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Sleeping Disorder Monitoring System

1. Introduction

1.1 Motivation

Around the world, millions suffer from sleep disorders, many of which remain undiagnosed due to the pricey and inconvenient nature of clinical sleep studies. Our objective is to develop a solution that is easy to access and inexpensive, allowing people to track their sleeping behaviors in the comfort of their own homes.

1.2 Problem Statement

Classic techniques for the sleep monitoring, like polysomnography, are not economical and straightforward, which hinders their application for prolonged round-the-clock monitoring. There exists a demand for dependable and low-cost methods for determination of sleep stages and its disorders.

1.3 Objectives

i. To develop a non-invasive system for monitoring deep and light sleep stages.
ii. To offer an affordable, portable and user-friendly sleep monitoring solution.
iii. To provide real-time data for understanding sleep quality and detecting disorders.

1.4 Method Used

The system relies on temperature, motion and pulse sensing to obtain physiological parameters while the user is asleep. It also tracks body movements to determine the stages of sleep, which gives a current status of the sleep pattern of the user.

1.5 Contribution

Our system presents an easy to use and reasonably priced unit for undertaking sleeping pattern surveillance within the home environment. It provides a solution to the limitation of clinical sleeping studies that require a person to undergo extreme body movement monitoring to evaluate their sleeping disorders and sleep stages.

2 Literature Review

2.1 Details literature review

2.1.1 Sleep Tracking: A Systematic Review of Research Using Commercially Available Technology

The study is based on scientific research using mass-produced devices and software applications knowing business tycoons are producing more and more of it everyday time. Lately, it has become widespread to monitor sleep duration and quality using FitBit tracking and Smartphone apps. Nevertheless, the adherence rate is weaker to polysomnography (PSG) which is considered to be a very accurate statistical tool. The study stresses out the requirement for new validation methods, with the typical data inaccuracy not only confusing issues but also presenting obstacles for users and researchers in the task of improving their sleep quality. [1]

2.1.2 The Promise of Sleep: A Multi-Sensor Approach for Accurate Sleep Stage Detection Using the Oura Ring

The article introduces a technique for determining the stages of sleep by means of Oura Ring that fuses the information from the accelerometer with the data of the heart rate. In another case, the research theme was to reach the highest accuracy rate using computer-based technology and in the second case, they managed to succeed in 96% of the times the technique was an early-wake detection and to recognize a person entering deep REM stage 79% of the time. Not to be overlooked, the authors call to mind the necessity for a larger, more diverse population, and variety of data for the study to have more reliable results in the future. [2]

2.1.3 Unobtrusive Sleep Monitoring Using Cardiac, Breathing, and Movements Activities: An Exhaustive Review

The paper gives an insight into the evidence-based sleep monitoring approaches by non-invasive methods relying on physical data from the human body such as heart rate, breathing, and body movements. Still, it has to be noticed that very often they do not quite measure up to PSG when it comes to the precision. The performance of these techniques has been improved by the inclusion of machine learning algorithms. The paper also mentions the development in signal processing and sensor technology which will make sleep monitoring with the non-obtrusive method even more convenient and reliable. [3]

2.2 Summary Table

Table 1 : Summary of Literature Review

Paper Name	Contribution	Methods	Experimental Results	Limitations
Sleep Tracking: A Systematic Review of Research Using Commercially Available Technology	Reviewed the effectiveness of consumer-grade sleep trackers.	Systematic review of studies using FitBit, smartphone apps etc.	Wearable trackers provided useful data but inconsistent accuracy.	Lacked large-scale validation; accuracy inconsistent compared to PSG.
The Promise of Sleep: A Multi-Sensor Approach for Accurate Sleep Stage Detection Using the Oura Ring	Developed a multi-sensor sleep stage detection model using Oura Ring.	Machine learning, accelerometer, ANS signals, and circadian features.	Achieved 96% accuracy for sleep-wake detection, 79% for 4-stage classification.	Needs larger datasets and validation across diverse populations.
Unobtrusive Sleep Monitoring Using Cardiac, Breathing and Movements Activities: An Exhaustive Review	Reviewed unobtrusive sleep monitoring methods using physiological signals.	Review of methods using heart rate, breathing, and body movement monitoring.	Promising for home-based monitoring but lacks PSG-level accuracy.	Current methods still lack the precision of clinical PSG testing.

