COMP5047 Pervasive Computing

Final Report

Project Name: SleepAnalyser

Group Name: NoviceTech

Group Members:

Michael Kam / 480103233

Nhan Tran / 480421861

Jung-Chang Liou / 490340293

Jie Lin / 490110892

Table of Contents

1. Abstract

Having good sleep quality has been proven to play an important role in good mental and physical health. In addition to sticking to a great sleep schedule, the environment also has a great impact on how good a person's sleep can be. In this project, we developed SleepAnalyser, a non-intrusive device which gathers sleep environment data including temperature, humidity, noise, brightness and air quality. A self-assessed sleep score is also implemented to analyse the correlation between users' quality of sleep and the collected environmental data. This information will then offer users recommendations on how to change their sleep environment to improve overall sleep quality. We also aim to avoid complicated hardware setup and intrusive wearable devices that can cause uncomfortable sleeping experience, which is the strong point of SleepAnalyser. However, this approach also leads to a few limitations, notably the cost and accuracy factors.

2. Introduction & Background

Sleep is vital to human well-being. Having enough good quality sleep can greatly boost one's physical and mental health. According to the National Heart, Lung and Blood Institute, sleep helps improve memory, attention span, creativity and decision making. At the same time, sleep also helps repair and heal heart and blood vessels, reducing the risk of heart disease, high blood pressure, stroke, etc. On the other hand, if a person does not get enough sleep, they are highly susceptible to sleep deprivation, which can lead to all the aforementioned chronic health problems. It can also cause problems related to brain such as memory loss, short attention span, negative emotions, etc.

To achieve good quality sleep, one can plan a good sleep schedule that allows adequate sleeping time and avoid staying up late. However, the sleeping environment also contributed to how well a person can sleep (Caddick et al., 2018). These environmental elements include temperature, humidity, light, air quality and noise. Whether the room temperature being too hot or too cold can negatively affect overall sleep quality (Joshi et al., 2016). At the same time, a rise in humidity levels can make people feel hotter whereas a drop in humidity levels can make people feel colder, which causes disturbance to their sleep experience (Caddick et al., 2018). In the case of air quality, air pollution that contains polluted air particles is usually the cause of sleep disruption and insomnia (Zanobetti et al., 2010). According to Mason et al. (2018), exposure to light during sleep can have a negative impact on insulin resistance, thus affecting one's metabolic function. In regards to noise, exposure to noise pollution can easily cause sleep disruption (Caddick et al., 2018). These unwanted sounds can result in awakening and shorten sleep length (Chiang, 2012). It can also have a negative impact on the mental health of those that do not sleep well (Sygna et al., 2014). Therefore, it is very important for a person to set up an optimal sleep environment, along with a good sleep schedule, to ensure that they always have an excellent sleep quality.

Currently, there has been a lot of products in the marketplace designed to assist people in finding their sleep quality, along with guidance on how to improve it. The Withings Sleep Tracking Mat by Withings offers users a tracking mat which they can put under the mattress. The mat will then track users' heart rate, determine their sleep cycles and subsequently produce the result of their sleep quality. However, the product needs extra gadget such as the Withings Aura to track sleep environment, which only tracks temperature, light and noise while ignoring humidity and air quality. This increases the expense and creates an unnecessary setup. Optionally, people can go for the Oura Ring, which offers the function to track accurate sleep quality and provide bedtime guidance without complicated hardware setup. Unfortunately, because the Oura Ring is in the form of a wearable device, it can easily cause uncomfortable sleeping experience for the users.

With SleepAnalyser, we try to provide users with a non-intrusive way to improve their quality of sleep. By collecting all the possible environmental data that can disrupt one's sleep (temperature, humidity, brightness, air quality and noise) and displaying these data in the form of graphs, users can view the environmental changes, if there are any, which they may not notice during their sleep time. Along with the self-assessment questionnaires to determine the sleep quality, recommendations are handed to users who will then have the opportunity to alter their environment for better sleep. No wearable device is required which means that users can freely change their posture during sleep without worrying that they might damage the device.

