AN INTELLIGENT SYSTEM TO ENHANCE MENTAL AND PHYSICAL HEALTH THROUGH SLEEP MONITORING AND RECOMMENDATIONS USING MOTION DETECTION AND ENVIRONMENTAL SENSORS

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ABSTRACT

This study introduces a new approach to tackling insomnia aimed at international students. It offers a comprehensive solution using environmental sensors and an integrated app. The motivation for this comes from many young students who have insomnia triggered by a new environment. The absence of sleep due to moving around and joining a new culture make it hard to accomplish many things. This app records sleep variables such as motion, light, ambient light, temperature, humidity, and sound. The data is then sent to a database to be pulled and analyzed. The app allows users to quickly and easily view sleep data and trends in real time with a calendar for date selection and viewing trends. When an environmental variable is deemed out of the range of widely accepted ideal sleep values, the app will give the user suggestions on what to correct. Experimental testing was conducted to assess the accuracy of the sensors and the algorithms used to translate that to viewable qualitative data for the user. We found that with using a frame differencing algorithm, there would need to be no motion of the physical camera throughout the night. A second discovery was that multiple people within the frame may affect the user's sleep data. Compared to existing methodologies, the app distinguishes itself by considering a range of environmental factors that offer subjective as well as objective sleep quality tracking. It also gives users the opportunity to form bonds and help each other on the community page. In conclusion, this product presents a reliable, cheap, and easy-to-use method to evaluate and correct sleep health as well as tackle sleep-related medical issues such as insomnia.

KEYWORDS

Firebase, Flutter, Insomnia, Sleep Efficiency, Sleep Deprivation

1. INTRODUCTION

Aiming to help with insomnia, we developed a solution for tackling the issue of sleep health. We developed a sleep tracking system with sensors that tracks environmental factors and sleep statistics to help aid with this disorder. A lot of international students who went to the U.S. for high school had a hard time adjusting their life there. The language barrier and culture shock

David C. Wyld et al. (Eds): SEAS, NLPI, SP, BDBS, CMCA, DMML, CSITEC -2023
pp. 55-67, 2023. CS & IT - CSCP 2023 DOI: 10.5121/csit.2023.131706

caused more difficulties for them to fit into the community compared to other local students. Many of them had a hard time making friends and fully understanding the lectures taught in English. According to data, over the past ten years, the total number of Chinese students worldwide, including those attending American higher education institutions, has nearly tripled. The number rose from less than 130,000 in the academic year 2009-2010 to more than 370,000 in 2019–2020 [18]. The data suggests that a lot of Chinese international students are experiencing many problems related to sleep health.

Along with being in a new environment with a language they do not speak, they are immersed into foreign academic systems, not being familiar with the U.S. cultural norms, without social connections, and being academically prepared. This causes a lot of stress and anxiety on someone who has been thrown into a new environment. This becomes a catalyst for sleep related issues, whether it is staying up due to jet lag, culture shock, worrying about the language barrier, or being a new student introduced to the U.S. compared to those who have been familiar with it since birth [17].

Insomnia and being over-stressed is not an issue that occurs only with just a few international students. It is a common occurrence that warranted the need for something to change. That is why we decided to do something about it and develop a means for these students to improve sleep health while at the same time building community with those who are experiencing similar things. We developed an app with a sensor that tracks our sleep data and gives suggestions to help aid with this disorder. The computer is connected to camera, light, sound, temperature, and humidity sensors. We are able to open the app and enter the sensor's ID to access our sleep data for a specific date by taking advantage of the app's built in sleep calendar. We can also access the suggestion page, where the app gives suggestions on how to improve our sleep quality based on research for the best sleeping environmental quantities. There is also a log page to select how we feel about our sleep - good, average, poor - also displaying the date. A sentence or paragraph can also be recorded in the log to help track the user's subjective sleep quality. For sharing ways to improve our sleep, we can post messages on the community page, while selecting to stay anonymous if we do not want our username to be public. A profanity filter is added in order to help stop antagonistic behavior directed at other users. Users also have the ability to block other users if they post hostile comments on the community page. This protects the environment in the community while leaving users with a sense of safety. The app becomes the best solution for users due to its accessibility and low cost. During experimentation by following the suggestions the app provided, sleep health has improved via quantitative sleep data. Sleep routine also improves with prolonged use of the log and app, which helps the user to establish a regular sleep schedule.

