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***Research Paper***

# Implement wrist-worn PPG and SpO2 monitoring system

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## Abstract

**Background/Objectives:** With the advent of an aging society, the advent of smartphones is changing the paradigm of medical services.Existing health care has been aimed at diagnosing and curing, but now there is a lot of focus on personal health monitoring and disease prevention.The PPG signal reflecting the activity state of the heart among the various biological information of the human body has a regular period and regular characteristic.In addition, it is possible to observe pathological and physiological abnormalities by observing changes in the components of the PPG signal according to the state of health and the body, and it can be utilized for diagnosis of heart disease.
**Methods/Statistical analysis:** In this research, we implemented a wrist - worn measuring system to monitor PPG and SPO2 in real time in daily life. Adaptive filter method was applied formotion-artifact removal of PPG and SpO2 signal measured in everyday life. A smart phone application applied the adaptive filter method can monitoring the measured physical information in real time.
**Findings:** For the performance evaluation, the PPG signal of the wrist wearing type measurement system implemented using the commercial PPG measuring device ubpulse 360 (Laxtha, Korea) were comparative evaluation. Also, we measured PPG signals according to activity and rest state in 9 college students. As a result of the experiment, it was confirmed that the mean correlation coefficient between the implemented system and the commercial system was 0.934. We confirmed that the measured results are very similar, and we can confirm the usefulness of the implemented system.
**Improvements/Applications:** In non-invasive SpO2 devices, even with slight movement, the noise is larger than the signal and the ratio of absorbance is incorrectly calculated when calculating SPO2. Therefore, it is difficult to obtain a normal waveform. In order to overcome these disadvantages, we implemented the PPG and SPO2 measurement monitoring system which minimizes the distortion of the PPG signal using the adaptive filter.In the future, we will research techniques for measuring PPG and SPO2 more conveniently in daily life and algorithms for improving the accuracy of PPG data.

***Keywords***: *PPG; SPO2; Adaptive Filter; Motion-Artifact Removal; Real-Time Monitoring.*

## 1. Introduction

Ubiquitous healthcare, which complements the scarce medical infrastructure, requires bio-signal measurement to monitor and manage the user's health.Bio-signals measured for health monitoring can be measured noninvasively and use ECG, PPG, body temperature, etc., which contain a lot of information[1]. Among them, PPG can be easily measured and include health indicators related to heart disease [2]. However in order to measure PPG, there is a disadvantage that measurement equipment is usually attached to the finger and the system is connected with a wired line.Existing hospitals use holders that can store PPG data for more than 24 hours, but because they contain large amounts of data, it takes a lot of time and money to analyze them directly by the medical staff.In addition, distortion of the signal occurs due to the inflow of the noise in accordance with the motionat the time of measurement of the biological signal accompanying motion in everyday life, and accurate measurement is difficult. In order to solve these problems, existing researches have been carried out on a user-centered measuring system which is convenient to wear and non-constraint measurement [3-6]. However, the real-time bio-signal classification technique requires a large amount of computation for accurate analysis and is not suitable for the healthcare environment for continuous monitoring.Therefore, it is indispensable to study the efficient classification of bio - signal classification techniques that require large amounts of computation and data transfer.In this research, we implemented a wrist - worn measuring system to monitor PPG and SpO2 in real time in daily life.

## 2. System configuration

In this research, we implemented a wrist - worn measuring system to monitor PPG and SpO2 in real time in daily life. Adaptive filter method was applied formotion-artifact removal of PPG and SpO2 signal measured in everyday life. A smart phone application applied the adaptive filter method can monitoring the measured physical information in real time. Figure 1 shows the implemented system configuration.