Recommendations on each environmental element are based largely on an optimal value obtained from multiple research and instructions. Joshi et al. (2016) suggested that the preferred room temperature for bedtime was 19 C, while Rohles & Munson (1981) suggested that the optimal value obtained from their research was 21 C. On the other hand, Caddick et al. (2018) suggested a range from 17 C to 28 C to be the optimal room temperature for sleeping experience. Combining both studies, we reduce to range to 17 C - 21 C to be the optimal value used in our product. This is assumed that users are well clothed and are using blankets during bedtime. For humidity, we set the optimal range from 40% to 60%, as suggested by Caddick et al. (2018). In the case of air quality, the instruction that comes with the Air Quality Sensor v1.3 that we used suggests that if the sensor data collected is larger than 300, then the air is slightly polluted. If this value rockets to 700, then the air is highly polluted. For brightness, Caddick et al. (2018) accounts for exposure of light before, during and after sleep, as well as how the timing of light exposure in these three stages affect sleep quality. However, in this project, we only focus on light exposure during sleep. As Mason et al. (2018) stated that exposure to light during bedtime can increase insulin resistance, we aim to recommend users to sleep under darkness and avoid turning the light on during bedtime. For noise pollution, we account for noises that happen outside and inside the bedroom by making the sensor detect vibration caused by the soundwaves in the air while tweaking its sensitivity to ignore noises produced by the SleepAnalyser itself (Raspberry Pi noise, other sensors' noises).

Finally, the SleepAnalyser also records users' body movements during sleep using a motion sensor. Lots of body movements during bedtime means that users might be susceptible to a periodic limb movement disorder, which cause long REM sleep latency (Shrivastava et al., 2014). We aim to warn users if SleepAnalyser records too many motions during sleep.

3. System Overview

In order to determine the correlation between one's sleep quality and sleep environment, NoviceTech has developed SleepAnalyser which measures important environment attributes such as temperature, air quality, noise, etc. and analyses these data against the user's sleep quality to provide recommendations for better sleep. SleepAnalyser uses a simple setup and runs non-intrusively in the background. Figure 3.1 illustrates the overview of the system. A video demonstration of the system can be found here.

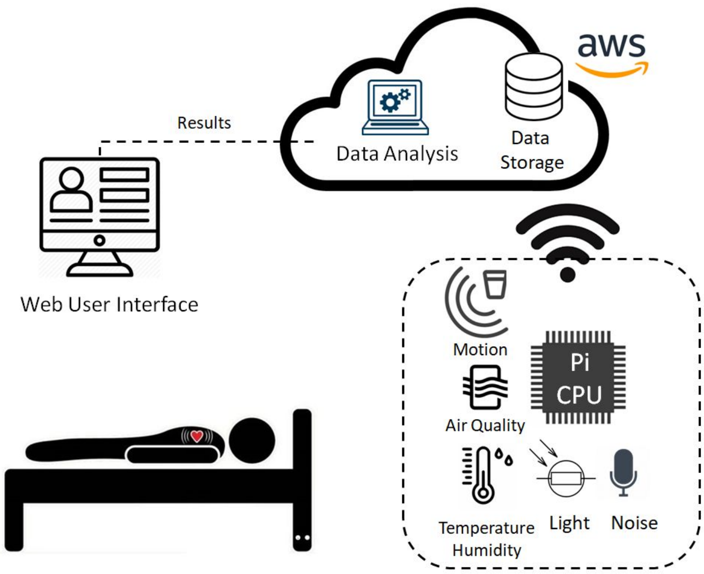

Figure 3.1 – the overview of the system

SleepAnalyser consists of two main components: a hardware sensor suite, a cloud data processing and storage system. All the sensors are embedded in the SleepAnalyser device which can be powered up by a single micro-USB cable. The device uses less than 5W and therefore a power adapter with 5V and 1A rating will provide ample power. To setup the device, the user only needs to connect the device to a Wi-Fi network via Raspberry Pi's desktop UI. This can be done by connecting SleepAnalyser to a monitor via an HDMI cable and by connecting a mouse and a keyboard via the USB ports. A desktop environment will show up on the screen and the user can connect to the Wi-Fi by clicking on the top right Wi-Fi icon as shown in Figure 3.2. This setup is only required to be done once and once it is completed, all the cables except the power supply can be removed from the device.

