

Effective PPG Sensor Placement for Reflected Red and Green light, and Infrared Wristband-type Photoplethysmography

SeungMin Lee^{* **}, HyunSoon Shin^{**}, ChanYoung Hahm^{**}

^{*} Computer Software, UST (University of Science and Technology), Korea

^{**} ETRI(Electronics and Telecommunications Research Institute), Korea

mr.engineer@etri.re.kr, hsshin@etri.re.kr, cyhahm@etri.re.kr

Abstract— Using a wristband-type Photoplethysmography (PPG) sensor, useful biomedical information such as heart rate and oxygen saturation can be acquired. Most of commercially-used wrist-type PPG sensors use green light reflections for its greater absorptivity of hemoglobin compared to other lights; this is important because wrists have comparably low concentration of blood flow. For reliable biomedical signal processing, we propose measurement sites for reflected red, green, infrared light PPG sensors on wrist. Amplitude, detection rate, and accuracy of heart rate are compared to determine the signal quality on measurement sites. Traditionally, wrist-type PPG sensors are implemented in measurement site 2, 3 or between 2 and 3 (between the distal Radius and the head of Ulna). Experiments show that all three reflected light PPG sensors generate good quality of PPG signals on measurement sites 4 and 11 (around the distal of Radius of left hand) in test subjects.

Keywords— Sensor placement, Measurement sites, Photoplethysmography, Wearable sensors, Wristband-type PPG

I. INTRODUCTION

Photoplethysmography is a method of detecting the change in blood volume inside capillary vessels using the property of reflection and absorption of light and producing usable biomedical information such as heart-rate and oxygen saturation. The wristband-type PPG allows continuous monitoring of the user's heart rate throughout the day. However, PPG signal generated from wrist-type sensors is not suitable in clinical use because the frequency components of PPG signal are affected by motion artifacts [1]. Many filters, algorithms [2, 3, 4], and hardware designs (e.g., PPG array module [5]) are suggested to minimize motion artifacts and yet, distorted PPG signal is not easily restore. Therefore, finding a better placement of PPG sensor can be an important design issue affecting the signal quality and acquisition for further signal processing. In this paper, we selected twenty-one points around wrist and tested these points to find an effective placement for each of red, green, and infrared light reflection measuring PPG signals.

II. EXPERIMENT

A. Experimental Setup

Initially, PPG data from 5 subjects (five males, aged 27 ± 5) were collected to find best measurement sites for each red green, and infrared PPG with the test module (figure 1). PPG signals were recorded using a pulse oximeter module AFE4403 (From Ti Inc.) and optical sensors (SFH7050). For comparison, test subjects wore commercial PPG module TSD200 (BIOPAC System Inc.) on their index finger.



Figure 1. Test module

B. Measurement Sites

The penetration depth depends on the wavelength of light and light absorption characteristics of tissues in the body; theoretically, the greater absorptivity, the better signal-to-noise ratio [6]. In this study, three light sources (Red, green, and infrared) are tested; the green light signal is known to be the strongest plethysmographic signal to analyse heart rate,

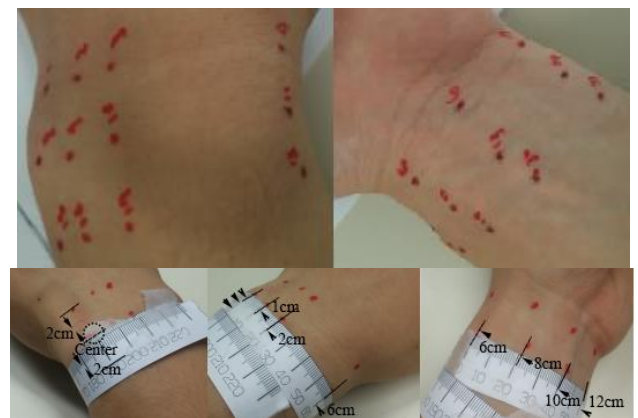


Figure 2. Twenty-one measurement points (top) and distance between the points (bottom)

and red and infrared light signals are known to be a good signal to determine oxygen saturation of arterial blood [7]. These reflected light PPG can be acquired from capillaries, arteries or veins in a wrist. Since patterns of capillary vessels, veins, and arteries are various from person to person, 21 measurement points are selected from the centre of head of Ulna as shown in figure 2; 3 points (Centre, 2 cm up and 2 cm down from the centre) and 18 points to the right side of the first 3 points (1cm, 2cm, 6cm, 8cm, 10cm and 12cm)

C. PPG signal analysis

A total of 5 subjects wear the PPG sensor in left wrist. Their wrist size ($17.34 \pm 1.025\text{cm}$) is varied but the measurement sites are selected from the centre of head of Ulna as indicated before. Three reflected light PPG signals are recorded on each measurement site for 16.384 seconds (sampling rate: 500 Hz).