3. Methodology

3.1 Workflow diagram

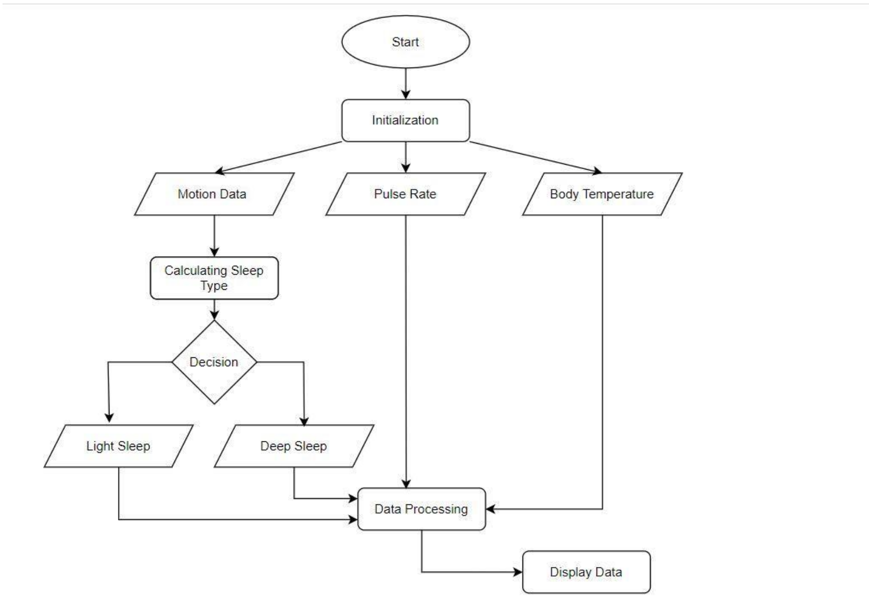

Figure 1: Workflow diagram

The flow diagram for the Sleep Disorder Monitoring System outlines the sequence of operations from initialization to data display.

Step 1: The system begins its operation.

Step 2: The system initializes all components, including the accelerometer (MPU6050), pulse sensor (MAX30100), and temperature sensor (MAX90614).

Step 3: The MPU6050 sensor collects motion data, detecting body movements throughout the night.

Step 4: The MAX30100 pulse sensor monitors the heart rate continuously.

Step 5: The MAX90614 contactless temperature sensor measures the user's body temperature.

Step 6: The collected motion data is analyzed to determine the sleep type.

Step 7: Based on the analysis, the system decides whether the user is in light sleep or deep sleep.

> **i. Light Sleep**: If the data indicates light sleep, it is categorized accordingly.
> **ii. Deep Sleep**: If the data indicates deep sleep, it is categorized accordingly.

Step 8: All collected data (motion, pulse rate, and temperature) is processed to comprehensively analyze the user's sleep.

Step 9: The processed data is displayed to the user, providing insights into their sleep patterns and quality.