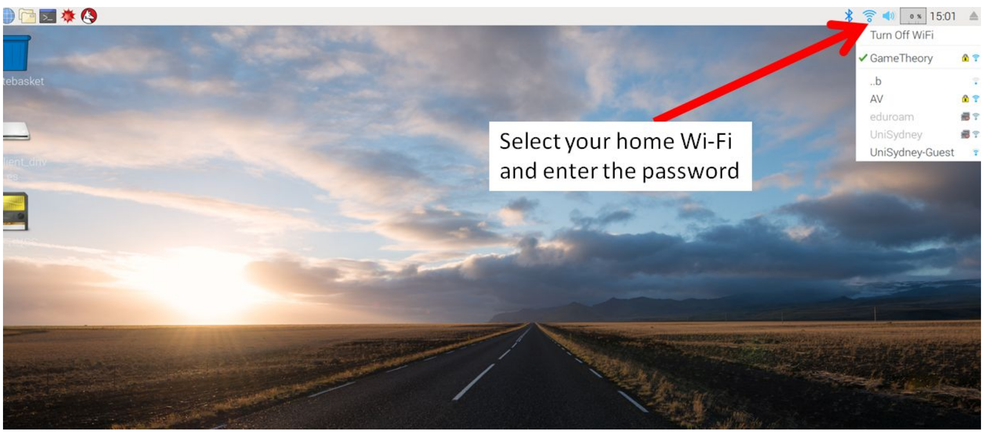

Figure 3.2 – SleepAnalyser initial Wi-Fi network connection setup

To use the device, the user only needs to press the 'start' button for 3 seconds and the yellow LED will light up indicating the synchronised air quality, temperature, humidity, light, noise and motion data are being recorded and uploaded to NoviceTech Database on Cloud. The motion sensor can detect movements of an object up to 7 metres away and is required to be pointed to the user's body to measure body movements during sleep. (See Figure 3.3)

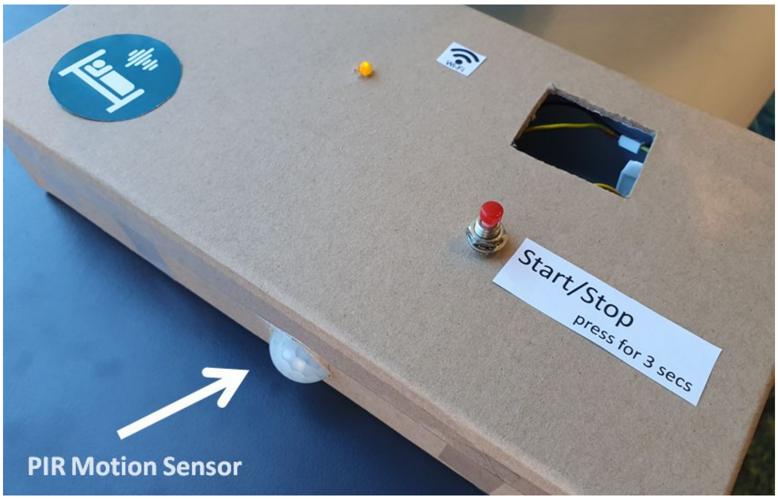

Figure 3.3 – SleepAnalyser prototype

On the next morning, the recording can be stopped by pressing the same button for 3 seconds and LED light will turn off. The user can then visualise all of the sleep environment data using a normal browser and complete an optional sleep quality assessment questionnaire for the system to further analyse the correlation between the environment data and his/her sleep quality. Figure 3.4 shows the web interface of some of the displayed environment data. The recommendations based on historical sleep quality and environmental data can also be accessed through this web UI.

Figure 3.4 – SleepAnalyser Web Interface

4. Implementation

The detailed implementation of the SleepAnalyser is illustrated in Figure 4.1. As mentioned in Chapter 3, SleepAnalyser is comprised of two main parts: an environment sensor suite and a cloud data processing and storage system. The environment sensor suite collects sensor data and sends it to NoviceTech Database while the main Node-Red program retrieves these data, analyses them and displays to the user. The Node-Red program also receives user sleep quality rating information and stores it in the database.