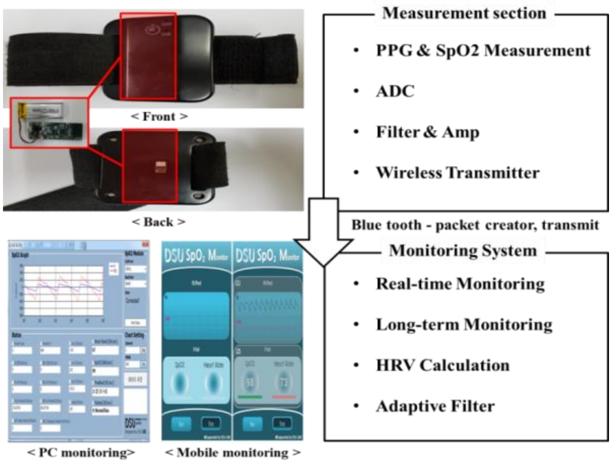


**Fig. 1:** System Configuration.

### 2.1. PPG measurement

When blood is squirted into the aorta by heart contraction, the aortic wall expands and is transferred to the artery branch. PPG is the measurement of this change in pulsation[7]. When the blood flow changes in the blood vessels due to the transfer of the pulse wave, the same blood flow changes are detected in the teloblast of the body such as the finger, toe, and earlobe.PPG is shows characteristic of peripheral blood vessels such as pulsating components and changes in blood flow, so they are very useful for determining blood vessel aging and atherosclerosis[8].PPG is can detect the heart rate by measuring changes in blood flow using the optical characteristics of the Beer-Lambert law of the measurement sensor.In this research, we implemented a reflection type PPG probe using infrared (IR) and red light(R) as the light sources and made it possible to perform continuous measurement for a long time with simple usage method which does not require user's expertise.The principle of PPG detection using a photodiode and an infrared LED of a reflective probe is shown in Figure 2 [9].

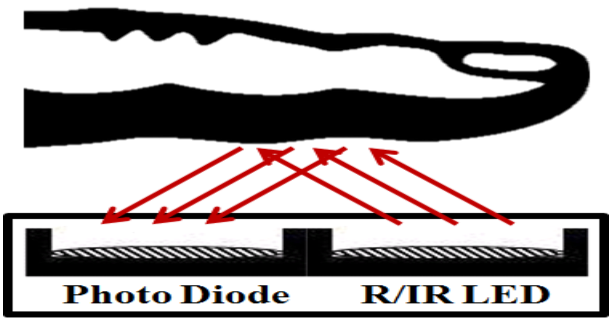


**Fig. 2:** Principle of PPG Detection.

### 2.2. SpO2 measurement

In humans, if there is no oxygen, an average of 5 minutes is followed by a brain death, and after 8 minutes, death. It binds to hemoglobin in the blood through the capillaries of the lungs to carry oxygen, and hemoglobin is divided into oxidized hemoglobin and reduced hemoglobin[10].SpO2 can be measured by analyzing blood flow through PPG signal. The calculation of SpO2 is a method of measuring the amount of HbO2 to the total amount of hemoglobin, and the measurement is made using two wavelengths. Hb and HbO2 use red light of 660nm with a large difference in absorbance and 905 nm infrared light with no difference in absorbance. Equation 1 is an equation for calculating SpO2.In this case, the absorption degree wavelength is A (λ1), A (λ2), and α and β correspond to the light absorption coefficients of Hb and HbO2, respectively. This can be expressed as Equation 2.

$$SpO_2 = \frac{HbO_2}{HbO_2+Hb} \times 100\% \quad (1)$$

$$SpO_2 = \alpha - \beta \frac{A(\lambda 1)}{A(\lambda 2)} \quad (2)$$

The arteries, veins, and other bio-tissues inside the finger absorb light at a constant rate to produce a DC component, and Make AC components due to movement in the PPG.The AC and DC components of PPG are used to calculate SpO2.Figure 3 shows the process by which the AC and DC components are produced through the absorption of light in bio-tissues.

