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A Study on LED Lighting Control according to Sleep Stage using PPG Sensor of Wearable Device

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Abstract

Recently, as the sleep disorder problem of modern people deepens, the interest towards quality of sleep is increasing. To increase the quality of modern people's sleep. This paper has suggested an LED lighting control system according to the sleep stage using PPG sensors of wearable devices. The pulse of the wrist radial artery was measured using a wearable device mounted with PPG sensor, which enables heart rate-measuring, and by using the point that heart rate lowers during stable sleep than non-sleeping, the LED lighting of indoors was controlled, which is the disturbing element when sleeping. For the performance evaluation, a 10-Fold cross analysis was conducted for performance evaluation, and a result of an average accuracy 87.02% was obtained as a result. Therefore, the LED lighting control system according to the sleep stage using a wearable device of this paper is expected to contribute to raise the quality of the user's life.

Keywords: LED Lighting Control System, PPG Sensor, Sleep Stage, Wearable Device

1. Introduction

In today's society, to increase the quality of sleep for those adults who are not satisfied with their sleep, it is on trend that the number of patients receiving medical treatment is also on the rise. Like this, people are having interest towards improving the quality of sleep, and the number of people that worries to improve are also increasing. Quality of life can be said as subjective feeling like, the degree of rest, depth of sleep, and satisfaction towards sleep due to sleep. The positive elements brought by good sleep are an essential element to lead people's day by recovering body condition of the body and getting energy[1,2].

In particular, even the hours of sleep are long, if you use the smart phone or sleep with the lights on, you get disturbed by the light[3]. Due to lights that is on bright, the number of awakening gets more frequent, which results the time to sleep again after awakening takes a long time, and eventually the quality of sleep drops. Modern people who had not good sleep will start a day with tired body, and the work efficiency also drops as they work with uninspiring mind.

To improve these negative effects, this paper suggests LED lighting control system using PPG sensors of wearable devices. Wearable device refers to an electronic equipment which can be worn, and as a part of fashion item that modern people can wear while living, it is an equipment which could receive living method or health information of modern people [4]. As a method to increase the quality of life, I would like to suggest LED lighting control system, which has high-efficiency and easy to control, according to defined sleep stage and define the depth of sleep through acquiring biometric information[5].

The composition of this paper is as follows. The chapter 2 explains about the system composition and design, the chapter 3 describes about system's realized results and realized system's performance evaluation, and the chapter 4 describes about the results of the study.

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2. System Configuration and Design

2.1 Heart Rate Measurement

The rhythmic patterns of the heart rate may vary

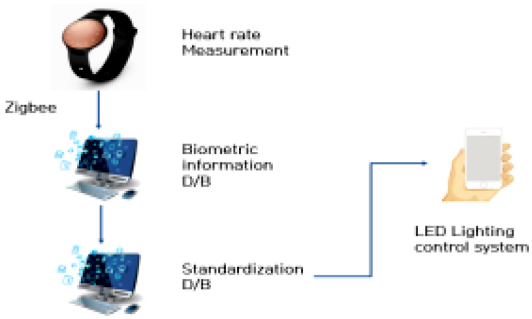

Fig. 1. Composition diagram of the system.

Fig. 2. Location of radial artery measurement on wrist.

slightly from person to person, but commonly, it shows dramatically reduces when they sleep[6]. Therefore, To classify the sleeping stage, this paper has measured the heart rate by mounting the Photo-plethysmography, PPG sensor wearable device inside. Fig. 1 is the composition diagram of the system suggested in this paper.

As a result of studying the existing PPG signal, it was confirmed that there is no difference when the extracted heart rate is compared with the heart rate measured in the actual laryngeal artery and the cervical artery using the PPG signal of the finger[7]. It is also non-invasive and non-binding to measure heart rate in response to the use of PPG signals, so it has the advantage of being able to accurately and quickly respond to various situations during sleep[8]. The radial artery pulse of the wrist was measured through the PPG sensor inside the wearable device.