Original PPG signals contain DC part and AC components. Signals passed through the 4th order bandpass Butterworth filter (0.5 to 3.0 Hz) to extract DC bias and AC noise component. Heart rates for each reflected light PPG were calculated from peak-to-peak (PP) intervals.

The amplitude of PPG signals, the detection percentage of

PP interval, and the difference of heart rates are calculated using parameters of PPG signals (figure 3) for the comparison. For the better comparison, we checked the correctness of all measured raw PPG signals (examples are in figure 4 (a) and (c)) with frequency analysis (figure 4 (b) and (d)). If the power spectrum of a PPG signal illustrates too much irregularity in frequency domain, that PPG signal is excluded for further comparison (figure 4 (b)).

The amplitude of PPG signals of i^{th} test subject is calculated as follows:

$$A_i = \left| \left(\sum_{j=0}^{n_{\max}} V_{\max_j} \right) / n_{\max} - \left(\sum_{k=0}^{n_{\min}} V_{\min_k} \right) / n_{\min} \right| \quad (1)$$

where is a min/max value that is detected at from the filtered signal shown in figure 4 and is the number of max/min value detected.

With, detection rate of PP interval can be determined:

$$D_i = (\# \text{ of } X_{\max}) / (\# \text{ of } \text{Peak}_{\text{verified by observer}}) \quad (2)$$

PPG-derived heart rates from each light source were compared with TSD200-derived heart rates. The output of TSD200-derived heart rates is considered the correct value of heart rate in this study. The similarity of HR is calculated:

$$S_{HR_i} = 1 - \left[(H_{\text{Source}} - H_{\text{TSD}}) / H_{\text{TSD}} \times 100 \right] \quad (3)$$

III. RESULT

Computed A, D, S_{HR} are graphically illustrated in figure 5 (a), (b) and (c), and the result is summarized in figure 5 (d). Efficient signals (strong signals, high detection rate and high similarity) are obtained in infrared reflection PPG in measurement sites 4, 11 and 18, in the red light reflection PPG in measurement sites 4, 11, and 19 and in the green light reflection PPG in measurements sites 4 and 18.

