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Heart rate Measuring and Performance Evaluation from Carotid Artery and Occipital Artery According to Posture during Sleep Using Multiple Photo Plethysmo Gram (PPG) Sensor

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Abstract

Objectives: This paper will suggest that heart rate can be measured without motion artifacts even when the sleeping position is not constrained, but changes. **Methods/Statistical Analysis:** It was implement a heart rate measurement system, using the multiple Photo Plethysmo Gram (PPG) sensor and Fast Fourier Transform (FFT). And in experiments using the implemented system, it comparatively evaluates the performance of measuring heart rates at the carotid artery and the occipital artery around the neck according to changed sleeping positions against the performance of measuring heart rates at the finger. **Findings:** The deviations of heart rates measured at the carotid artery (1 minute: 1.07-6.21 bpm, 10 minutes: 0.57-5.18 bpm) and heart rates measured at the occipital artery (1 minute: 0.46-3.96 bpm, 10 minutes: 0.34-5.2 bpm) from heart rate measured at the finger were found to be relatively low, with max 6.21 bpm at the carotid artery and max 5.2 bpm at the occipital artery. If heart rate had been found to be 0 or an abnormally high value, the deviation from heart rate at the finger would have shown a great difference. From this, It was found that there is almost no difference in the performance of heart-rate measurement the carotid artery and the occipital artery around the neck between the finger. Therefore, this paper suggested that it is possible to measure heart rates without noise even when sleeping positions are unconstrained and are subjected to changes. **Improvements/Applications:** From this, Can be measured during sleep, the unconstrained use heart rate in a variety of situations.

Keywords: Carotid Artery, Heart Rate Measurement, Multiple Sensor, Occipital Artery, Photo Plethysmo Gram (PPG), Sleep

1. Introduction

In modern times, citizens' health improves and life expectancy continues to increase due to rapid economic growth and advances in science and technology and medicine. In this context, it is expected that the elderly population aged 65 and over in South Korea will exceed 25% of the total population by in[1,2] as a consequence of this social phenomenon, ubiquitous healthcare, an emerging type of medical service for preventing diseases and preserving health, is recently attracting much attention. If a disease develops, the diagnosis and analysis of the disease are essential. At this time, heart rate measurement can be considered a basic step for them.Among methods for measuring heart rate, the method for detecting a Photo Plethysmo Gram (PPG) by means of the PPG sensor can be cited as an existing case of applying the ubiquitous healthcare technology. It is a technique that measures

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the pulsatile component generated during heartbeat by illuminating the human body with light of a specific wavelength band and detecting the light either reflected or transmitted.In general, the PPG is measured by a probe worn on the earlobe or the finger, and allows cardio motility in the diastole and the systole to be observed at blood vessels[3,4]. Owing to these characteristics, research on PPG is recently being carried out lively so as to apply it to diverse areas including healthcare.In most of the existing studies on the PPG, a site for measuring PPG has been the finger; however, the finger is a region that shows the most movements in the body, and thus if a sensor is worn on the finger, there occur problems such as inconvenience for finger movements and sensitive reaction to motion artifacts[5].To solve such problems, a method has been proposed for detecting heartbeat or respiration signals from the posterior neck region of a subject who lies on an air pillow to which a sensor is attached[6].This method can resolve inconvenience for hand motion caused by wearing a sensor; however, it still has the shortcomings of being sensitive to motion artifacts and having to fix the neck onto the area of a sensor attached to a pillow.This paper intends to comparatively evaluate the performance of measuring heart rate at the finger and the performance of measuring heart rate at the carotid artery and the occipital artery according to changes in positions during sleep, using the multiple PPG sensors and the Fast Fourier Transform (FFT). From this, it will suggest that heart rate can be measured without motion artifacts even when the sleeping position is not constrained, but changes.This paper is organized as follows: Chapter 1 is the introduction, and Chapter 2 is relevant studies on the FFT and the multiple PPG sensors. Chapter 3 explains the locations of arteries in the face and sleeping positions. Chapter 4 designs a heart rate measurement system. Chapter 5 describes the measurement of heart rate using the multiple PPG sensors. Chapter 6 analyzes the heart rate measurement performance of the suggested system through an experiment that compares deviations of the system's measurement performance from measurement performance at the finger. Lastly, Chapter 7 concludes.

