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Implementation of Glove-Type Wearable Healthcare System for Heartrate Measurement During Daily Life

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ABSTRACT

Background/Objectives: In recently, U-Healthcare has evolved into Smart-Healthcare due to growth of IoT technology and entry into an aging society; it is able to provide variety of medical service technologies. Wearable technology for health monitoring in everyday life is provided with a variety of medical service models through linkage with existing ICT infrastructures.

Method/Statistical Analysis: In the proposed system is first to filter and amp the data measured thought the PPG sensor in the measurement section, and then to perform the ADC conversion in the control section. Then, heart rate was detected from the filtered data by the IBI method after remove the motion noise using the adaptive filter. Finally, heart rate display is possible on the LCD in the control section and transmitted to the monitoring section through Bluetooth communication.

Findings: To evaluate overall performance of implemented system, experiment was conducted to comparative evaluation with commercial system, adaptive filter evaluation and performance evaluation in daily life. For a reliable system evaluation, we conducted a comparative experiment with the commercial system (PSL-iPPG2) of Physio lab company and confirmed the similarity of 98.44%. Evaluated the adaptive filtering implemented by adding artificial noise to the original signal, and it was confirmed that the motion noise remove performance is excellent. In addition, heart rate detection precise of the detection system using the general detection method and the adaptive filter was evaluated. As a result, heart rate detection of 89.19% was found to be low in the case of the general detection method and 98.02% in the case of the heart rate detection method using the adaptive filter.

Improvements/Applications: The implemented system designed an adaptive filter for motion noise remove for precise heart rate measurement in daily life. In addition, confirmed that the system implemented in this paper can be applied to everyday life through experiments. In future research, it is aimed to implement a heart rate monitoring system optimized for motion noise for measuring heart rate with various activity states and psychological changes.

Keywords: *PPG, Wearable, Healthcare, Inter beat Interval, Beer-Lambert law, Adaptive filter.*

Introduction

In recently, U-Healthcare has evolved into Smart-Healthcare due to growth of IoT technology and entry into an aging society, it is able to provide variety of medical service technologies[1]. Wearable technology for health monitoring in everyday life is provided with a variety of medical service models through linkage with existing ICT infrastructures[2]. The wearable device is currently used most in Activity device field and Healthcare

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device field. Activity devices[3,4] can monitor motion and physical activity information, and healthcare devices[5,6] can monitor bio-signals such as blood pressure, ECG, EMG, EEG and etc. and transmit to users or external agencies. In particular, ECG and PPG are bio-signals that reflect the activity state of heart, and serve as the important criteria signal when diagnosing heart disease and vascular diseases. The heart rate that represents the activity cycle of heart is the overall rhythm determined by count of contraction and relaxation activities of the SA-node[7]. Blood released from the left ventricle during systole moves to the peripheral blood vessels and increases arterial dimensions. Thereafter, pulse generated at a portion where blood is drawn into the heart from peripheral blood vessels during diastole. At this time, analyzing the penetrance and the reflectance using the light to the pulse generated can measure the PPG signal moving according to the heartrate. Although it is common to use contact-type measurement methods that attach to the body to measure heart activity state, there are many problems such as cost and wearing limitations to use in daily life. To solve this problem, PPG and heart rate measurement systems using non-contact type measurement have been studied [8-10]. This paper proposes a glove-type wearable healthcare system that heart rate monitoring according to heart activity state and minimizes noise due to external light or user movement. The system implemented reflection type PPG probe using infrared led (IR) and red led(R) as the light source, enabling non-invasive measurement for a long term with simple operation method without specialization. In addition, adaptive filter is designed for remove to noise caused by ambient bio-signal and user motion when measuring the PPG. The implemented system can monitor the heart rate information according to the activity state as well as the physical information, and it can transmit the current location information and health information to the surrounding people in case of emergency.