2. CHALLENGES

With attempting to make a sleep health app and product, there are many different factors to consider. Many apps have tried and don't quite create a good experience for users while also providing the best results possible. We thought through these issues and through research and experimentation came up with the best way to display data and improve users sleep.

2.1. How to Integrate Diverse Sleep Data for Comprehensive Analysis in Real-Time?

In order to accurately capture a user's movement data, it is essential to have a detailed and comprehensive sleep analysis. However, the movement of inanimate objects affects the accuracy of capturing and analyzing data. Other issues involved in recognizing a user's motion include identifying their sleep state and determining a method of capturing data. Users rely on accurate sleep health monitoring because it is crucial for promoting a user's mental and physical health. Sleep plays a crucial role in cognitive functions, a person's ability to regulate emotion, and the process of memory consolidation. Humans rely on cognitive functions in every essential part of life. Some processes include attention, decision-making, and problem-solving [2]. Emotion regulation significantly impacts a person's ability to think rationally and causes impulsive behavior. Being well-rested is a critical factor in consolidating both short-term and long-term memories because while sleeping, your brain will replay neural patterns and strengthen memory traces. Without enough sleep, we do not reactivate neural regularities, causing a lack of memories to transfer from the hippocampus to the neocortex. The hippocampus is responsible for short-term memory, while the neocortex is responsible for long-term memory [1]. One way we could go about solving the issue of extraneous variables could be to remove the subject and account for all unwanted movement variables before re-introducing the subject into the environment. By removing the unwanted motion, we are only left with activity from the user. With these changes, we allow for accurate sleep data unaffected by confounding factors.

2.2. How to Ensure Seamless Accessibility for Users to Obtain their Sleep Data and Connect With the App Effortlessly?

With technology today, everything is becoming more streamlined and more user-friendly. Having a tough-to-use User Interface or User Experience is the difference between having a failed product and a successful product. For that reason, we have to be able to provide the easiest and most user-friendly product we can. An issue with having a sleep monitor connected to an app is how we can distinguish one user from another. A second is how we allow the user to connect to their monitoring system via the app. A user's ability to navigate the user interface efficiently and quickly affects the subjective well-being of the user [3]. For an app to be successful in providing users with helpful sleep data, the app must be easy to access, view suggestions and integrate data seamlessly. A proposed way to solve these issues could be to add unique device identifiers that would allow the app to communicate through a database with the sleep data obtained through their monitoring system. For this to work, authentication is required to save the user's device and populate the devices' data.

2.3. What to Choose for Optimal Sleep Data Representation?

There are an infinite amount of ways to display data. This makes choosing one way of displaying a user's sleep data incredibly challenging. Displaying the data is just as or even more important than the collection of data itself. If we are unable to display a user's data efficiently and aesthetically, the app will fail its purpose. Data is collected to be rendered and analyzed; without an effective representation, we cannot accurately reflect on our sleep health. The best way to visualize the data is to average the sensor's data throughout the sleep session and render that to the user. We then will calculate the total time, time spent sleeping, and time spent active and add that to our user interface. Lastly, we could add a color implementation to render green on the calendar for good sleep, yellow for average, and red for poor sleep. Users would then be able to appropriately view sleep trends and correct them.