2. Literature Review

2.1 FFT

FFT is an algorithm that improves the speed of the Fourier transform by removing redundant operations from the Discrete Fourier Transform (DFT)[7]. Figure 1 shows the waveform of the PPG signal in the time domain and the waveform in the frequency domain to which FFT was applied.The heart rate measurement performance can be improved by performing FFT on the collected PPG signal and removing a specific part judged to be an artifact.

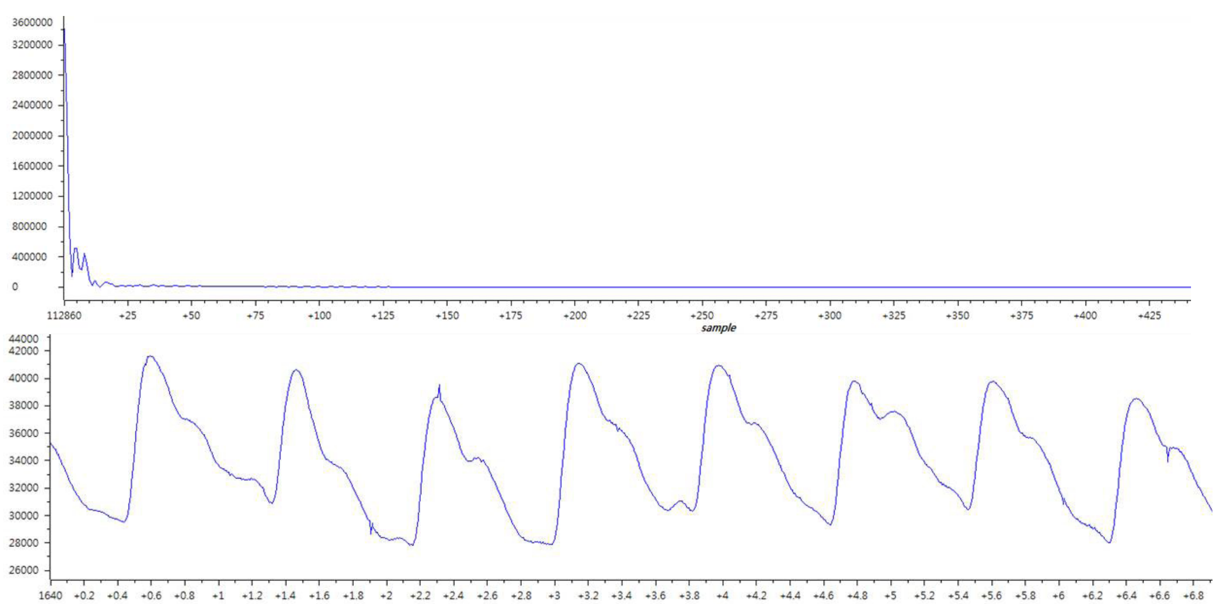

Figure 1. PPG signal's waveform in the time domain (above) and waveform in the frequency domain (below).

2.2 The Multiple PPG Sensor

Owing to its broad surface area, the multiple PPG sensors can measure a signal even in a location where the artery as well as the capillary of the finger passes. Figure 2 is the schematic diagram of a PPG-array sensor module to be used as the multiple PPG sensor[8]. A smaller module is better attached to a pillow, and thus the SG-105F PPG sensor, in which a 3.0x3.0-mm GaAsIRED of 940nm wavelength (source of light) and a photo-transistor (sensor) were combined into one device, was used[9].

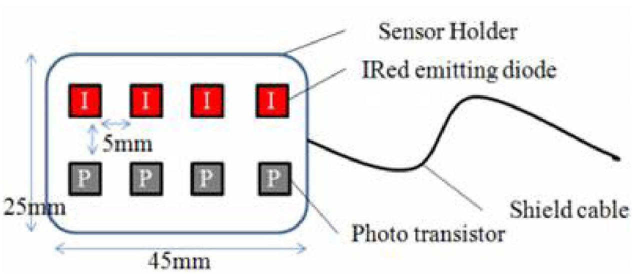

Figure 2. Composition diagram of PPG array sensor module.