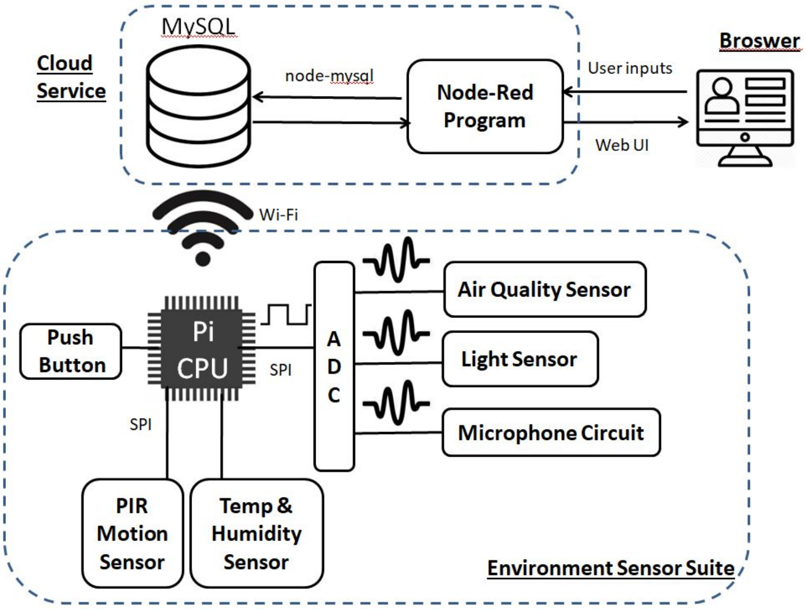

Figure 4.1 Detailed implementation of SleepAnalyser

4.1. Environment Sensor Suite

Raspberry Pi 3B is used as the central processing unit to manage and synchronise all the sensor data. Raspberry Pi with built-in Wi-Fi module and desktop interface provide users an easy way to set up the device and its processing power allows additional functionalities such as voice interaction with Alexa to be implemented if needed.

AM4011, TEMT6000, DHT22, Grove Air Quality Sensor v1.3 are used to collect noise, brightness, temperature & humidity and air quality respectively. Since AM4011, TEMT6000 and Grove Air Quality Sensor all produce an analogue signal, an Analogue-to-Digital Converter (ADC) MCP3008 is used for Pi's digital inputs as shown in figure 4.1. In addition, the sensor suite includes a generic passive infrared sensor (PIR) to detect the user's movement during sleep. All the sensor data are sent to Pi via SPI protocols.

To provide a better user interface with minimal setup, we created a crontab job to run the Python script which listens to the start/stop button input and initiates recording process if the button is pressed for three seconds. All of the devices are embedded inside a box and hidden from the user for better user experience (see. Figure 3.3)

Figure 4.2 demonstrates the system logic of the sensor control program in Pi. Regarding the system logic of the sensor control program in Pi, on startup, Pi continuously listens to the start/stop button signal. When it is pressed for 3 seconds, Pi initialises the setup of the pins and begins to read data from all sensors synchronously. Then it attempts to write to a local file as well as push onto NoviceTech Database. This process is repeated every second. When the button is pressed for another 3 seconds, the data acquisition program will terminate and Pi waits for the button signal again. The logic flow diagram is provided in Appendix D (Figure D1).

4.2. Cloud Service

The SleepAnalyser cloud service consists of Amazon RDS for MySQL database and Amazon EC2 instance for Node-Red.

4.2.1. Database

MySQL database is used to store environmental data sent from the Pi (in SleepData table) and sleep score submitted by the user through the web UI (in SleepScore table). For SleepData table, temperature, humidity, light level, noise level, motion and air quality data are stored in SleepDataTemp, SleepDataHumid, SleepDataBright, SleepDataNoise, SleepDataMotion and SleepDataAir column, respectively. SleepDataEpoch column (for storing timestamp) is used to indicate the sleeping time on the X-axis in each corresponding graph. For SleepScore table, DateEpoch and DateString column are used to store the timestamp when users submit their sleep score, which is then stored in the SleepScore column. These data can then be retrieved again for the graph in the sleep score history section of the UI.

4.2.2. Node-Red

We use Node-Red as the main logic layer for SleepAnalyser. This layer handles the process of retrieving sensor data and sleep score records from the database and displaying them in forms of graphs in the web UI, as well as receiving user inputs through the web UI and storing them back to the database. This layer also handles the logic behind recommendations and display them in the UI dashboard. Two extra libraries are required for all these operations: node-red-node-mysql for interaction with MySQL database and node-red-dashboard for designing the UI dashboard. During the production phase, the Node-Red development dashboard that contains flows of logic will be hidden from the users. The detailed dashboard is provided in Appendix C (Figure C1).