3. Solution

This product is a sleep monitor that allows us to track sleep data, and from its suggestions, improve sleep health. It is written in Dart, a programming language developed to aid in android and IOS development, using Flutter. Flutter is the framework used to translate Dart into both Swift and Kotlin, the native language for IOS and Android development. We can use a sensor recording device to track our sleep data. From there, our data, including ambient light, humidity, lux, motion level, sound, temperature, and sleep time, are uploaded to our database. Both ambient light and lux are recorded using Adafruit's, "VEML7700 Lux Sensor - I2C Light Sensor - STEMMA QT / Qwiic," similarly the humidity and temp are recorded using Adafruit's, "Sensirion SHTC3 Temperature & Humidity Sensor - STEMMA QT / Qwiic." These sensors allow for environmental factors to be recorded and give the user an opportunity to adjust them based on app given suggestions.

Figure 1. App Flow

In order to capture motion, we installed a camera that takes in an image and compares it to the previous, it then outputs the percentage of changed pixels, indicating motion. The data is then received on our front end and processed in Dart. We are first prompted to log in, allowing for user specific data to render correctly. There are methods to calculate the average of all motion from a given night and to determine our total, active, and sleep time. The app renders suggestions according to this data. Along with displaying suggestions, the data is output to the screen for us to view and interpret. The application also has log, community, and settings pages. The log allows us to record how we felt about our night's sleep, or how our mental and physical health was in association with our sleep data. The sleep quality logged on this page is then rendered on the calendar, so we can view trends in our perceived sleep quality.

We are able to connect and share experiences in the community page. This page promotes sharing our own sleep suggestions with others trying to improve their sleep health. The settings page allows us to customize our experience, with options to change our usernames, profile picture, device ID, and units of measurement. All of these components lead to a very efficient and helpful sleep health improvement app.

One of the components we used is the backend, which communicates with the device recording our data. The purpose of the program is to take data from our various sensors and upload it to the database to later be analyzed by our app. Every time the camera takes a picture, it will compare one pixel to the next in the same position on a different frame. It will then determine how many pixels have changed. We then get the percentage of changed pixels and determine if it is great enough to be sleep motion from the user. This concept is known as frame differencing [4]. In order to account for unwanted background motion, the application will first for five seconds with the user out of frame get a base amount of motion to compare to. If the motion is determined to be different enough from the base percentage to be a user moving, the recordData method is called and will write the data to Firebase.

```
def recordData(percentage_changed, sound_level, today):
    ts = str(int(time.time()))
    # Create a reference to the database with the path for the device
    ref = db.reference("devices/%s" % deviceID)
    new_entry_ref = ref.child(today).child(ts)
    new_entry_ref.set(
        {
            "Temperature": sht.temperature,
            "Humidity": sht.relative_humidity,
            "AmbientLight": veml7700.light,
            "Lux": veml7700.lux,
            "Time": int(ts),
            "MotionLevel": percentage_changed,
            "Sound": sound_level,
        }
    )

    # Update the "color" node without overriding other data
    color_entry_ref = ref.child(today)
    color_entry_ref.update(
        {
            "color": "grey",
        }
    )
    print("Written to Firebase")
```

Figure 2. recordData

Figure 2 displays a method called record Data. Its function is to upload data to Firebase when called. In our project, it is called when we are tossing and turning or moving during a sleep period. There are three parameters passed in, percentage_changed, sound_level, and today. The percentage_changed reference is the percentage of changed pixels, which also triggers this function to run. Sound level is the recorded sound level at the time of the capture in decibels. Lastly, today is a string variable that holds the date for today in the form “yyyy-mm-dd”. The reason the date is passed in is that if we run the program, and it passes midnight, the date has changed, so we must call the date outside the loop running the captures. The variable ts is an int cast to a String of the current time in seconds since epoch. The Unix Epoch was a solution to the computing issue of time zones and having a consistent and standard time. There was a selected date, January 1, 1970 00:00:00, that would serve as 0, from there every second after was counted[5]. Our database, Firebase works by creating a reference or a sort of location where the data should be stored. The variable ref holds the database location to “Devices/(The User's Device ID). From there, the new_entry tells the computer to write the sleep data with the date and time of each capture. There is also a color corresponding to each day which later will be changed to reflect the user's sleep experience, which is written to the database with color_entry_ref.