Materials and Method

In the proposed system is first to filter and amp the data measured thought the PPG sensor in the measurement section, and then to perform the ADC conversion in the control section. Then, heart rate was detected from the filtered data by the IBI method after remove the motion noise using the adaptive filter. Finally, heart rate display is possible on the LCD in the control section and transmitted to the monitoring section through Bluetooth communication. Monitoring section can precise heart rate monitoring as well as transmit the current location information and health information to the surrounding people in case of emergency. Figure 1 shows the flow chart of glove-type wearable health management system.

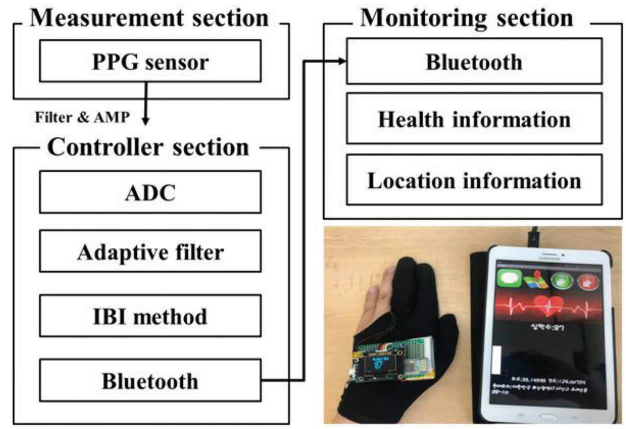


Figure 1: Flow chart of the glove-type wearable healthcare system

Beer-Lambert Law for PPG Measurement: The Beer-Lambert law built in the measurement sensor was used for PPG measurement. Beer-Lambert law detects the heart rate from changes in blood flow using optical feature. Figure 2 shows the flowchart of Beer-Lambert law.

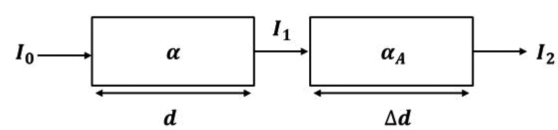


Figure 2: Flowchart of the Beer-Lambert Law

Light generating from light source (I_0) is partially absorbed in the process of penetrating skin tissue. This can be seen as a DC component since the penetration length of light (d) and absorption of light (α) are not changed. In addition, penetration light (I_1) after passing through the DC component can be represented by the light of the AC component (I_2) if it is influenced by relative absorption (α_A) of arterial blood and penetration length (Δd) due to changes arterial blood dimensions. The AC component shows the effect of changes in light penetration length and relative absorption of arterial blood. Equation 1 shows the calculated equations of (I_1) and (I_2).

$$I_0 \exp - ^{(\alpha d + \alpha \delta d)} \quad \ldots(1)$$

Adaptive Filter Design for Motion Noise Remove: Since the PPG signal is measured using an optical method, it is highly affected by noise. There are not only light sources analyzed when light penetrance skin tissue, but also ambient light noise, noise caused by physical combining errors in measuring sensors and measuring parts, electromagnetic noise of the measuring equipment itself, etc. Using PPG signals that are affected by these noises will cause distortion of waveforms and changes in amplitude it is making accurate measurements impossible. Therefore, while the PPG signal measures the heartrate cycle, is also necessary to remove motion noise because the signal related to breathing is also measured. In this paper, we implemented an adaptive filter using LMS(least mean square) algorithm based on the steepest descent method to remove the motion noise generated when PPG measurement. The adaptive filter iteratively adjusts the filter coefficients with the least mean square algorithm based on a given filter coefficient to estimate remove noise or features of the desired signal. Figure 3 shows a diagram of the implemented adaptive filter. Equation 2-4 shows the equations of the implemented adaptive filter.