5. Evaluation

We have performed usability testing on our web application interface using think-aloud. In doing the think-aloud study, users are given certain tasks and say what they think during their attempts to complete them with the interface (Nielsen, 2012). For the purpose of this project, we have written six concrete or benchmark tasks as outlined by Hartson & Pyla (2012). The table below has the abstract and related concrete tasks for this study.

Task ID	Abstract Task	Concrete Task
1	Self-assess sleep quality score	Let’s say you just had a great rest and you think you would rate it 8 out of 10, show us how you would do that in the system
2	Find insights and recommendations to improve the sleeping condition	Suppose you had some issues with your sleep last night and you want to know what the cause was and how to improve your sleep quality, show us how you would find this information
3	View the environmental factors data	Let’s say that you have turned the device on last night. Find a graph that shows how cold or warm your bedroom was from 12 to 1 am. Point your finger at it.
4	View the environmental factors data	Let’s say that you have turned the device on last night. Find out how to see the changes in the light level of your bedroom from 4 to 5 am. Point your finger at it.
5	View past sleep quality scores	Suppose you just used the system for about 7 days and you want to find out whether your sleep has improved. Show me how you do that.
6	View past sleep quality scores	Suppose you have used the system for 30 days and you want to find out whether your sleep has improved. Show me how you do that.

Table 1 - Abstract and Concrete Tasks

As recommended by Nielsen (2000), we have decided to select five users to do usability testing. The diversity in the testers is important as they would represent the user groups that might use our system. The demographic information of our users is listed in the table below. In terms of gender, we are fairly representative. Although the age group is quite diverse, it is leaning towards younger people, as we do not have any from 36 to 50 years old. However, we also have people with different sleep quality awareness and level of familiarity with technology.

Detail	P1	P2	P3	P4	P5
Age Group	26 - 35	> 50	26 - 35	26 - 35	18 - 25
Gender	Female	Female	Male	Male	Female
Aware of Sleep Issues	Yes	No	No	No	No
Enough Sleep Generally	Neutral	Agree	Agree	Somewhat disagree	Somewhat agree
Consider tech-savvy	Neutral	Somewhat disagree	Somewhat agree	Somewhat agree	Somewhat agree

Table 2 - Demography of the Users

The performance summary of the interface with respect to the concrete tasks by the users are shown in Table 3. We can observe that two users were not able to complete Task 2 which leads to interface failure. Meanwhile, to complete Task 1, two users need help to finish it.

Task ID	P1	P2	P3	P4	P5
1	✓	!	!	✓	✓
2	✘	✓	✓	✘	!
3	✓	✓	!	✓	✓
4	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	✓
6	✓	!	✓	✓	✓

Table 3 - Performance Summary of Think-Aloud Users

✓ - Success **! - With Help** **✘ - Interface Failure**

We have also gathered qualitative feedback from the users and summarise the comments and issues as follows:

- The recommendation should be categorised or visually made appealing so people can tell which ones are the issues and which ones are not. Wordings should be more instructional.
- Some users comment on the flexibility and recommend to allow zoom in and zoom out of the graphs so they can see the overview and the detailed numbers.
- The abbreviated button labels of 1W, 1M, and 3M (representing 1 Week, 1 Month, and 3 Months respectively) were not easily and quickly grasped by some users.
- Some users comment on the cosmetic details such as theme colour, margin, alignment, etc.

- The charts showing the environmental factors do not have axis labels so this confuses users on the unit of the measurement.
- Some users commented that the usefulness of the system that can help them track their sleep environment and how it affects their sleep quality.

As the quantitative approach of evaluating the interface, we have utilised two questionnaires: Single Ease Question (SEQ) at the end of each task a user attempted and Usability Metric for User Experience (UMUX) Lite version at the end of the study. In this project, both SEQ and UMUX used a 7-point Likert scale. SEQ was introduced by Sauro & Dumas (2009) to measure the difficulty of the tasks given to users. Meanwhile, UMUX Lite was developed by Lewis, Utesch, & Maher (2013). It consists of only two questions and is claimed to be comparable to System Usability Score (SUS) which is commonly used for usability testing. Both the SEQ result and the UMUX Lite result are provided in Appendix B, Table B1 and Table B2, respectively.