Almost every high level product or program will take advantage of a database. A database is a collection of organized data in which we are able to reference and change. In the context of our app, the database stores sleep, log, community, and settings data. The database we decided to use was Firebase Realtime Database. Firebase Realtime database is a quick and easy way to read and write data, as well as defining rules for the protection of data. Along with a Realtime database, we are also utilizing Firebase Authentication. Authentication handles logging in and signing up as a new user. For storing data, we use two concepts, Hierarchical Data Modeling and Unix Timestamps. Hierarchical Data Modeling is the concept of modeling your data in a structured, tree-like format. Each level represents a different category, and within that category are one or many subcategories. Every category and subcategory has the ability to contain a subcategory itself, creating a tree-like data structure[6]. We also use Unix Timestamps to record data, this is for two purposes. First, if we use the Unix idea where each piece of data is marked by the time in seconds since the Unix Epoch, then they will all be unique, and we will not have any data overriding itself that we do not want to override. The second is we do not want motion recorded twice, so if there is motion at the same time it will override itself, ensuring only one capture per second. Our backend program will get data from the sensors and write that data to the Realtime database. It will then read the data from our database for analysis and will render it on the screen.

Figure 3. Hierarchical Data Model

Firebase was developed by Andrew Lee and James Tamplin in 2011 as a means for developers to store asynchronous data across users [7]. It was then bought by Google and transformed into much more than just a real time database. The current features at the time of this writing are Authentication, Hosting, Messaging, Analytics, Storage, Real-time Database, Crash Reporting, App indexing, and AdMob [8]. Real-time Database is cloud hosted and stores data in a JSON format. We can connect IOS, Android, Web, and many other device types to one single synchronized database. Because it is synchronized, all device data is added and removed in real-time across devices. Before Firebase, many developers would have to develop their own database using time and resources. Our app also uses Authentication, which allows users to login and authenticate using email and Google auth. Firebase handles all the backend processes related to logging a user in and out, including storing their credentials and managing accounts.

Another component is our frontend IOS/Android application is an intelligent system to enhance mental and physical health through sleep monitoring and recommendations using motion detection and environmental sensors. The frontend allows the user to see the system's recommendations to the data that has been recorded. It also has a home screen for displaying daily data and sleep trends, a log for users to record how they felt, a community to get in touch with others and customization options. The app runs with Firebase Authentication for logging in with email and password, Google Sign In for logging in with Google, or Apple sign in for IOS. The app utilizes many special concepts such as Authentication, Sleep Data Analysis, Ideal Sleep Range Analysis, Sleep Quality Logging, Community Interaction, and Data Storage and Security. Sleep Data Analysis consists of taking a lot of data from a night's sleep and converting it into human-readable analyzed data. Ideal Sleep Range Analysis is the process of taking the environmental values for an ideal night of sleep and comparing that to the data collected. Sleep Quality Logging allows the user to keep a detailed log of their sleep for reference. Community interaction is the concept of allowing users to communicate with each other in a social media aspect. We can post and read posts from others to help improve sleep quality. Data Storage and

Security is essential to any applications taking in any kind of data, to protect the user from any unwanted data collection. Detailed below, we will focus on the Ideal Sleep Range Analysis concept within our frontend.