3.2 System Architecture

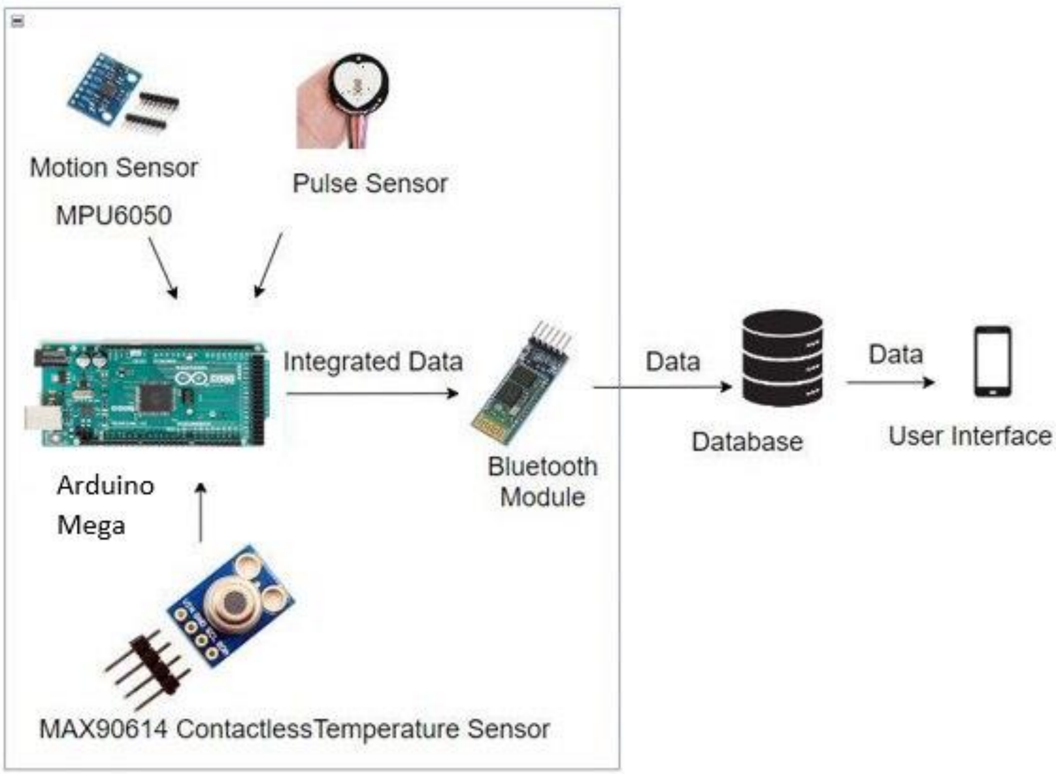

Figure 2: System Architecture

The architecture design explains a sleep monitoring system using motion, pulse, and body temperature sensors integrated with Arduino UNO. These sensors record important body-specific actions during sleep, for instance, movement, heartbeat, and temperature. After the information has been collected by the corresponding sensors, the figures are processed in an Arduino UNO and transmitted to a data center wirelessly with a Bluetooth module. The data is then stored and processed in a remote data center, and made available through an interface such as a mobile application or a web application, where users are able to track and evaluate their sleep and other physical activities as per the data in the system in real time.