Fig. 2 shows the radial artery pulse of the wrist, which is the measurement position of the heart rate, The radial artery pulse is an artery that passes through the outside of the forearm and is usually an artery that strikes the vein, which divides from the brachial artery and extends toward the periphery along the outside of the lower arm.

In this paper, I have measured the heart rate signal from the radial artery of the wrist by attaching optical

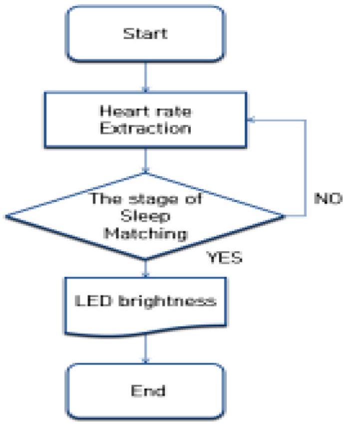

Fig. 3. Flowchart of heart rate measurement and classification algorithms.

sensors and photodiode to wrist band type wearable device to measure heart rate of wrist[9].

The sleep stage was defined as five steps based on the study that the measured heart rate value was lower than that of non-sleep when sleeping[10]. Because the ultimate goal is to control the lighting according to the sleep stage, the heart rate is measured and classified every 30 seconds as shown in Fig. 3 to know the fast and accurate sleep stage. Fig. 3 is a flowchart of heart rate measurement and classification algorithms.

2.2 ZigBee-based Database Communication

In this paper, to make LED lighting control after classifying the sleep stage according to measured heart rate through PPG sensor, it has used ZigBee, a sensor network supporting wireless NFC.

The system suggested in this paper uses the ZigBee for a long time, so it have used standard IEEE 802.15.4 ZigBee. IEEE 802.15.4 ZigBee is an NFC wireless communication technology, which maintains low power consumption, low speed, low cost and enables realization[11].

The heart rate extracted from the PPG sensor installed inside the wearable device by ZigBee communication was transmitted to the biometric database. The biometric database server serves as a converter for temporarily storing extracted data, that is, a heart rate, and a heart rate data stored in a biometric database, into standard data. It also provides protocol and packet processing capabilities to work with a standardized database server.

In the standardized database, the measured heart rate is divided into the stages of the five levels of sleep stages, and it corresponds to the set brightness level of each sleep stage.

2.3 LED Lighting Control System

The hormone that induces sleepiness is melatonin, and a bright light above 30 Lux will inhibit the secretion of melatonin, and if you are sleeping, you may lose the secretion of melatonin if it is illuminated. In general, the brightness of light in the room is about 300-500Lux which is enough brightness to interfere with the sleep. Also, light exposure during sleep lowers working memory ability. Work memory ability is very important because it is closely related to concentration and cognitive ability, emotion control, and appetite control as part of short-term memory. The human visual system reacts to the stimulation of light and tries to wake up from the sleep when the brightness of the bedroom becomes brighter[12].

Therefore, this paper has controlled the LED lighting brightness by measuring biometric data range through PPG sensor according to 5 stages of sleep.

Table 1 have responded the biometric data measured through PPG sensor with appropriate lighting brightness.

For LED lighting control, after responding to the appropriate stages of sleep, I have detected LED lighting brightness for each stage of sleep for the heart rate stored in the biometric database through standardized database.

The system suggested in this paper transmits the value transferred from biometric database, which stores the heart rate like Fig. 4, to embedded integrated control board.

Transferred data value is transmitted to output equipment, and the LED lighting operation condition was checked. In non-sleeping condition, the LED lighting

Table 1. Biometric data rang measured by PPG sensor

Heart Rate (bpm)	Sleep Stage	Brightness of Lighting (Lux)
80 - 100	1	Lighting ON (300 Lux Standard)
70 - 80	2	200 Lux
60 - 70	3	100 Lux
50 - 60	4	30 Lux
0 - 50	5	Lighting OFF

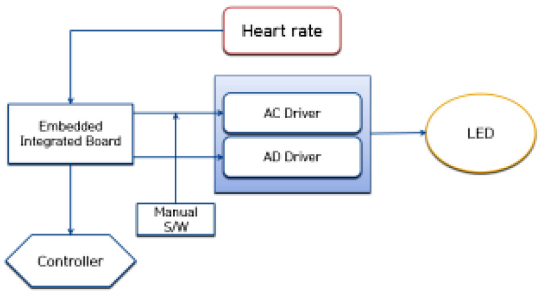

Fig. 4. The configuration diagram of the LED lighting control system.