As we refer to Table B1, we can observe that Task 2 and 3 have the lowest SEQ score (4.2 and 5.4 respectively). This confirms the finding of Task 2 from the Think-Aloud performance (Table 3) with this result. Meanwhile, Task 3 is the first task for users to explore the part that shows the environmental condition on graphs. As users might not familiar with the system and the graphs were too detailed, this might affect the difficulty of this task for users. However, the bottomline all the tasks seem to be easy for the users with a global mean of 6.03.

In reference to Table B2, the calculation of UMUX-Lite Score for each user has been done according to the formula outlined by Lewis, Utesch, & Maher (2013). The scores are between 0 to 100, similar and therefore comparable to SUS. We can notice that P2 and P3 gave the lowest score (60.82) which means they were unsatisfied with the system. However, we can see also that the mean (69.48) and median (71.65) are slightly above average (68) SUS score as explained by Sauro (2011). This means that as a prototype, the interface has shown promise for usefulness and ease of use.

6. Conclusions

Even though the SleepAnalyser succeeds in collecting data and offering users recommendations accordingly, it has some limitations. As we developed SleepAnalyser to be a non intrusive device, the cost of contactless sensors is very high. As a result, we were not able to embed contactless sensors that record heart rate, blood pressure and body temperature to calculate the user's sleep quality in an objective way. Instead, we used subjective method (self-assessed questionnaires) to record the user's sleep score. Some of the sensors that collect environmental data are of low quality, which result in imprecise data. These problems, however, can be overcome in the future with a more lenient budget.

As SleepAnalyser is developed and tested in a short amount of time, we could not get enough data required for the correlation and regression between environmental data and sleep quality. At the moment, recommendations will be handled using if-then rule based logic, based on the optimal value for each environmental elements from the research. In the future, if enough data are collected, we will be able to factor in the correlation for a better recommendation system.

Based on the evaluation of the dashboard, we found that generally, test users were able to complete most of the given tasks, except for finding the recommendation. We noticed this along with the low SEQ score and the comments. The issues and feedback from the think-aloud study are very useful to improve the usability of the system. Based on the overall quality from UMUX-Lite questionnaire results, the system was rated slightly above average by the users with a mean score of 69.48.

7. References

Caddick, Z., Gregory, K., Arsintescu, L., & Flynn-Evans, E. (2018). A review of the environmental parameters necessary for an optimal sleep environment. Building and Environment, 132, 11–20. https://doi.org/10.1016/j.buildenv.2018.01.020

Chiang, R. (2012). Introduction to modern sleep technology. Dordrecht: Springer.

Hartson, R., & Pyla, P. S. (2012). *The UX Book: Process and guidelines for ensuring a quality user experience*. Elsevier.

Joshi, S., Lesser, T., Olsen, J., & O'hara, B. (2016). The importance of temperature and thermoregulation for optimal human sleep. Energy & Buildings, 131, 153–157. https://doi.org/10.1016/j.enbuild.2016.09.020

Lewis, J., Utesch, B., & Maher, D. (2013). UMUX-LITE: when there's no time for the SUS. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2099–2102. https://doi.org/10.1145/2470654.2481287

Mason, I., Grimaldi, D., Malkani, R., Reid, K., & Zee, P. (2018). 0117 Impact of Light Exposure during Sleep on Cardiometabolic Function. SLEEP, 41(suppl1), A46–A46. https://doi.org/10.1093/sleep/zsy061.116

National Heart, Lung and Blood Institute. Sleep Deprivation and Deficiency. Retrieved 7 November 2019, from https://www.nhlbi.nih.gov/health-topics/sleep-deprivation-and-deficiency

Nielsen, J. (2000, March 18). Why You Only Need to Test with 5 Users. Retrieved 6 November 2019, from https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/

Nielsen, J. (2012, January 15). Thinking Aloud: The #1 Usability Tool. Retrieved 6 November 2019, from https://www.nngroup.com/articles/thinking-aloud-the-1-usability-tool/

Rohles, F., & Munson, D. (1981). Sleep and the sleep environment temperature. Journal of Environmental Psychology, 1(3), 207–214. https://doi.org/10.1016/S0272-4944(81)80039-4

Sauro, J., & Dumas, J. (2009). Comparison of three one-question, post-task usability questionnaires. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1599–1608. https://doi.org/10.1145/1518701.1518946

