Development of sleep monitoring system for observing the effect of the room ambient toward the quality of sleep

W. H. M. Saad*, C. W. Khoo, S. I. Ab Rahman, M. M. Ibrahim, N. H. M. Saad
Faculty of Electronic and Computer Engineering (FKEKK), Universiti Teknikal Malaysia Melaka, 76100 Melaka, Malaysia

E-mail: *wira_yugi@utem.edu.my

Abstract. Getting enough sleep at the right times can help in improving quality of life and protect mental and physical health. This study proposes a portable sleep monitoring device to determine the relationship between the room ambient and quality of sleep. Body condition parameter such as heart rate, body temperature and body movement was used to determine quality of sleep and Audio/video-based monitoring system. The functionality test on all sensors is carried out to make sure that all sensors is working properly. The functionality of the overall system is designed for a better experience with a very minimal intervention to the user. The simple test on the body condition (body temperature and heart rate) while asleep with several different ambient parameters (humidity, brightness and temperature) are varied and the result shows that someone has a better sleep in a dark and colder ambient. This can prove by lower body temperature and lower heart rate.

1. Introduction
Based on the general definition, sleep is a type of “brain activity” and the purpose of this activity is to recover from brain fatigue [1]. Good sleep quality can contribute in many positive outcomes including in having better health in general, reducing daytime sleepiness and a better psychological health [2]. According to [3], there are three major factors that cause the sleep abnormalities which are psychological, physiological, and environmental. Psychological factors of sleeping disorder are usually short-term and it is involving in mental issue such as stress that being the number one cause. Physiological factor is involving in changes of physiological system that affect the quality of sleep. This factor can occur because of discrepancies in the nervous system, brain activity, immune system, metabolic functions and cardiovascular system. Lastly, environmental factors involving in environmental parameter such as temperature, light, humidity and other ambient factors including the comfortability of the room, the quietness or perhaps sound that make one feel calm to asleep.

When someone is asleep, heart rate and respiration rate will be varied. The paper [4] stated that the change in heart rate and respiration rate can be determined by Electrocardiogram (ECG)-derived respiration (EDR) during apnoea. By using real respiratory signal, accuracy up to 85% of sleep apnoea can be detected. Other than that, movement of the chest can be used to detect the breathing phase. This movement shows the changes of ontogenetic [5]. The duration of without interrupt periods of sleep can be used to investigate the sleep continuity. In order to measure the movement of body during sleep stage, movement time (MT) and movement events (ME) are two important parameters to be measured. Brain is
always in a very active phase but it will keep on reducing in term of regulatory response when someone is in REM sleep stage. Low ambient temperature can cause REM sleep to decrease while more heat may cause slow-wave sleep (SWS) to decrease. Regulation of temperature and sweating response will be decreased during sleep stage if only if the body’s thermoregulatory responses are dependent [6].

Typical healthy person will experience up to five complete sleep cycle per night. It comprises of one stage for Rapid Eye Movement (REM) and four stages of Non–Rapid Eye Movement (NREM) sleep stages from NREM1 to NREM4 [7][8]. NREM3 and NREM4 are called as deep sleep. Each phase of NREM sleep can be last from 5 to 15 minutes. NREM1 is the beginning of sleep which named as transition stage [9]. When someone is in this stage, his or her eyes will move slowly, the muscle activity will be slowing down and people can be awakened easily. During stage two, the eyes movement will stop and the physical parameter like heart rate and body temperature will be decreased. During stage 3 and 4, he or she will be more difficult to be awaken. Dream sleep is the state of REM where people fall asleep and dream is taking part. In this stage, brain and body need a lot of energy and it will supply by high heart rate and body temperature [10]. The most common measurement to differentiate each of NREM sleep stages is by using electroencephalogram (EEG) reading, while the most commonly use in differentiating REM sleep from other sleep stages are electromyogram (EMG) and electrooculogram (EOG). Muscle tone is normally measured by using electromyography (EMG) method. Electrical signals are transferred by the electrodes and cause muscles to contract [11]. Needle electrodes are placed into the muscle to record electrical activity and the signal will be translated into graphs or numerical values for a specialist to interpret. EEG is a very powerful tool in the neurological field as it can capture normal electrical activity of brain as well as abnormal activity. It is measured directly from the electrocardiogram which is the cortical surface of the brain. Although these measurement is powerful but there also have a major limitation which is only can be performed by trained professionals and only in clinical environment. They also limit the monitoring to one or two night.

Nowadays, there are many existing procedures and methods to measure the quality of sleep that use several different types of sensor and from the measurement, it can be relate to the sleep stages. Polysomnography (PSG) for an example is used to measure the physiological variables including brain electrical activity, muscle movement respiratory effort and oxygen saturation [12]. Through this technique, researchers can identify sleep-onset and wake-up time [13]. A device must be worn on the wrist of user during sleep to measure their activity. The device must be placed on the user’s wrist because it is believed that there is a strong connection between wrist movement and sleep status of the user [14]. The other method that is available is the use of video and audio recording together with Passive Infra-Red (PIR) sensor to detect the user sleep status [15]. The paper in [16] presented a research on ambient sleep monitoring which using sensors that are installed inside living apartments. The type of sensors that had been used in this study include passive infrared (PIR) sensors as motion detection, contact sensors that had been attached to the windows and doors, temperature sensors to detect room temperature and sensors that can detect heat application usage and electricity.