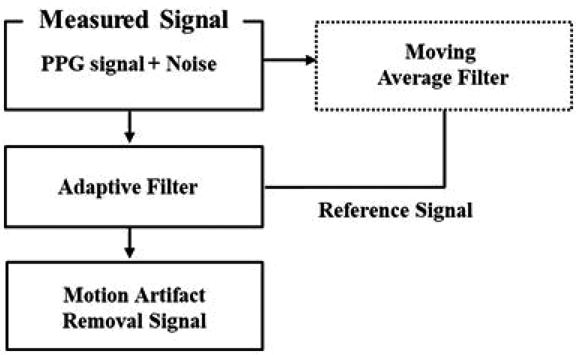


Figure 3: Diagram of the implemented adaptive filter

$$E(n) = P(n) + N(n) - eN(n) \quad \ldots(2)$$

$$eN(n) = \sum_{k=0}^{L} h_k N_R(n-k) \quad \ldots(3)$$

$$h_k(n+1) = h_k(n) + 2\mu E(n) N_R(n-k) \quad \ldots(4)$$

P_n is the original signal, L is the degree, $N_{(n)}$ is the noise component signal, $N_R(n)$ is the reference noise signal extracted from the low frequency band by applying the moving average filter, eN(n) is the estimated noise signal, $h_k(n)$ is the filter coefficient, and μ is the convergence constant.

IBI Method for Heart Rate Analysis: To reliably measure the IBI(Inter beat Interval) between PPG bits, an 8-bit hardware timer timer2 was set in the ATmega128-based control section to generate an interrupt every millisecond. This allows a sampling rate of 500 Hz and a bit timing of 2ms. After calculating the maximum and minimum points from the measured data every 2ms, measure the first beat and second beat if the 10 IBIs become one function. By calculating the average IBI using the two measured functions and dividing by 60000, the BPM can be obtained. Finally, if the range of data transmitted to the monitoring system is 0 or more than, the range of BPM is given and it is judged whether there is an abnormal or normal. If there is no input data, check for connection again. When an abnormal bpm is detected, BPM, latitude, longitude, and location address information are sending to surrounding people. Android studio program based application has been implemented to monitoring precise heartrate graphs. Figure 4 shows the flow chart of the IBI method and Application

