG) could also be determined in this way. This will assist physicians to observe abnormal physiological changes in apparently healthy subjects at an early stage and help the development of home healthcare and the research of sleep apnea.

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