2.3 Proposed Work Locations of Arteries in the Face and Sleeping Positions

Figure 3 shows the locations of the carotid artery and the occipital artery for the measurement of heart rate during sleep. Figure 4 classifies the types of changed positions that may appear during sleep. In Figure 4, thefetus position, the log position, the yearned position, and the freefaller position allow heart rate to be measured from the carotid artery; and the soldier position and the starfish position allow heart rate to be measured from the occipital artery.

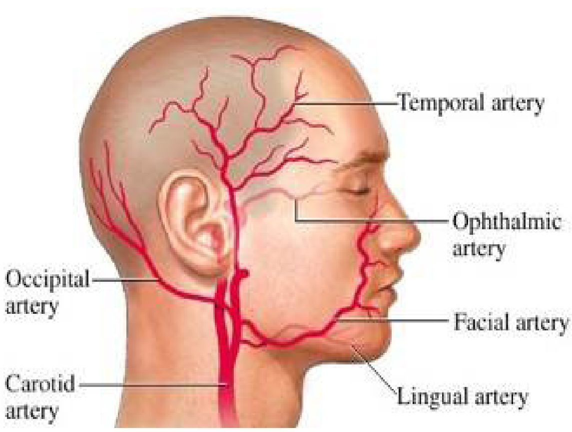

Figure 3. Position of carotid artery and occipital artery.

Figure 4. Classification of posture during sleep.

2.4 System Structure

2.4.1 System Configuration

As shown in Figure 5, the heart rate measurement system consists of the PPG sensor, which changes the amount of current according to changes in light; the PPG signal correction module, which is to remove artifacts inputted from the outside; and a microprocessor, which has the functions of Analog-Digital Converter (ADC) and FFT. The PPG signal correction module comprises an I-V Converter, which converts any change in the currents detected by the PPG sensor into an equivalent change in the voltage; a 2nd-order 60-Hz Twin-T Notch filter for rejecting 60-Hz power supply noise; a high-pass filter, which has the cutoff frequency of 0.5Hz to detect signals of 0.1-10Hz, PPG's effective frequency band; and a low-pass filter, which is designed to have the cutoff frequency of 3Hz, for human pulse rate hardly surpasses max. 200[9].For the filtered PPG signal, Texas Instruments' TMS320F28335 microprocessor, which allows an extremely high-speed operation, is used to perform the functions of ADC and FFT.

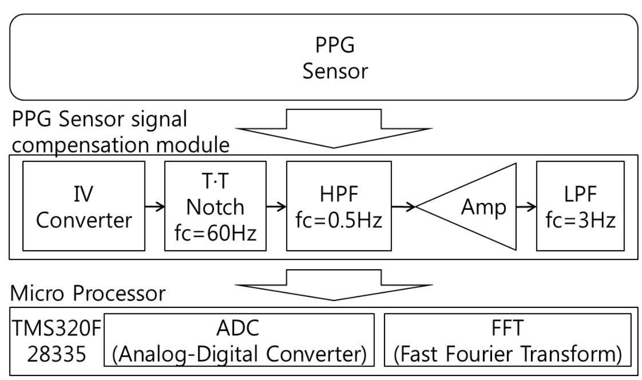

Figure 5. System structure of heart rate measurement system.

2.5 Measuring the Heart Rate using the Multiple PPG Sensor

The heart rate (HR_n) can be calculated as shown in Expression (1), using the inter-pulse period (SBT_n).

$$HR_n = \frac{60(sec)}{SBT_n} \quad (1)$$

The inter-pulse period was obtained by dividing the difference between maximum points ($max\square$) by the sampling frequency ($\mathbf{f_s}$) of 128Hz, with the highest value among signal values obtained within each frequency range being as the maximum point ($max\square$), as shown in Expression (2).

$$SBT_n = \frac{(f_s - max_{n-1}) + (max_n - f_s - 1)}{f_s} \quad (2)$$

Figure 6 indicates the process for measuring heart rate, using the multiple PPG sensors.Among PPG signals collected from multiple sensor and subjected to FFT, one with the least noise and the smallest difference between maximum and minimum is selected and set as the optimal signal. Only the value of this signal is collected and analyzed continuously. In case of a change in the sleeping position, the signal value becomes 65520 or 0 because of the instantaneous motion artifact. At this time, the values of multiple PPG sensors are initialized. And PPG signals are collected again, and only the optimal signal is extracted in the same way as in Figure 6. This is an easy method to measure heart rate from the carotid artery and the occipital artery during sleep.