3.3 Circuit Diagram

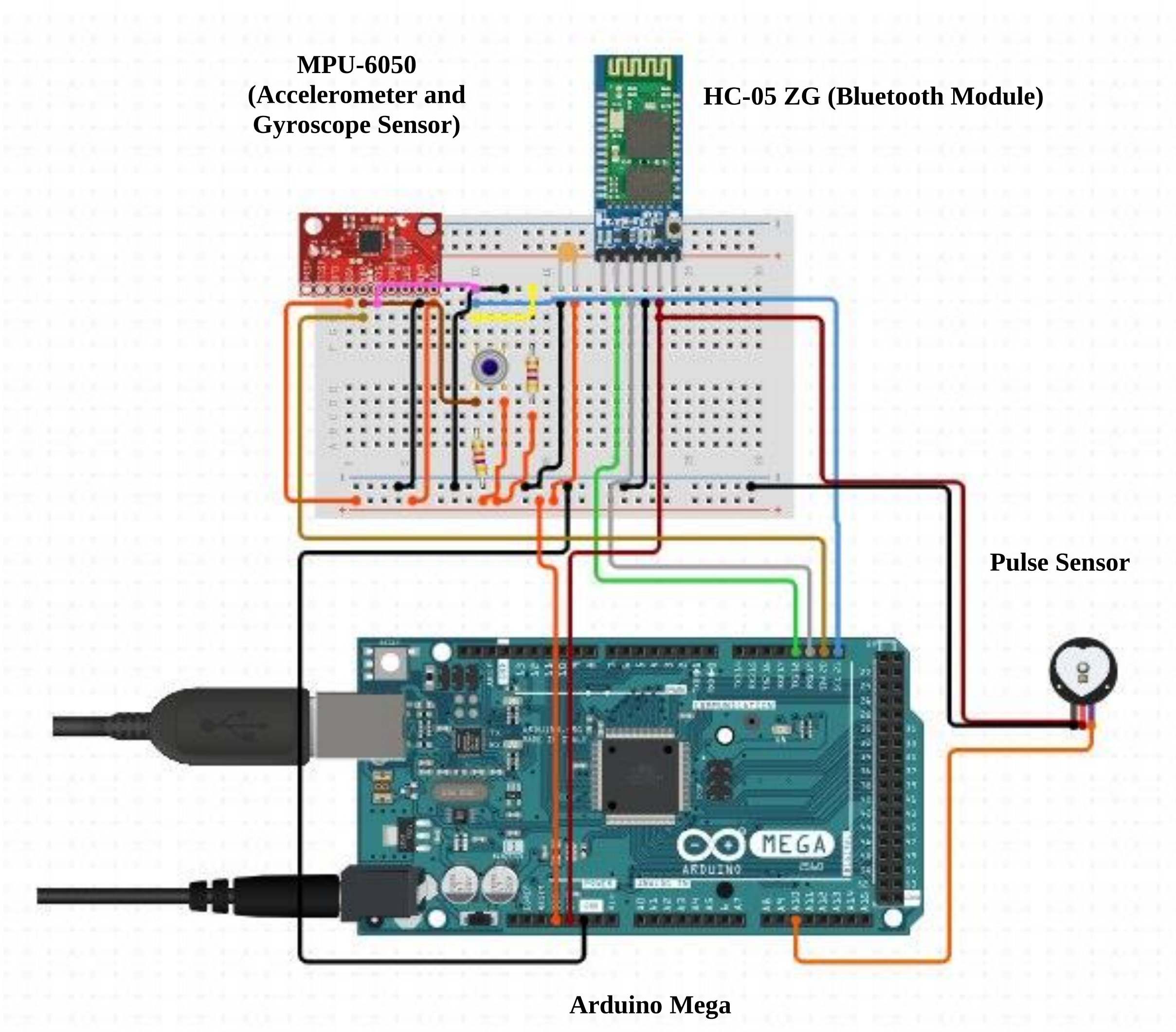

Figure 3: Circuit Diagram

The Sleep Disorder Monitoring System is designed to evaluate the sleeping patterns, as well as the different sleeping disorders, if any. There are multiple components involved in this system, and each is dedicated to a specific function.

3.3.1 Arduino Nano Connections:

i. **MPU-6050 (Accelerometer and Gyroscope Sensor):**
   - VCC → 3.3V
   - GND → GND
   - SDA → A4

- SCL → A5

ii. **MAX30100 (Pulse Oximeter and Heart Rate Sensor):**
   - VCC → 3.3V
   - GND → GND
   - SDA → A4
   - SCL → A5

iii. **HC-05 ZG (Bluetooth Module):**
   - VCC → 5V
   - GND → GND
   - TX → RX (Digital Pin 0)
   - RX → TX (Digital Pin 1)

3.3.2 Power Supply:

To power the Arduino Nano and its connected sensors, a rechargeable Li-ion battery is connected to the VIN and GND pins of the Arduino Nano.

3.3.3 System Integration and Functionality

i. Data Acquisition:
The Arduino Nano continuously collects data from: MPU6050 to detect body movements. MAX30100 to monitor heart rate and blood oxygen levels.
ii. Data Processing:
The Arduino processes raw sensor data to determine sleep stages (wakefulness, light sleep, deep sleep). Algorithms analyze body movement patterns and heart rate fluctuations to classify sleep stages.
iii. Data Transmission:
The HC-05 ZG Bluetooth module sends the processed sleep data to a paired external device (e.g., smartphone, computer) for real-time monitoring or later analysis.
iv. User Interaction:
Users can view their sleep patterns and trends on an application running on the paired device.
The application visualizes sleep data, helping users make informed decisions to improve their sleep hygiene.