Sauro, J. (2011, February 2). Measuring Usability with the System Usability Scale. Retrieved 7 November 2019, from https://measuringu.com/sus/

Shrivastava, D., Jung, S., Saadat, M., Sirohi, R., & Crewson, K. (2014). How to interpret the results of a sleep study. Journal of Community Hospital Internal Medicine Perspectives, 4(5), 24983. https://doi.org/10.3402/jchimp.v4.24983

Sygna, K., Aasvang, G., Aamodt, G., Oftedal, B., & Krog, N. (2014). Road traffic noise, sleep and mental health. Environmental Research, 131, 17–24. https://doi.org/10.1016/j.envres.2014.02.010

Zanobetti, A., Redline, S., Schwartz, J., Rosen, D., Patel, S., O'Connor, G., … Gold, D. (2010). Associations of PM 10 with sleep and sleep-disordered breathing in adults from seven U.S. urban areas. American Journal of Respiratory and Critical Care Medicine, 182(6), 819–825. https://doi.org/10.1164/rccm.200912-1797OC

Appendix A. Demographic Questionnaire for Think-Aloud Study

Please choose your response in regards to the questions. We will anonymise your identity for the report. Thank you for filling this survey!

Your age group
18 - 25 years old   26 - 35 years old   36 - 50 years old   > 50 years old

Gender
Male   Female   Prefer not to say

Do you have any sleep issues that you are aware of?
Yes   No   Not sure

How do you consider this statement:
Generally, I have enough sleep
Disagree   Somewhat disagree   Neutral   Somewhat agree   Agree

I consider myself to be tech-savvy
Disagree   Somewhat disagree   Neutral   Somewhat agree   Agree

Appendix B. Questionnaire Results

Single Ease Question (SEQ)

Task ID	P1	P2	P3	P4	P5	Mean
1	7	7	7	7	6	6.8
2	1	7	7	3	3	**4.2**
3	4	6	5	6	6	**5.4**
4	6	7	5	7	7	6.4
5	7	7	5	7	7	6.6
6	7	6	7	7	7	6.8
Global Mean						**6.03**

Table B1 - Post-Task SEQ Result

Usability Metric for User Experience (UMUX) Lite Version

User ID	This system's capabilities meet my requirements (a)	This system is easy to use (b)	UMUX-Lite Score*
P1	4	7	71.65

P2	7	2	**60.82**
P3	3	6	**60.82**
P4	6	6	77.07
P5	6	6	77.07
Mean			69.48
Median			71.65

Table B2 - Post-Study UMUX-Lite Questionnaire Result

Note:
* The formula to compute the UMUX-Lite = 0.65 * ((a - 1 + b - 1) * 100/12) + 22.9.