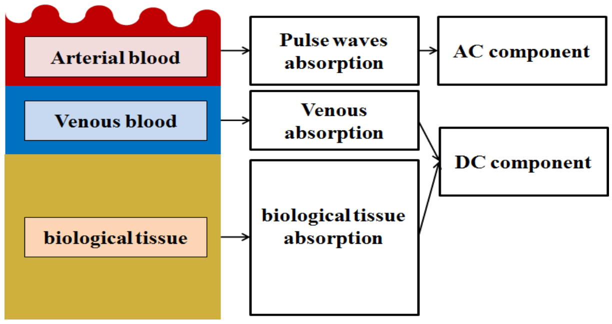


**Fig. 3:** Process of Generating AC and DC Components.

### 2.3. Adaptive filter design for motionartifactremoval

Motion-artifact distorts the baseline and waveform of the PPG signal, making it difficult to make accurate measurements, and causing errors in the measurement results.PPG signal measures the signal period due to the heartbeat, but since the signal from the respiration is also measured, filtering for noise removal is needed.In this research, we implemented a signal processing method using an adaptive filter for efficient removal of motion-artifact.Adaptive filter is implemented using the LMS (least mean square) algorithm of the Wiener filter theory based on the steepest descent method.Configuration of the applied adaptive filter is shown in Figure 4.

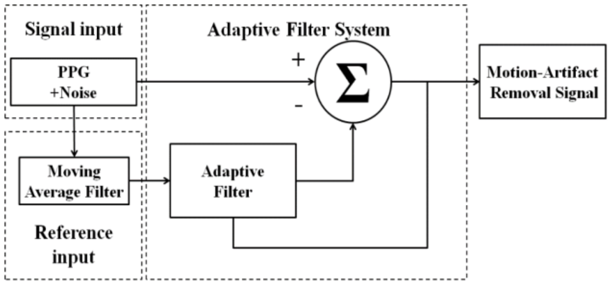


**Fig. 4:** Configuration of the Applied Adaptive Filter.

LMS adaptive filter is a method for repeatedly adjusting a filter coefficient with a least mean square algorithm based on a given filter coefficient to remove noise or to calculation the characteristics of a desired signal.Output of the Adaptive filter is shown in Equation 3-5.

$$E(n) = P(n) + N(n) - eN(n) \quad (3)$$

$$eN(n) = \sum_{k=0}^{L} h_k N_r(n-k) \quad (4)$$

$$h_k(n+1) = h_k(n) + 2\mu E(n) N_R(N-K) \quad (5)$$

In the equation 3-5, $P(n)$ is the original signal, $L$ is the order, $N(n)$is the noise component signal, $N_R(n)$is the reference noise signal,$eN(n)$is the estimated noise signal, $h_k(n)$is the filter coefficient, $\mu$ is the convergence constant. If the noise $N_R(n)$ in the adaptive filter is weak but contains the signal component$P(n)$, the removal of $P(n)$as well as the removal of $N(n)$ may occur. However, when the low-frequency band such as motion-artifact is removed by using a high-pass filter in the process of the PPG signal, it is possible to reduce the distortion of the ST segment.In this research, low frequency band $N_R(n)$ is extracted using moving average filter and used as reference signal.

## 3. Experiments and results

### 3.1. PPG measurement performance evaluation

In this research, the correlation coefficient was calculated using SNR (signal-to-noise ratio) for the performance evaluation of the implemented PPG measuring device.

$$SNR = 10 \times log_{10}\left(\frac{Average\ signal\ power}{Average\ noise\ power}\right)(dB) \quad (6)$$

For the performance evaluation, the PPG signal of the wrist wearing type measurement system implemented using the commercial PPG measuring device ubpulse 360 (Laxtha, Korea) were comparative evaluation. Also, we measured PPG signals according to activity and rest state in 9 college students. Table 1 shows the results of the performance comparison evaluation.As a result of the experiment, it was confirmed that the mean correlation coefficient between the implemented system and the commercial system was 0.934. We confirmed that the measured results are very similar, and we can confirm the usefulness of the implemented system.

**Table 1:** SNR Comparison Result of Implemented PPG Measuring Instrument and Commercial PPG Measuring Instrument

| Subject | SNR<br>Implemented PPG measuring instrument |
|---|---|
| 1 | 0.944 |
| 2 | 0.921 |
| 3 | 0.8991 |
| 4 | 0.951 |
| 5 | 0.966 |
| 6 | 0.9355 |
| 7 | 0.937 |
| 8 | 0.9117 |
| 9 | 0.948 |
| AVG | 0.9348 |

### 3.2. SpO2 measurement performance evaluation

In order to verify the SpO2 algorithm of the PPG measurement system implemented in this research, a comparative experiment of SpO2 detection performance was performed using commercial biometrics device OxSim(Pronk technologies, USA) were comparative evaluation.Experiments were carried out in four steps from 85% 80 bpm to 99% 140 bpm using a SpO2 measurement simulator and the error rates of the two systems were checked.Table 2 shows the results of the error rate comparison evaluation.