3.4 Algorithm

```
initialize system();
calibrate sensors();
gyro data ← read MPU6050();
if activate = 0 then
    if gyro data indicates minimal movement then
        start sleep timer();
        if timer ≥5min then
            activate sleep mode();
        end if
end if
else if activate = 1 then
    light_sleep ← calculate light sleep time();
    if light_sleep ≥ 1hr 10min then
        if no interrupt then
            if light_sleep − interrupt_timer ≥ 5min then
                deep_sleep ← light_sleep − interrupt_time();
            end if
        end if
        if movement detected then
            update interrupt timer();
        if 5 interrupts in 5min then
                reset sleep mode();
            end if
    end if
end if
delay(1000);
```

4. Environment Setup/ Implementation

4.1. Hardware

To develop the Sleep Monitoring System, the following components are used:

i. **Microcontrollers:** Arduino Nano
ii. Sensors:
  - **MPU6050 Accelerometer Motion Sensor:** To track the movement of an individual sleeping on the bed.
  - **MAX30100 Pulse Sensor:** To check user's pulse.
  - **MAX90614 Non-Contact Infrared Thermometer:** To get the body temperature of the user without the need of touching the user.

iii. **Communication Modules:** HC-05 Bluetooth Module is provided for the wireless connectivity of the device to the phone or computer.
iv. **Power Supply:** Rechargeable Li-ion Battery, ensuring the system runs without any interruptions.
v. **Storage:** Micro SD card for data logging in case the Bluetooth gets disconnected.
vi. **Supplies:** Arduino wires and jumpers are used to join the devices.

4.2. Software

The Arduino IDE (version 2.3.2) is used for writing coding, compiling codes and uploading to the Arduino board. The IDE has libraries that allow the communication with the sensors and communication modules. Also, the application is implemented with an interface software to display the relevant metrics such as light sleep, deep sleep, total sleep time, and other necessary calculations.

4.3. Physical Environment

The system adapts to certain environmental conditions to ensure proper data collection. Some of the environmental factors are:

i. **Stable Indoor Conditions:** The conditions must be in a controlled environment where the temperature remains constant over the period to prevent changes in sensor measurements.

ii. **Low Outside Noise and Light:** Outside factors must be limited in order to maintain uninterrupted sleep for accurate readings from the sensors.
iii. **Uniform Bed Surface:** An appropriate and level sleeping platform is important so that the accelerometer does not cause any unnecessary motion detection due to its column limitations.

4.4. Technical Setup

In order to obtain the desired performance, the technical setup of the Sleep Disorder Monitoring System is comprised of the following components:

i. **Power Supply:** A fully charged Li-ion battery is used so that there will be no interruptions in data collection.
ii. **Sensor Placement:** Sensors (MPU6050, MAX30100, MAX90614) have to be positioned correctly on the user's body for data collection purposes. The pulse and body temperature sensor should be in direct contact with the skin.
iii. **Sensor Calibration:** These sensors have to be calibrated prior to each use, in order to use them accurately.
iv. **Bluetooth Connectivity:** The HC-05 Bluetooth module should be able to stay connected to the paired device for up to ten meters and should be able to operate fully within that range. This connection is indispensable, as it facilitates continuous data streaming over a period of time.
v. **Arduino Configuration:** The Arduino Nano should be appropriately configured in regard to firmware and software updates to the latest versions for it to work properly.

4.5 Control Measures

In order to ensure that the data collected remains consistent, the system incorporates a control measures system:

i. Experimental Variables:

Sensors are calibrated and positioned in the same way for all test subjects.

The same parameters are set for the Arduino software and Bluetooth module when transmitting data to avoid discrepancies.

The hardware elements of the system are checked and maintained on a regular basis to avoid inconsistencies.

ii. **Comparison Baseline:**

A group of some individuals whose sleeping habits are already known is introduced to assess the performance of the sleep monitoring system.

Measurement data, which are collected for the purpose of comparison, are provided from existing sleep monitoring.

Identical time-logging periods and time-logging systems are implemented for efficient comparison of the conducted tests which occur at separate times.