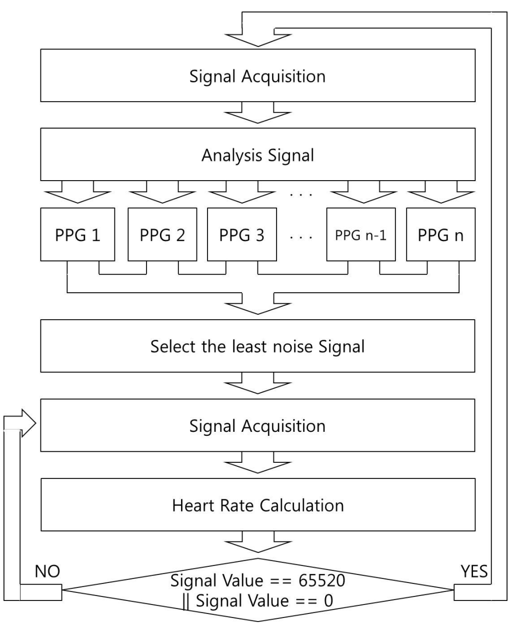

Figure 6. Heart rate measurement process using multiple PPG sensor.

2.6 Experiment

2.6.1 Method of Experiment

The subjects who participated in the experiment were five male and female university students aged 22-55. It was possible to proceed with this study without difficulty, thanks to the unconstrained use of non-invasive sensor. The laboratory, in which the subjects were situated, was a soundproof space; its temperature was controlled within 23-25°C; and the experiment was conducted 30 minutes after lights were put out. The experimenter collected data during the experiment for 3 hours and half via a line connected to the outside of the laboratory, lest the subject be disturbed during sleep.For the collection of signals from the carotid artery and the occipital artery, the subjects took their initial positions as shown in Figure 7.There may be changes in positions due to movements during sleep. The degree of PPG-signal measurability in case of movements should be judged, when a single sensor or multiple sensor are attached to a pillow. For this, comparison was made between the multiple sensor method and the commonly used method of attaching a sensor to the finger.

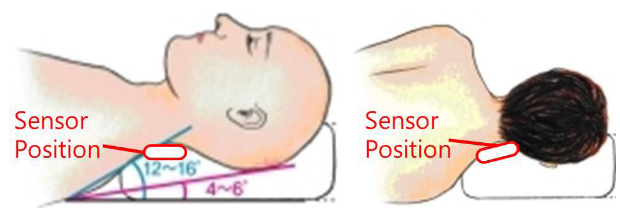

Figure 7. Locations of a pillow for measuring heart rate at the occipital artery (left) and at the carotid artery (right)[10].

2.7 PPG Signal Measurement in the Finger Region

Due to movements of the finger, as follow comparing signals between the single PPG sensor and the multiple PPG sensor.

2.8 In Case of no Movement

Figure 8shows the comparison of signals between sensors of the two types in case of no movement.When comparing signals between the multiple PPG sensor and the single PPG sensor, there is no great difference in terms of noise and period; however, it is found that the multiple PPG sensor signal is a little clearer and more periodic.