Mobile device is now a very useful and synonym to our daily life. It can do a lot of work including attached with sleep monitoring system. A system which named as ubiquitous architecture is a system with heart rate, accelerometer and sound signals. The idea is joining the sleep monitoring system with smart watch and smartphone. Framework with API need to be developed in order to able the data exchange between the smart watch and smart device. Other than that, this system also includes the novel algorithms for signal treatment. Ubiquitous architecture can be considered to be very suitable and feasible for sleep monitoring system.

In this study, we would prefer to use PC instead of smartphone because while we are in sleep, we did not require too much of mobility ergo PC with higher processing capability is more suitable than smartphone that allowing user to do a lot of processing and video recording. The developed sleep monitoring system is a combination of sensors and BLUNO microcontroller board to monitor and record the ambient parameters and body condition while user is sleeping. Our goals is to develop a sleep monitoring system that can be used at home and can do the monitoring in more than one night. Other
than that, this monitoring system can help to determine the relationship of room ambient and quality of sleep.

2. Methodology
The monitoring system is developed by using two different type of BLUNO microcontroller board, light dependent resistor (LDR) and DHT22 as an ambience sensor and pulse sensor, thermistor and accelerometer as a body condition sensor. The audio video recording is also a part of this project to monitor the behavior of user during sleep. The obtained value of light intensity, temperature, surrounding humidity, heartrate, body temperature and the movement of the user will be displayed on the Windows Apps interface.

The value obtained which is light intensity, temperature, humidity of the room surrounding, heart rate, body temperature and the movements of the user will be displayed on the Window surface apps.

2.1. System Overview
The whole developed system consists of two separate systems which are ambient monitoring system and portable body monitoring system. Figure 1 shows an illustration on how the system work.

Ambient monitoring system included LDR and DHT22 while portable body monitoring system included heart pulse, thermistor and accelerometer. The ambient sensor and body condition sensor are connected to BLUNO and BLUNO NANO respectively to capture the input data. In this system, the room temperature, light intensity and humidity is the input for ambient sensor hence to measure heartrate, the pulse sensor is simply clipped anywhere near to the blood vessel. To measure body temperature, the thermistor need to be clipped on any of fingertip for a few second to get a consistent reading.

This sleep monitoring system involves Arduino IDE software and Visual Studio 2015. After done with designing interface in Visual Studio software, the values obtained are displayed in the Window apps interface. Arduino IDE is programmed that consist of sensor algorithms to enable those sensors and to read the value that has been captured from room ambience and body condition. A Window
Application was programed by Visual Studio to display the value of those parameters as can be seen in Figure 2. The sensor value is transferred between hardware part and software part via Bluetooth communication. The video recording using a webcam is also included in this project.

![Figure 2](image.png)

**Figure 2.** Window apps display in *MainPage.xaml* file.

### 2.2. Room Ambient Monitoring System

DHT22 sensor is a combination of a thermistor and capacitive humidity sensor to read the analogue value of temperature and humidity of the surrounding. It is also comprised with basic chip that convert the analogue signal to digital signal of both temperatures in degree Celsius and humidity in percentage of relative humidity (%RH) [17]. To measure the intensity of light in the surrounding, Light Dependent Resistor (LDR) is used which act as light sensors. BLUNO is an Arduino UNO module that is integrated with Bluetooth BT 4.0 (BLE). Connection between sensors and BLUNO is shown as in Figure 3.

![Figure 3](image.png)

**Figure 3.** Hardware connection for Ambience monitoring device
2.3. Portable Body Monitoring System
Pulse Sensor is used to measure heart rate of user while thermistor is used to measure body temperature. To monitor the movement of user in x, y and z axis during sleep, accelerometer is used as well. BLUNO NANO is the Arduino NANO module that is integrated with Bluetooth BT 4.0 (BLE). The data is transferred via wireless communication that makes the system is comfortable to be used. Connection between these components is shown in Figure 4.