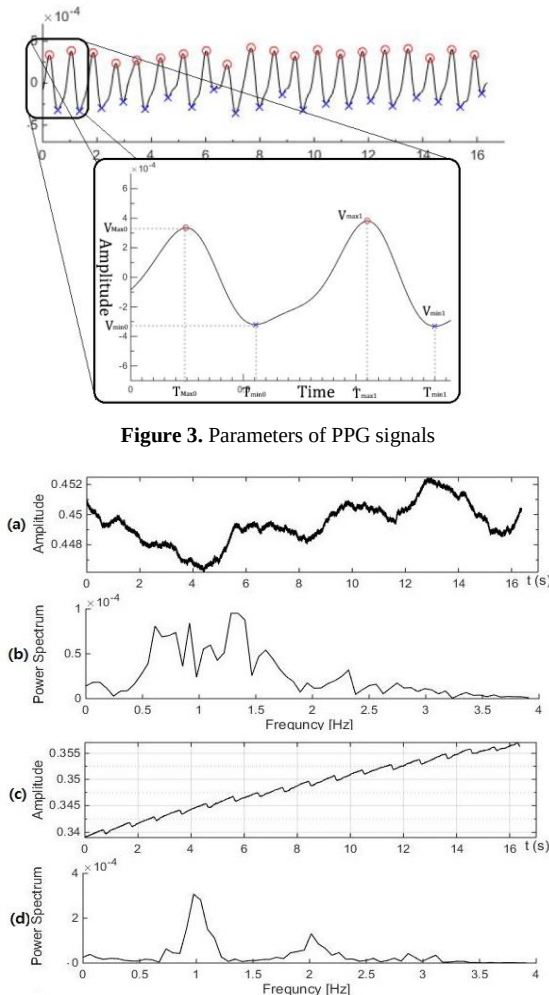


Figure 3. Parameters of PPG signals

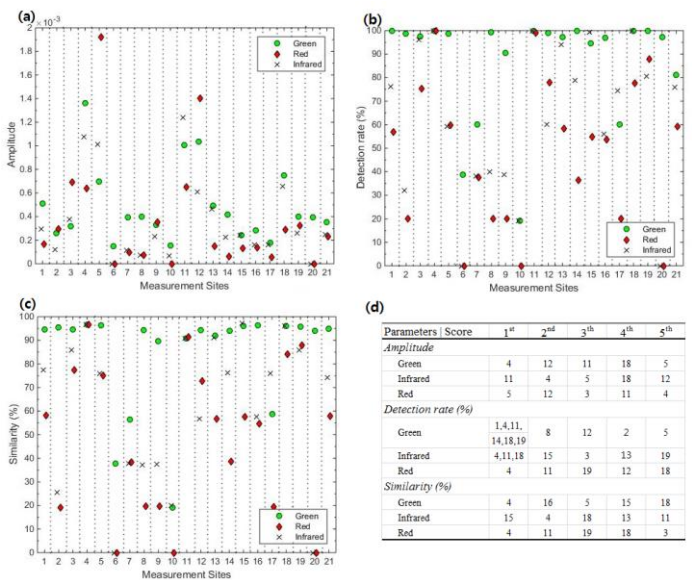


Figure 5. (a) Amplitude of collected signal (b) Detection rate of PP interval (c) Similarity of HR between reference and collected signal (d) Ranking of measurement site for each PPG and parameters

IV. CONCLUSIONS

This paper reports effective measurement sites for each light source in the wrist in stationary. Reflected green light PPG signals show a good quality of signal in most of test locations in the wrist. This illustrates why many commercial companies use green-light-based PPG. The measurement site 4 and 11 show qualified PPG signals in all green, infrared and red light. In other words, the location of PPG sensor around the distal of Radius shows a better quality of PPG signals than the conventional location of PPG sensors. Results for female may differ due to the difference in wrist-size; thus, further examination is required. Moreover, testing the robustness of PPG signals in motion artifacts of these measurement sites will be conducted to verify that these sites are the important factor acquiring the better signal quality and signal-to-noise. Further experiments on these measurement sites may result in the design modification of conventional wrist-type PPGs and, we will be able to measure more reliable and accurate information for biomedical processing.

ACKNOWLEDGMENT

This work was supported by the IT R&D program of SMBA. (Sleep monitoring service technology development using wearable smart band and smart device).

REFERENCES

- [1] Han, Hyonyoung, and Jung Kim. "Artifacts in wearable photoplethysmographs during daily life motions and their reduction with least mean square based active noise cancellation method." *Computers in biology and medicine* 42.4 (2012): 387-393.
- [2] Wei, Pengfei, et al. "A new wristband wearable sensor using adaptive reduction filter to reduce motion artifact." *Information Technology and Applications in Biomedicine*, 2008. ITAB 2008. International Conference on. IEEE, 2008
- [3] Asada, H. Harry, Hong-Hui Jiang, and Peter Gibbs. "Active noise cancellation using MEMS accelerometers for motion-tolerant wearable bio-sensors." *Engineering in Medicine and Biology Society*, 2004. IEMBS'04. 26th Annual International Conference of the IEEE. Vol. 1. IEEE, 2004.
- [4] Foo, Jong Yong A. "Comparison of wavelet transformation and adaptive filtering in restoring artefact-induced time-related measurement." *Biomedical signal processing and control* 1.1 (2006): 93-98.
- [5] Lee, Yongkwil, et al. "Development of a wristwatch-type PPG array sensor module." *Consumer Electronics-Berlin (ICCE-Berlin)*, 2011 IEEE International Conference on. IEEE, 2011.
- [6] Barolet, Daniel. "Light-emitting diodes (LEDs) in dermatology." *Seminars in cutaneous medicine and surgery*. Vol. 27. No. 4. No longer published by Elsevier, 2008.
- [7] Tamura, Toshiyo, et al. "Wearable photoplethysmographic sensors—past and present." *Electronics* 3.2 (2014): 282-302. *Journal of Production Research*, vol.15, pp. 107-111, 1977



SeungMin Lee received the B.S. degree in Electrical engineering with biomedical option from the University of British Columbia in 2013 BC, Canada. He is currently working towards his M.S. degree in Computer software at the University of Science and Technology (UST) in Electronics and Telecommunication Research Institute (ETRI) campus, South Korea. His research interests are in the area of emotion recognition algorithm, bio-signal & emotion-signal processing, and wearable devices.