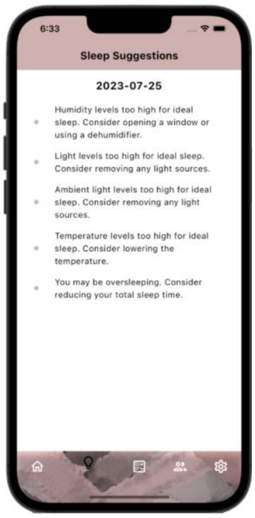

Figure 4. Sleep Suggestions

Figure 5 is a method used to output sleep suggestions to help improve a user's sleep health. It begins first by clearing the sleep suggestions list to prevent previous days suggestions from affecting the currently selected day, which is displayed at the top of the screen. The local variable sleepSuggestions is a list of strings meant to hold all the suggestions that apply to a specific user and specific day’s data. There is then a try block to prevent errors and crashing if the total time variable, which holds the total amount of time slept by a user in a specific night, is not parsable. Inside the try block are a number of conditional statements to test the users' data against ideal sleep values. Each if-statement will test if an environmental variable is within a specific range. Each environmental variable has a specific range for ideal sleep, too high or too low and sleep health decreases [9]. If a conditional statement is found to be true, it will then test if it is above or below ideal values and add a suggestion to the list. For example, if the humidity is too high a suggestion will be added to, “Humidity levels too high for ideal sleep. Consider opening a window or using a dehumidifier.” These will then be rendered to the suggestions screen as shown in figure 5.

```
// Function to check sleep suggestions based on various environmental factors
void checkSleepSuggestions() {
  // Clear the sleepSuggestions list before adding new suggestions
  sleepSuggestions.clear();

  try {
    // Check humidity levels
    if (humidity < 30.0 || humidity > 60.0) {
      if (humidity < 30.0) {
        // Humidity is too low for ideal sleep, suggest using a humidifier
        sleepSuggestions.add('Humidity levels too low for ideal sleep. Consider using a humidifier.');
      } else {
        // Humidity is too high for ideal sleep, suggest opening a window or using a dehumidifier
        sleepSuggestions.add('Humidity levels too high for ideal sleep. Consider opening a window or using a dehumidifi
      }
    }

    // Check light levels
    if (light > 30.0) {
      // Light levels are too high for ideal sleep, suggest removing any light sources
      sleepSuggestions.add('Light levels too high for ideal sleep. Consider removing any light sources.');
    }

    // Check ambient light levels
    if (ambientLight > 200.0) {
      // Ambient light levels are too high for ideal sleep, suggest removing any light sources
      sleepSuggestions.add('Ambient light levels too high for ideal sleep. Consider removing any light sources.');
    }

    // Check temperature levels
    if (temp <= 60.0 || temp >= 75.0) {
      if (temp <= 60.0) {
        // Temperature levels are too low for ideal sleep, suggest raising the temperature
        sleepSuggestions.add('Temperature levels too low for ideal sleep. Consider raising the temperature.');
      } else {
        // Temperature levels are too high for ideal sleep, suggest lowering the temperature
        sleepSuggestions.add('Temperature levels too high for ideal sleep. Consider lowering the temperature.');
      }
    }

    // Check total sleep time
    if (totalTime.isNotEmpty) {
      int sleepTime = int.parse(totalTime.split(' ')[0]);
      if (sleepTime < 7) {
        // Suggest getting more sleep if sleep time is less than 7 hours
        sleepSuggestions.add('You may need more sleep. Aim for at least 7 hours.');
      } else if (sleepTime > 12) {
        // Suggest reducing total sleep time if sleep time is more than 12 hours
        sleepSuggestions.add('You may be oversleeping. Consider reducing your total sleep time.');
      }
    }
  } catch (e) {
    // Handle any errors that occur during parsing
    print('Error parsing total time: $e');
  }

}
```

Figure 5. checkSleepSuggestions()

4. EXPERIMENT

A possible blind spot in our program that needs testing is the frame differencing algorithm. If there is movement in the camera, the pixels being compared in a frame differencing algorithm will be inaccurate. If there is a swinging camera, that would mean that every capture would show motion, and the computer would determine that to be movement from us.