4.6. Assumptions

The Sleep Disorder Monitoring System is bound by certain assumptions which are fundamental for the system to operate correctly and for the data obtained to be valid:

i. **Sensor Placement:** It is expected that the user will place the pulse rate sensor and temperature sensor on his or her body.
ii. **Stable Environment:** The system is assumed to be used in a calm, constant environment without excessive vibrations or movements that might disrupt the readings collected by the sensors.
iii. **Battery Performance:** The Li-ion battery is assumed to be fully charged before each use.
iv. **Bluetooth Connectivity:** The system operates on the assumption that the connected mobile device or computer shall remain within range of Bluetooth (which is not more than ten meters). Where the device goes beyond the range, data will be logged on the micro SD card as an alternative.
v. **Operating Temperature:** Sensors and the Arduino system are taken to operate within their respective temperature ranges for effective data collection.
vi. **User Knowledge:** A user is considered to be familiar with the installation and the functioning of the device, mainly in the issues of sensor placement, battery usage, and wireless connections.

5. Experimental Result

With our device, we can measure the following:

i. Body temperature in Celsius
ii. Total sleep in minutes
iii. Total light sleep in inutes

iv. Total deep sleep in minutes
v. Total percentages of light and deep sleep

The sleep monitoring device is attached to the wrist of a person and worn when slept. Then it calculates the all the above parameters and tracks the person's sleep pattern. All the necessary parameters are seen on the app interface.

The sleep statistics after a period of sleep is given below:

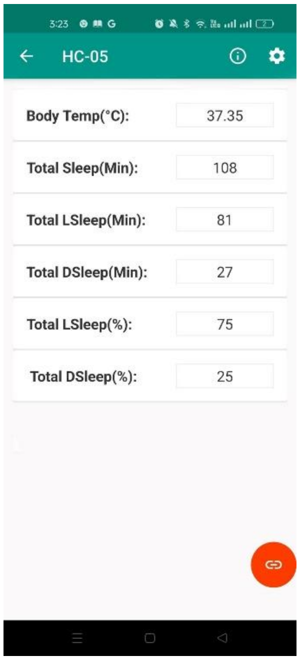

Fig: Sleep Statistics

Here, it can be seen that the body temperature of the person is 37.35 in Celsius. And the total amount of sleep the person had is 108 minutes. The device then differentiates the light and deep sleep from this. The person had 81 and 27 minutes of light and deep sleep respectively. And the percentages of light and deep sleep are 75% and 25%.

6. Impact

The Sleep Disorder Monitoring System project which is based on Arduino Uno platform incorporates motion sensors, temperature sensor and pulse oximetry sensors to study sleep stages but mostly light and deep sleep. The main goal of the project is to encourage healthy sleeping patterns and it is also necessary to consider other aspects, the environmental, economic, and social perspectives of the project is a must.

6.1. Environmental Impact

The Sleep Disorder Monitoring System has a mix of environmental advantages and disadvantages:

i. **Positive Environmental Impact:** The Arduino Uno uses very little power hence the environmental impact is less than that of sleep monitor devices available in the markets today. In addition, using off-the-shelf parts makes it easy to fabricate the system and thus promotes the use of available resources in the fabrication process minimizing waste.
ii. **Negative Environmental Impact:** On the contrary, all advantages aside from the very helpful electronic components and recharge batteries in this project will encourage the practice of e-waste and its disposability. In addition, the processes that go in making these parts also include energy and natural resources, and should be recognized. The actual source of the ambition is small due to the type of the project but sustainability would call for the right materials and their disposal to be incorporated in the project in order to reduce the environmental impact.

6.2. Economic Impacts

The most basic economic benefits of this initiative include factors beyond mere cost savings for single users.

i. **Democratization of Sleep Technology:** This open-source project which is low priced, aims at making sleep tracking easy thereby motivating the development of more sleep-based products and services. By providing a cheaper substitute to pricey commercial systems, it assists users learn and practice self-monitoring technology.
ii. **Encouragement of the Sleep Health Sector:** With the increasing adoption of such devices, anonymized sleep information can be a potential catalyst for advancement in sleep health. It is anticipated that this project will further market this technology resulting in more sophisticated and competing products for sleep monitoring systems.
iii. **Self-Monitoring:** The project being open source encourages self-tracking, and self-care culture. As many people embrace self- sleeplessness tracking, the market for inexpensive, self-made devices of that sort will grow, and perhaps will affect many other sleeping product markets as well.