**Table 2:** Error Rate Comparison Result of Implemented PPG Measuring Instrument and Commercial PPG Measuring Instrument

| Subject | SpO2<br>Implemented PPG measuring instrument | Commercial PPG measuring instrument |
|---|---|---|
| 85% 80bpm | 85% | 89% |
| 95% 40 bpm | 95% | 95% |
| 98% 80bpm | 97% | 97% |
| 98% 140bpm | 97% | 98% |

### 3.3. Performance evaluation during daily life

To monitor the long-term PPG and SpO2 in daily life, the possibility of health monitoring in daily life was evaluated. For the performance evaluation of the implemented system in daily life, PPG signal for 1 hour was measured in healthy twenties college student..The results of measurement of SpO2 are shown in Figure 5, and the results of PPG measurement are shown in Figure 6.

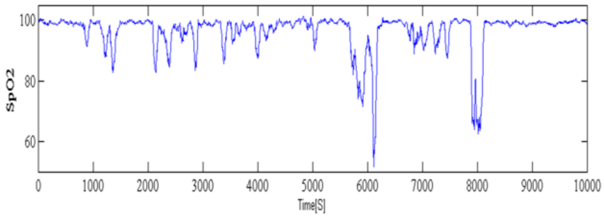


**Fig. 5:** Spo2 Measured During Daily Life.

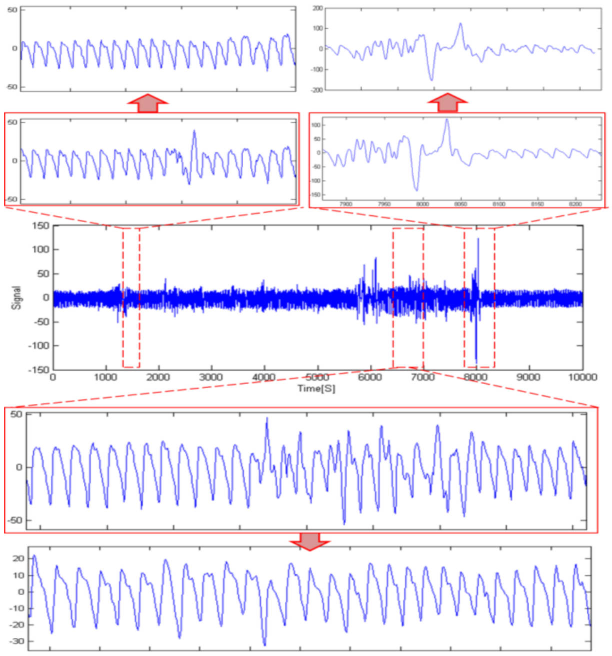


**Fig. 6:** PPG Measured During Daily Life.

## 4. Conclusion

In this research, we implemented a wrist - worn measuring system to monitor PPG and SpO2 in real time in daily life. For the performance evaluation of the implemented system, the correlation coefficient was calculated using SNR(signal-to-noise ratio). As a result of the experiment, it was confirmed that the mean correlation coefficient between the implemented system and the commercial system was 0.934. We confirmed that the measured results are very similar, and we can confirm the usefulness of the implemented system. In non-invasive Spo2 devices, even with slight movement, the noise is larger than the signal and the ratio of absorbance is incorrectly calculated when calculating SPO2. Therefore, it is difficult to obtain a normal waveform. In order to overcome these disadvantages, we implemented the PPG and SPO2 measurement monitoring system which minimizes the distortion of the PPG signal using the adaptive filter. In the future, we will research techniques for measuring PPG and SPO2 more conveniently in daily life and algorithms for improving the accuracy of PPG data.

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