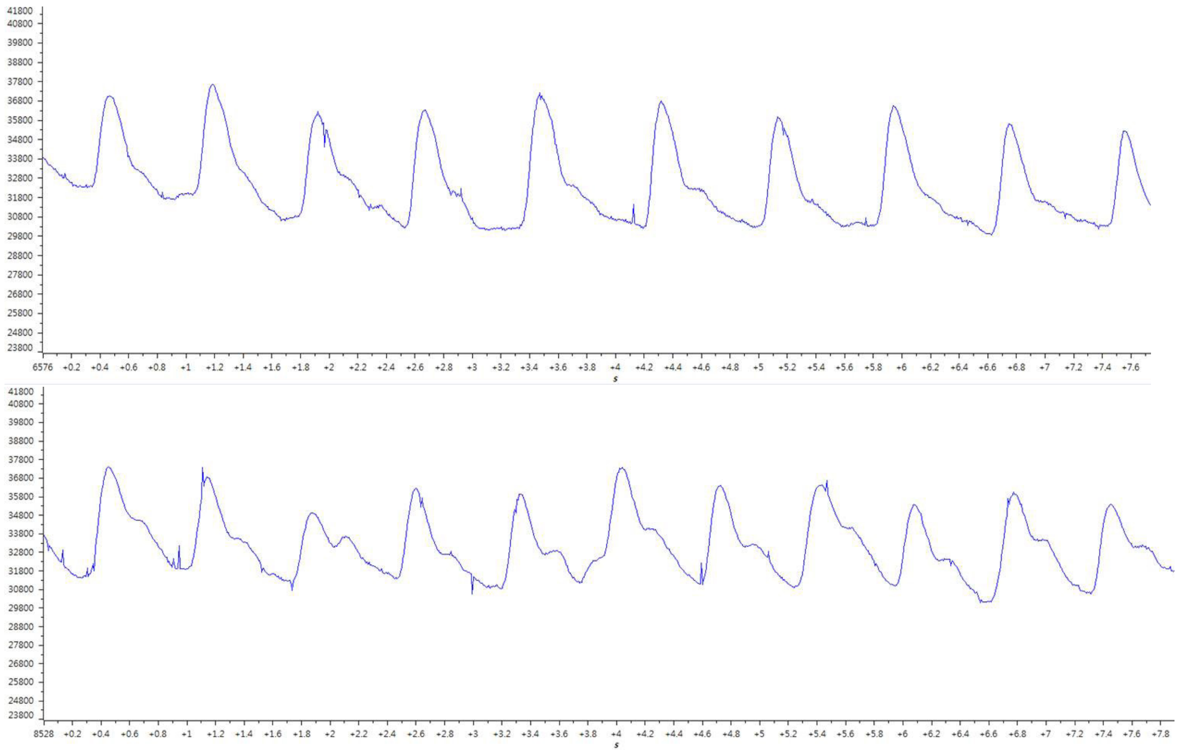

Figure 8. Comparison of signals in case of no movement between the multiple PPG sensors (above) and the single PPG sensor (below).