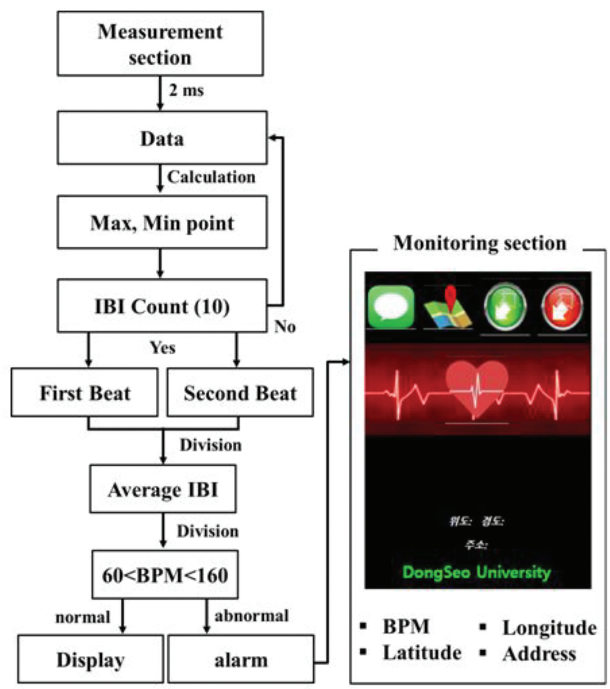


Figure 4: Flowchart of the IBI Method and Application

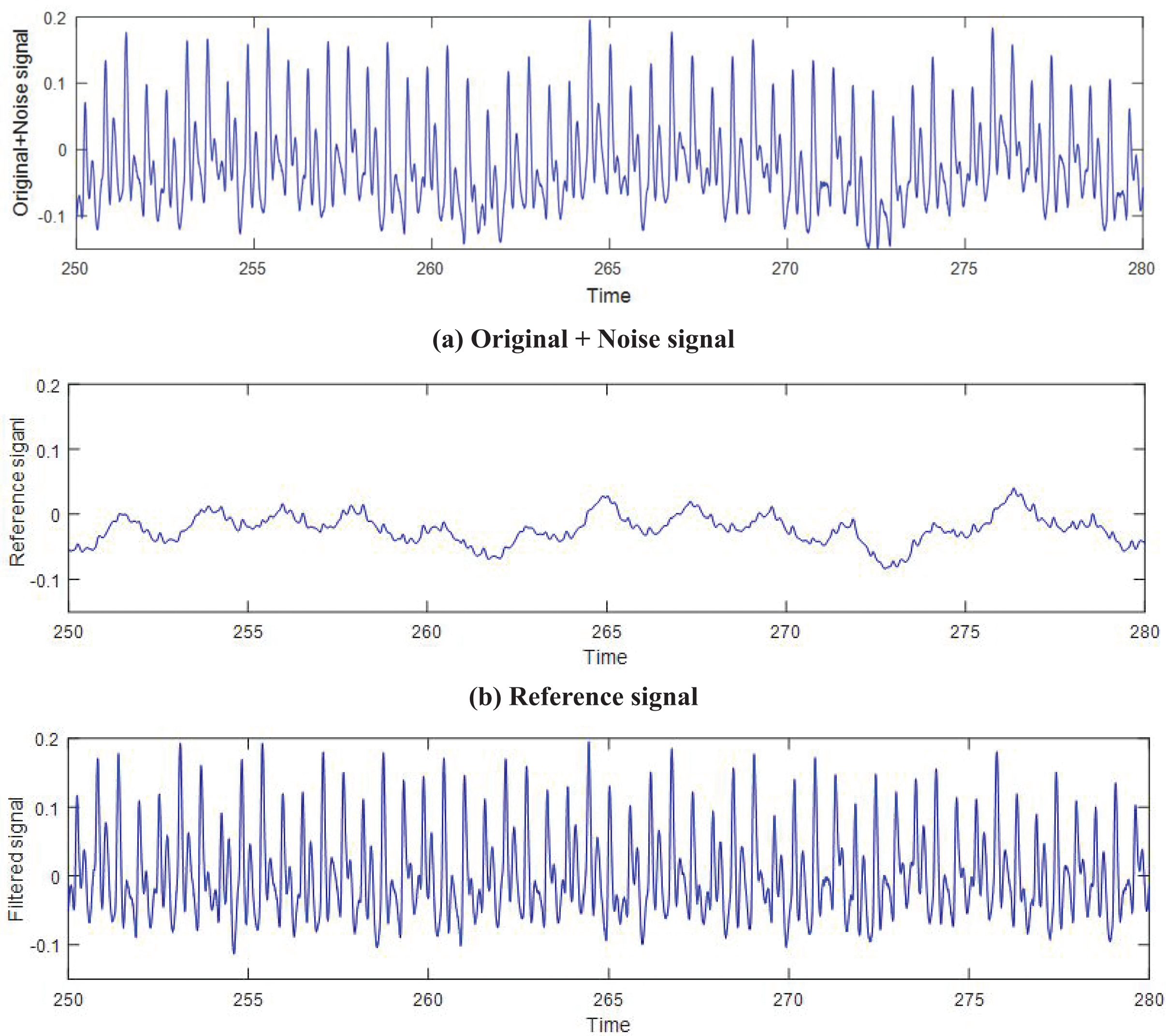
Results and Discussion

Comparison Evaluation with Commercial Systems: An experiment was conducted with Physio lab company PPG measurement system (PSL-iPPG2) for comparative evaluation with commercial systems. The experiment was progress for 5 minutes with 5 subjects. Experimental results showed that the similarity of heart rate detection between the implemented system and commercial system was 98.44%, which is an excellent detection performance. Table 1 shows the heart rate comparison results between the implemented system and the commercial system.