6.3. Social Impact

One of the foremost merits of the project is its social impact, and this starts with giving power to the people and encouraging the public to take more interest in sleep health.

i. **Empowerment Through Self-Monitoring:** The provision of feedback of individuals' sleep behavior has a positive implication in the Sleep Disorder Monitoring System and thus in the health of the user. If individuals are able to monitor the patterns of their sleep, this can enhance their general wellness including both their mental and physical health.
ii. **Community and Collaboration:** Internet encourages people to participate in open-source initiatives like the ones associated with sleep health and design. This has a positive effect on people’s sleeping patterns and their motivation toward a healthier way of live.
iii. **Data Privacy Concerns:** One of the social problems that push this project to its limits is making sure no user’s data is compromised. A plan on how to collect, manage, and use the sleep data should be straightforward and well understood. The users should have the post and editing right for their information, and even have an option of not making any information available for the purpose of this project. Data protection and assurance measures will contribute to the confidence of users in the device as it is sensitive and collects health information.

7. Limitation & Future Work

The Sleep Disorder Monitoring System is afflicted with various drawbacks, especially concerning the accuracy of the sensors employed as well as the sensitivity to the surrounding environment. The sensors, categorized as the MPU6050, MAX30100, MAX90614, need accurate use and calibration because inaccurate readings on sleep stages may arise due to improper handling or fitting environmental conditions. Furthermore, the external environmental determinants, light, sound or even hotness variations might compromise the efficiency of the system in recognizing the sleep patterns.

There is also the issue of battery life since the real-life settings of the system may drain the Li-ion battery quicker than anticipated resulting in loss of data within the system. Bluetooth connection within range of 10m is essential as extending beyond this range helps to avoid real-time transmission instead all the data is written down on a micro-SD card which can result in loss of timely suggestions.

Another problem is that of data protection since there are chances that such sensitive biological data may be accessed if suitable security systems are not put in place. In addition, the system only addresses simple parameters such as motion, pulse, and temperature limiting its accuracy to professional-grade sleep trackers.

The forward-looking developments in the sleep monitoring device would integrate improved sensor calibration and more sophisticated sensors for an effective sleep stage detection. The careful selection of components, in addition to the incorporation of energy saving features, will help in prolonging battery life thus allowing for continuous monitoring. Furthermore, it will address the need of the users as its expansion will promote offline use of the system allowing the users to access their sleep data from different devices with the help of friendly or mobile application-based interface.

Enhancing the existing system by adding auxiliary sensors such as SpO2 or EEG units can deepen the understanding of sleep health. Information of such nature will attract users since their private data will be kept safe through end-to-end encryption. Lastly, such inexpensive and easy-to-use tools or kits can be made together with the help of healthcare practitioners in order to make this technology available for the wider audience and to eliminate the difference between personal sleep monitors and clinical ones.

8. Conclusion

To summarize, the Sleep Disorder Monitoring System efficiently fulfills the purpose of finding a low-cost and easy to use method in tracking sleep cycles, especially the light and deep sleep phases. Many different types of sensors – accelerometer, temperature sensor to name a few, are employed for effective data collection in the system to evaluate the quality of sleep. Moreover, the connection to a mobile application through the use of Arduino Nano and Bluetooth facilitates the transmission of the collected data without the use of wires, thus enhancing mobility and allowing a user to analyse and monitor the system real time from a mobile phone or web applications.

On the other hand, the system also presents challenges in as far as the accuracy of sensors, sensitivity to environment and data protection are concerned and that will be for the next versions of the system. If the calibration of the sensor was improved, Sp02 or EEG sensors were added, and battery life was increased, the device would greatly increase in its capabilities. Besides this, addressing strict information protection policies and developing much more user friendly offline features will increase client's trust and its acceptance.

In the last place, this project fulfills the underlying goal of the task, which is to "make sleep monitoring technology available to all," thus allowing focus on other sleep health issues beyond mere treatment.

9. References

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