was set as 300Lux, which is the normal indoor brightness, and in the light sleeping condition, as the heart rate lowered, I have lowered the LED lighting brightness from 300Lux to 30Lux, and induced the sleep of the user to be stable and deep sleep. In stage 5, which is the last stage, the lighting brightness were controlled by turning off the light as it is a deep sleeping condition.

Fig. 4 is the configuration diagram of the LED lighting control system proposed in this paper.

3. System Implementation and Performance Evaluation

To realize user friendly interface of the system suggested in this paper, I have realized the lighting conditions according to heart rate during sleep, and showed as an application.

The heart rate has displayed measured heart rate by 1 hour period, and sleep stage and lighting brightness

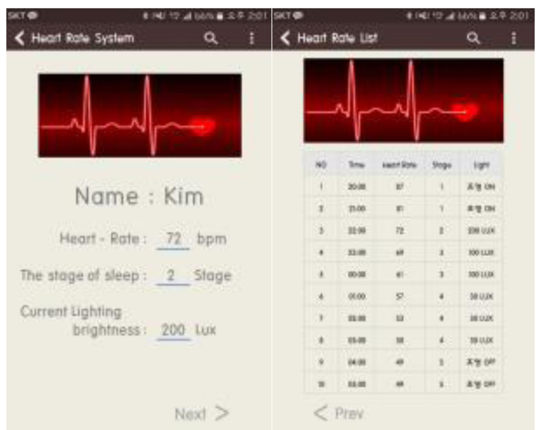

Fig. 5. Implementation of the system (Application).

Table 2. Results of 10-fold cross validation

Fold No	Accuracy(%)
1	83.5
2	87.2
3	85.9
4	88.7
5	90.1
6	84.5
7	83.7
8	86.5
9	90.8
10	89.3

according to heart rate was displayed. Fig. 5 is the realization result of LED lighting control system according to the stage of sleep using the PPG sensor of wearable device.

In addition, to secure the reliability of the system that this paper have suggested, a 10-Fold cross verification was conducted. As a test data, the biometric data was measured using the PPG sensor of wearable device suggested in this paper based on 4 healthy adults in mid 20s. According to the measured biometric data, the stage of sleep was classified, and LED lighting control was performed which responds to the classified stage of sleep. As a result of performance evaluation, an accuracy of 87.02% average were shown. Table 2 is the result of 10-Fold cross verification.

As a test results of controlling the LED light's brightness based on the heart rate measured through wrist band-type wearable device, it was checked that the heart rate stabilizes in the sleep stage as there is no disturbance by the lighting light, and that it was possible to reach deep sleep from light sleep naturally. Therefore, it is expected that high quality sleep condition will be brought according to the control of LED lighting brightness according to the sleep stage through the system suggested in this paper.

4. Conclusions

The purpose in the paper is to enable high quality of sleep to block the disturbance element of sleep.

This paper suggests a LED lighting control system according to the sleep stage using the PPG sensor of wearable device. The wrist pulse, which is easy to measure the heart rate, was measured by mounting the PPG sensor to wearable device, and based on the study results that the heart rate is low during sleep than the non-sleeping by the number of heart rate value measured. Through each sleep stage, the LED lighting was controlled as stage 1 lighting ON, from stage 2 to stage 4, the brightness of 300Lux to 30Lux was gradually lowered, and in stage 5 the lighting OFF.

The system of this paper have realized for the LED lighting conditions according to the change, the change of sleep stage according to the hear rate, and the heart rate of the user measured through wearable device to be checked by application.

10-Fold cross verification was performed for the performance evaluation of the system, and it brought high accuracy of 87.02% average as a result of performance. It is expected that LED lighting control through wearable device will bring a stable and high-quality sleep without disturbance of user's sleep as the light is not exposed during sleep.

Acknowledgments

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