Table 1: Comparison Results Between the Implemented System and the Commercial System

	Detection Heart Rate		
	Implement system	Commercial system	Similarity [%]
Subject 1	348	354	98.30
Subject 2	379	382	99.21
Subject 3	366	372	98.38
Subject 4	388	396	97.97
Subject 5	359	365	98.35
Avg.			98.44

Adaptive Filter Performance Evaluation: In order to evaluate the performance of the adaptive filter, artificial noise signal and motion noise signal were added to the original signal to remove the noise using the proposed adaptive filter. First, in order to evaluate the features of motion noise components, we analyzed PPG signal measured after a 10 - minute rest and PPG signals measured at walking and running. As a result, it was possible to identify a specific frequency component which appears only in the activity state such as walking and running, unlike the frequency component in the sitting static state. Therefore, the frequency of 3Hz, 2.7Hz, and 4.1Hz was determined as a specific frequency, and an artificial motion noise signal was generated by mixing the noise signal of the specific frequency band with the white noise. Experimental results show that the proposed adaptive filter has superior motion noise removal performance. Figure 5 shows the results of the adaptive filter performance evaluation.



(a) Original + Noise signal

(b) Reference signal

(c) Processing with adaptive filter

Figure 5: Results of the adaptive filter performance evaluation

Performance Evaluation in Everyday Life: To evaluate overall performance of measuring heart rate in everyday life, an experiment was conducted to measure heart rate during the activity state for 10 minutes with 5 subjects wearing implemented system. The experimental environment established different sections of moving path as shown in figure 6 (a: downhill, b: flatland, c: uphill) on the campus and took a 30-second break before moving by section. In addition, heart rate detection precise of the detection system using the general detection method and the adaptive filter was evaluated. In order to determine the heart rate detection of the two methods, MATLAB was used to visually count the heart rate recorded in the heart rate recording papers and set them as reference heart rate. As a result, heart rate detection of 89.19% was found to be low in the case of the general detection method and 98.02% in the case of the heart rate detection method using the adaptive filter. Table 2 shows the heart rate detection results of the two methods. Figure 7 shows result of remove motion noise in daily life.

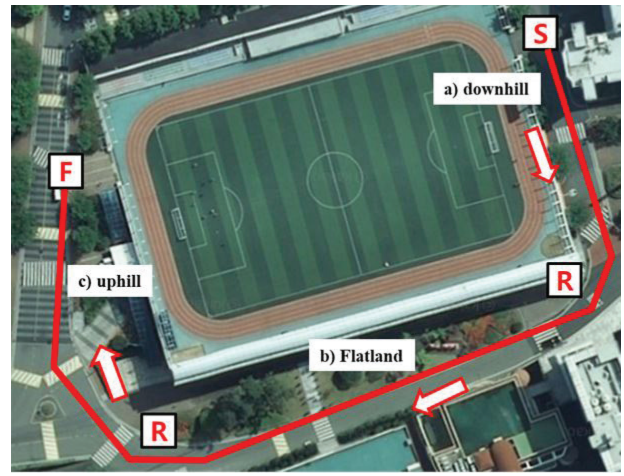


Figure 6: Moving path

Table 2: Heart Rate Detection Results of the Two Methods

	a section			b section			c section		
	RS	**WF**	**NF**	**RS**	**WF**	**NF**	**RS**	**WF**	**NF**
Subject 1	234	228	206	213	207	203	249	243	207
Subject 2	246	243	217	222	216	213	261	255	218
Subject 3	261	255	214	237	233	227	279	273	242
Subject 4	296	291	267	228	225	221	301	293	246
Subject 5	267	261	233	224	220	218	283	279	243
Detection [%]		98.30	87.13		97.95	96.25		97.81	84.19
	[RS]Reference signal, [WF]with adaptive filter, [NF]not adaptive filter WF=98.02% NF=89.19%								