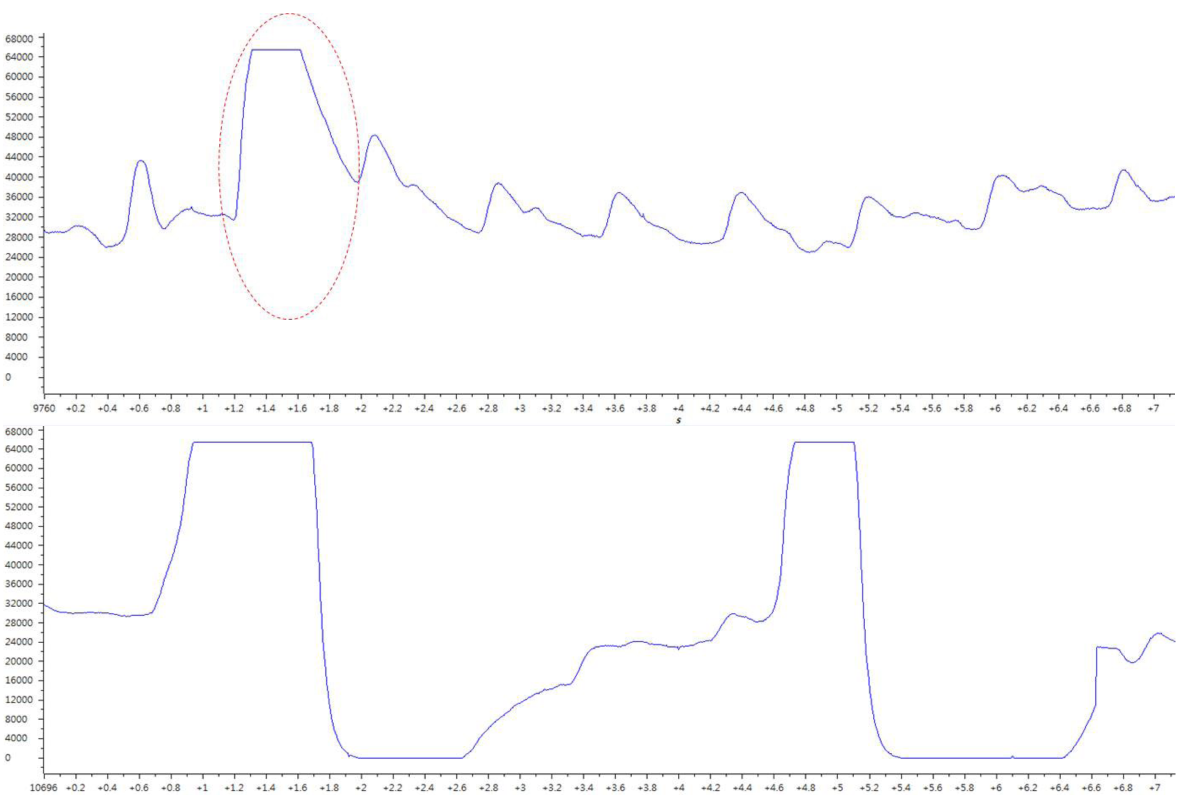

Figure 9. Comparison of signals in case of movement between the multiple PPG sensors (above) and the single PPG sensor (below).

2.9 In Case of Movement

Figure 9 shows the comparison of signals between sensors of the two types in case of movements.As shown from the multiple PPG sensor in Figure 9, in case of movements, the signal value increases instantaneously; at the same time, however, it is possible to measure the PPG signal without noise by using another sensor among the multiple PPG sensor.Unlike this, when the single PPG sensor is used, it is found that it is difficult to measure heart rate because the value repeatedly increases and decreases in case of movements.

2.10 Comparison of Each part

Figure 10 shows the comparison of signals measured by the multiple PPG sensors at the finger, the carotid artery, and the occipital artery according to sleeping positions. It was found that the three kinds of signals change on the same sampling frequency (f_s), though varying in period characteristics and sizes. From this, their respective heart rates (HR_n) are also measured without any problem.