Appendix C. Node-Red Development Dashboard

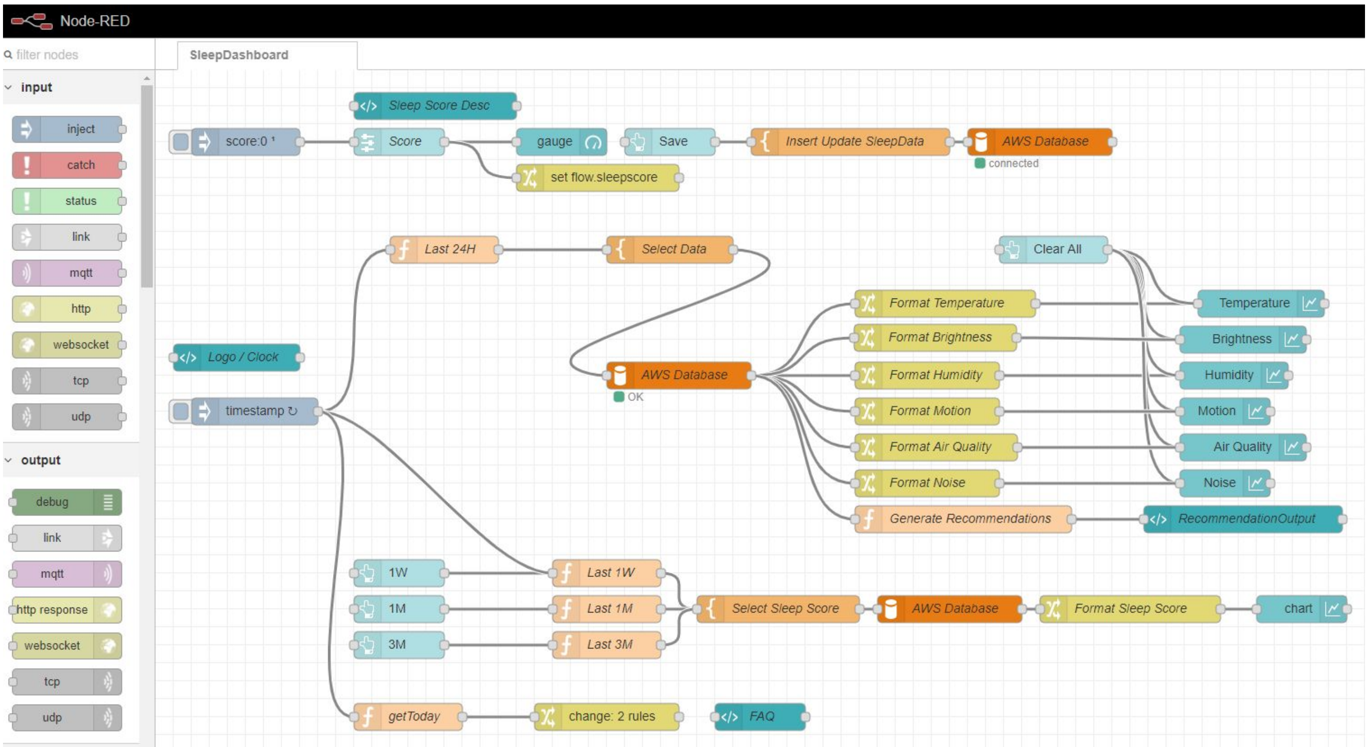

Figure C1. Node-Red Development Dashboard

Appendix D. Logic Flow Diagram of Raspberry Pi

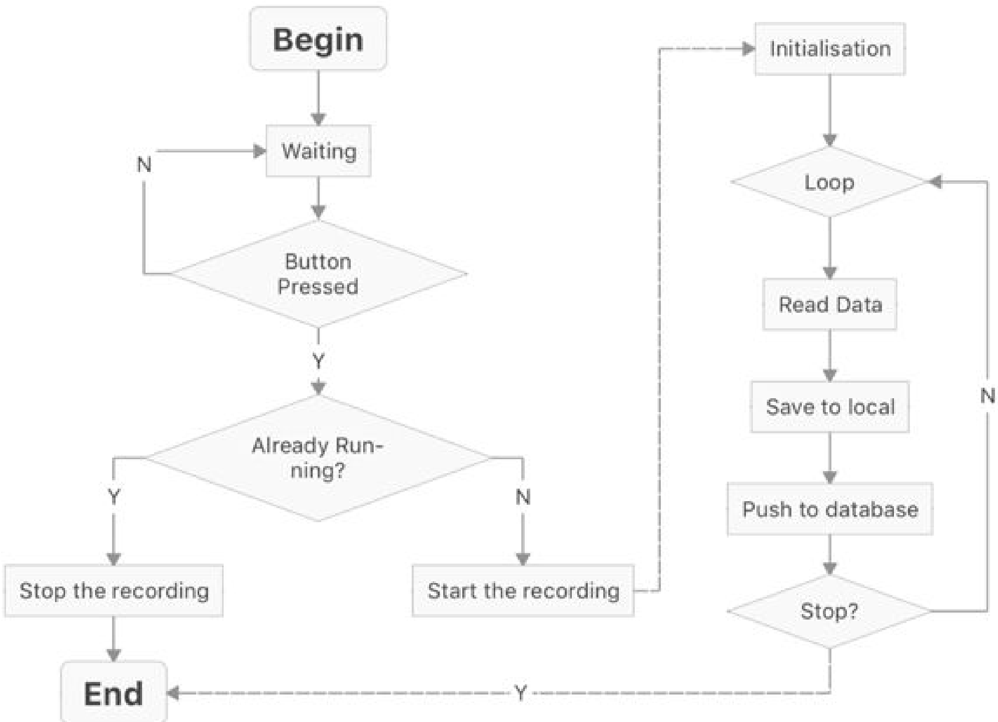

Figure D1. Logic flow diagram of Raspberry Pi