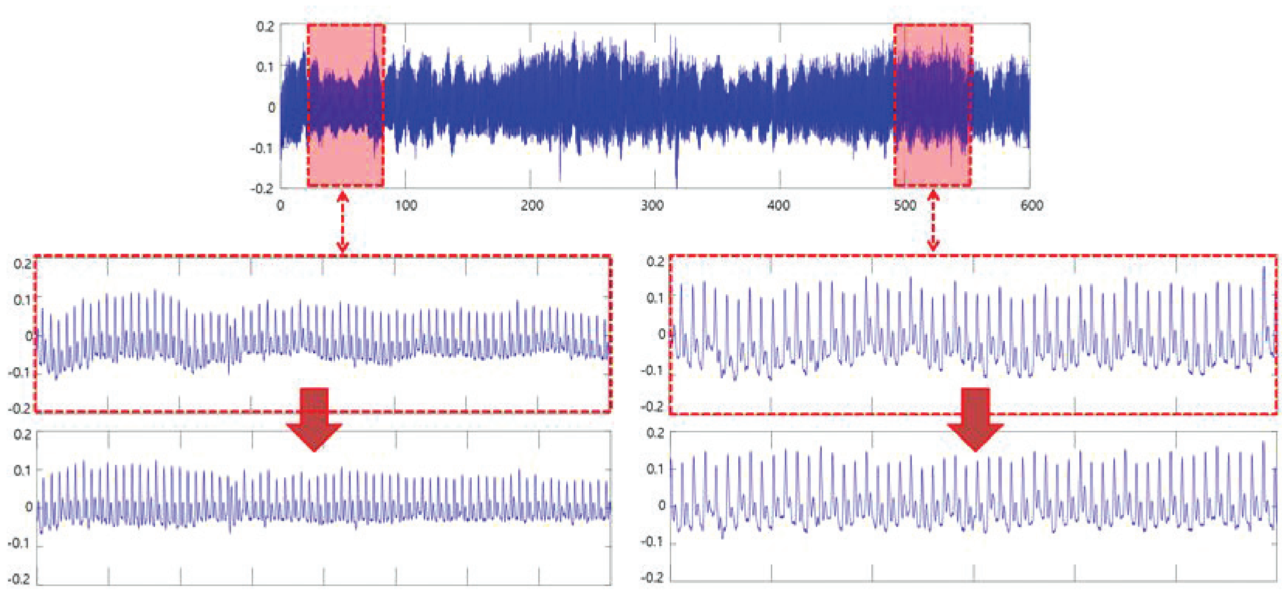


Figure 7: Result of remove motion noise in daily life

Conclusion

This paper has implemented a glove-type wearable healthcare system for measuring heart rate in daily life. The implemented system measured PPG using Beer-Lambert law for PPG sensor. Also, in this paper implemented an Android-based monitoring section for real-time monitoring. Monitoring section can precise heart rate monitoring as well as transmit the current location information and health information to the surrounding people in case of emergency. To evaluate overall performance of implemented system, experiment was conducted to comparative evaluation with commercial system, adaptive filter evaluation and performance evaluation in daily life. For a reliable system evaluation, we conducted a comparative experiment with the commercial system(PSL-iPPG2) of Physiolab company and confirmed the similarity of 98.44%.Evaluated the adaptive filtering implemented by adding artificial noise to the original signal, and it was confirmed that the motion noise remove performance is excellent. In addition, heart rate detection precise of the detection system using the general detection method and the adaptive filter was evaluated. As a result, heart rate detection of 89.19% was found to be low in the case of the general detection method and 98.02% in the case of the heart rate detection method using the adaptive filter. Therefore, it is confirmed that the system implemented in this paper is applicable to everyday life. In future research, it is aimed to implement a heart rate monitoring system optimized for motion noise for measuring heart rate with various activity states and psychological changes.

Acknowledgment

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