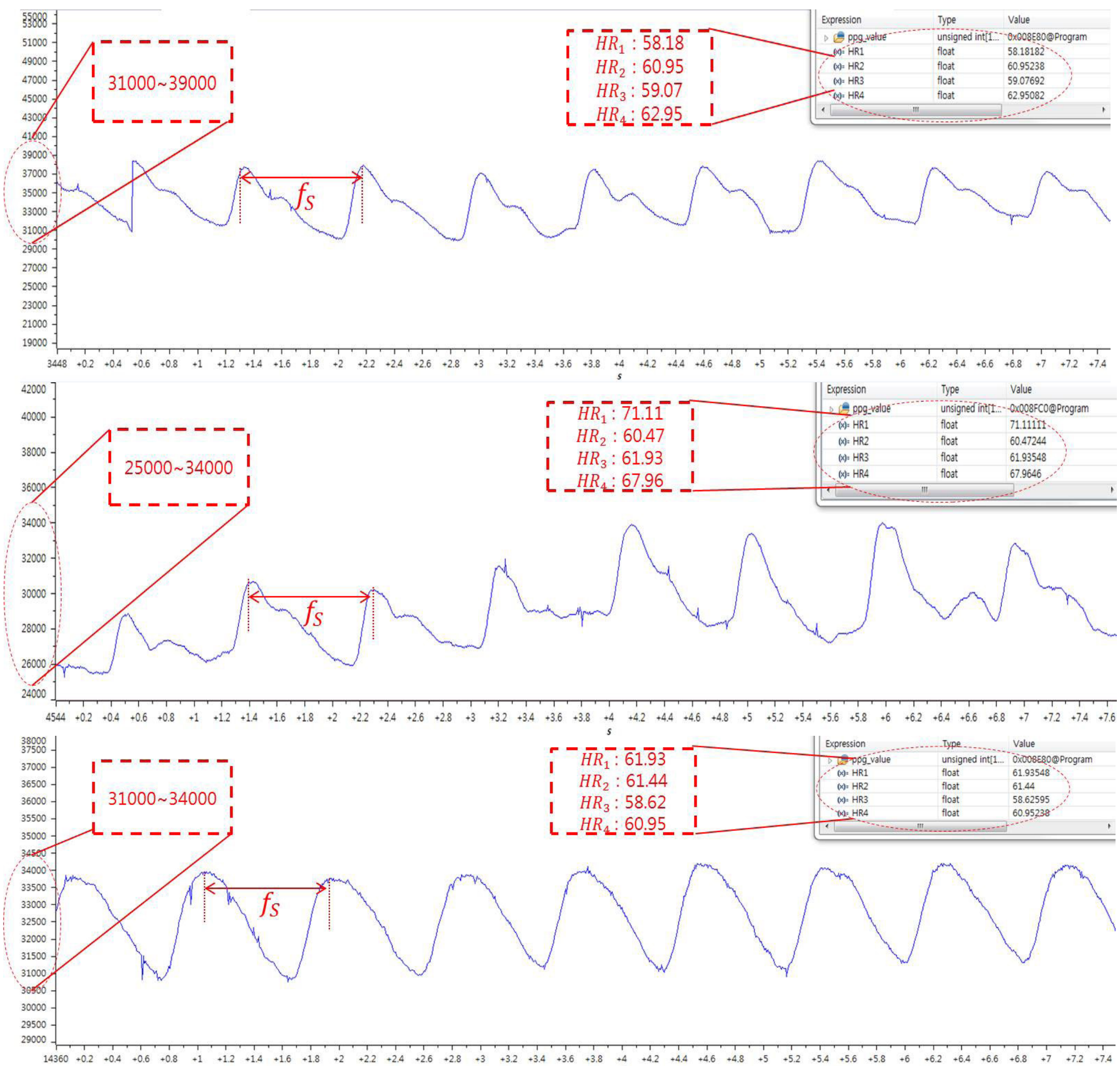

Figure 10. Comparison of signals in case of movement between the multiple PPG sensors (above) and the single PPG sensor (below).

2.11 Result of Experiment

Table 1 show the results of calculating deviations in comparison with signals of the finger so as to quantitatively evaluate signals measured during the subjects' sleep. The deviation by region was calculated on one-minute and ten-minute bases, and was indicated in terms of mean.The deviations of heart rates measured at the carotid artery and the occipital artery ($\mathbf{reg_n}$) from heart rate measured at the finger ($\mathbf{fin_n}$) are as in Expression (3).

Table 1. Deviation experimental results for the heart rate compared by finger's one

Part	Subject	Position during sleep	Deviation with finger	
			1min	10min
Carotid artery	1	Foetus	3.03	1.37
		Free faller	4.41	2.21
	2	Log	1.24	2.41
		Yearner	1.07	0.57
		Free faller	2.21	1.54
	3	Free faller	1.12	2.23
	4	Yearner	6.21	3.12
		Free faller	3.2	1.37
	5	Log	1.09	2.18
		Yearner	2.45	2.01
Occipital artery	1	Soldier	3.11	2.65
	2	Soldier	0.46	1.93
	3	Soldier	1.87	1.55
		Starfish	1.22	0.78
	4	Soldier	3.96	5.2
	5	Soldier	1.32	0.34

$$deviation_n = \left\| \left|\frac{HR_{reg_n}}{reg_n}\right| - \left|\frac{HR_{fin_n}}{fin_n}\right| \right\| \quad (2)$$

The deviations of heart rates measured at the carotid artery (1 minute: 1.07-6.21 bpm, 10 minutes: 0.57-5.18 bpm) and heart rates measured at the occipital artery (1 minute: 0.46-3.96 bpm, 10 minutes: 0.34-5.2 bpm) from heart rate measured at the finger were found to be relatively low, with max 6.21 bpm at the carotid artery and max 5.2 bpm at the occipital artery.If heart rate had been found to be 0 or an abnormally high value, the deviation from heart rate at the finger would have shown a great difference. Subjects 1 and 4 showed high deviations compared to other subjects. On the other hand, subjects 2, 3, and 5 showed stable heart rates. This was due to the subjects' different sleep, and thus it is judged that the measurement of heart rate at the carotid artery and the occipital artery during sleep has no problem.

3. Conclusion

This paper evaluated the possibility of measuring heart rates at the carotid artery and the occipital artery according to sleeping positions, using the multiple PPG sensors. In general, PPG signals are measured by wearing a probe on the earlobe or the finger, but it was found that good signals can be obtained from the carotid artery and the occipital artery during sleeping, when using the sensor attached unconstrainedly to a pillow. In addition, as a result of comparing the signals with the signal obtained at the finger, it was possible to extract signals as excellent as the signal obtained at the finger. From this, it was confirmed that there is no problem in measuring heart rate at the carotid artery and the occipital artery even during sleep. During sleep, it is possible that apnea or various physiological phenomena occur according to a subject's age. Assessing the measurement of heart rate during sleep in consideration of such variable factors remains as a future task.

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