![Figure 4. Hardware connection Portable Body monitoring device.](image)

2.4. Functionality test of ambient monitoring system
The experiments on testing the functionality of ambient sensors is carried out to ensure each sensor working properly. The experiment that has been done to measure room temperature, light intensity and room humidity. The reading of light intensity was measured using LDR sensor. Ten readings were taken for each of five set of conditions which are very dark, dark, dim, bright and very bright. The value of light intensity is obtained based on the digital value with a range between 0 and 1023. For the condition 1, the value of light intensity is recorded between the ranges of 1 to 9 which indicate very dark surrounding such as during the night and the lamp inside the house is turned off. For condition 2, the value is between the ranges of 10 to 20 which indicate dark surrounding conditions such as in the early morning and the lights is turned off. For the condition 3, which refer to dim surrounding such as in the morning or late in the evening, the value of light intensity is recorded between the ranges of 21 to 45. Next, the condition 4 recorded the value of light intensity between the ranges of 70 to 487 which indicate bright surrounding in the afternoon in the house. Lastly, the condition 5 is recording the light intensity between the ranges of 501 to 1021 which indicate very bright surrounding such as in the afternoon outside the house. The reading is shown in Figure 5.
The reading of room humidity was measured using DHT 22 sensor. There are 10 reading taken in few conditions which are dry, medium or moist condition. Based on the data measured, the humidity reading for dry condition is ranging between 1 to 2% RH that indicates a dry condition during sunny day such as in the afternoon and in the evening. For the moderate condition, the measured reading is between 3 to 8% RH. The reading indicates medium humidity in several surrounding conditions, such as during raining. The reading of humidity is ranging between 13 and 32% RH which is referred to moist condition when there is raining for quite a long time and right after the raining when the temperature is low. The reading of all condition is shown in Figure 6.

**Figure 5.** The value of light intensity in 10 readings
Figure 6. The value of humidity in 10 readings.

Figure 7 shows the reading room temperature in few different conditions. The reading of temperature is compared between sensor reading and thermometer reading. According to Figure 7, the reading obtained from a thermometer and a sensor is almost the same for every measured reading. This proved that sensor that used in this monitoring system can detect the room temperature with high accuracy. The temperature is divided into five different conditions which are very cold, cold, moderate, hot and very hot. Very cold conditions such as inside the room with air conditioner or during heavy rain in the midnight. The measured reading is recorded between 18 and 22 degree Celsius. Cold condition have a range of temperature between 23 and 27 degree Celsius. The reading is taken in the bedroom with a speed of fan 3 during the day or night. The temperature for very hot condition is between 37 and 40 degree Celsius. The reading can be obtained outside the house in the afternoon or in the evening.
Figure 7. Compare the value of room temperature in 5 readings using thermometer and sensor.

3. Result and Discussion
There are three sets of experiments that have been carried out to monitor the body condition of user based on different ambient. The author in [18] state that a normal heart rate is ranged from 50-100 as most people’s hearts beat is between 60 to 80 bpm. At resting time such as when sleeping, the heart rate reading become slows and tends to be lower if the person are very fit. Usually, heart rate reading during sleep will be slower. It faster when doing daily activities or when exercising and the heart rate will be recover quickly back to a resting rate a few minutes after exercise. The normal body temperature is usually 37°C, and can be slightly decreased during sleep [19]. According to [20], temperature sensor able to measure body temperature with high accuracy but it need about 35 second to read a stable reading.

Experiments with different ambient condition are carried out and the value is compared. Heart rate also recorded by using manual method (count the heart beat) and using sensor. Reading of heart rate is also compared. The ambient condition for the experiment set is summarized as in Table 1.

Table 1. Ambient condition of experiment set.

| Experiment | Light Intensity | Room Temperature (Celsius) | Humidity (%) |
|------------|-----------------|-----------------------------|--------------|
| Set 1      | Very Dark       | 32                          | 1            |
| Set 2      | Bright          | 32                          | 1            |
| Set 3      | Dark            | 35                          | 1            |
The values of body temperature on different ambient condition are measured by using sensor and thermometer. Both values taken have been compared. It shows that the reading was almost the same with not much different. The results are summarized as in Figure 8 and Figure 9.

**Figure 8.** Effect of body temperature on different ambient condition (using sensor)

**Figure 9.** Effect of body temperature on different ambient condition (using thermometer)
According Figure 8 and 9, when the experiment is carried out in set 1, the sensor show average body temperature is 36˚C while the thermometer shows 35.4˚C. For set 2, the sensor show average body temperature is 35.6˚C while the thermometer shows 35.5˚C. Lastly, the sensor show average body temperature is 37˚C while the thermometer shows 36.4˚C for set 3.

3.1. Heart Rate
Heart rate also recorded by using manual method (count the heart beat) and using sensor. Both values taken have been compared. It shows that the reading was slight different. The results are summarized as in Figure 11 and Figure 12.

![Figure 10. Effect of heart rate on different ambient condition (using manual method)](image)

![Figure 11. Effect of heart rate on different ambient condition (using sensor)](image)
According Figure 10 and 11, when the experiment is carried out in set 1, the manual method shows average heart rate is 74 bpm while the sensor shows 73 bpm. For set 2, the manual method shows average heart rate is 80 bpm while the sensor shows 79 bpm. Lastly, the manual method shows average heart rate is 79 bpm while the sensor shows 80 bpm for set 3.

4. Conclusion
At the end of this project, a portable sleep monitoring system for ambience and body condition have been developed. At the same time, camera and microphone application inside the laptop is used to record the person's behavior while sleeping. The ambience and body condition monitoring is successfully displayed on the Window App. Functionality of all the sensors used is proven using functionality test. The simple experiment is carried out to monitor the body condition on several differences ambiances.

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