In order to test for this issue, we will set up the camera with a fan blowing it side to side while hanging by a cord. A second camera will be placed that is completely still. This will test how accurate the data is when the camera is moving vs when it is still. Both experiments will run for one hour and will be recorded on a camera for human analysis to determine which data is more accurate. The experiment is set up to test the accuracy of the algorithm with and without motion. The control will be from the actual video footage of sleeping that will be analyzed by hand. For the time spent moving, we will start a stopwatch and subtract the active time by the total time to get the time spent sleeping. This will then be compared to the moving and still camera.

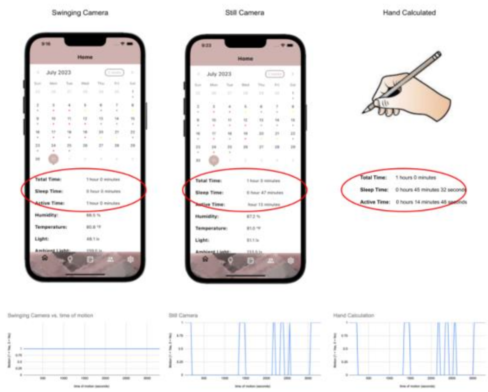

Figure 6. Swinging Camera Data

According to this data, a swinging camera will completely ruin the accuracy of any data taken. For this reason, the camera must remain as still as possible in order to obtain accurate data. Along the x-axis is the time in seconds where motion was captured or recorded. On the y-axis is a range from zero to one, zero being no motion, and one being movement. The swinging camera showed that we were active the entire sleep period and never fell asleep. The still camera showed decently accurate data, varying from the hand calculation by only 2.83%. Some reasons for the varying data from the still camera could be that the user only slightly moved, which was picked up from us watching the footage but was not at a high enough threshold to count as movement to a computer. This could be adjusted in our frame differencing algorithm. This outcome was expected because if we are comparing a frame to a previous frame, a swinging camera would produce a completely different output. Solutions to this issue could be a housing for the camera and sensors that would keep it from swinging or being affected by winds.

Along with many other sleep apps, there is the issue of two people sleeping in the same frame. When two people sleep in the same frame, both users' motion is picked up and recorded. This is an obvious issue due to the fact that the user's data will not be accurate. The more people in frame, the more motion that will be picked up.

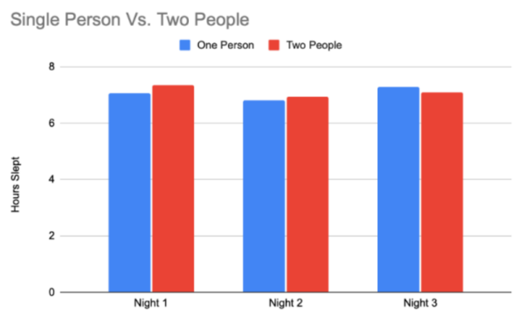

Figure 7. Bar Chart

To test how greatly two people affect the data, we set up a six-day-long experiment. The first three days are with one person in frame in a controlled room with no other changed variables. The next three days were with two people in frame in the same manner. All experiments had times to sleep and times to wake up, starting at 11:00PM and waking up at 7:00 AM. The experiment is set up in order to test the difference in sleep calculations with two users in the frame. All other variables including sleep time, wake-up time, and location are kept the same in order to provide consistency across experiments.

The data shows that there is actually not a completely drastic change to the data when adding a second person. The highest amount of sleep time was from the two people at 7 hours and 22 minutes, while the lowest sleep time was from the single person at 6 hours and 48 minutes. The higher average sleep time was actually the two people at 7 hours and 7 minutes, while the single person averaged 7 hours and 2 minutes. This was fairly surprising because we had expected the data to be much higher with two users than with one. We believe that it turned out that way because the first person may be blocking the second, depending on where the camera is. Another factor might have been the users not wanting to wake each other up, so they could have been suppressing motion usually seen in the single person's data. The biggest effect on the results was most likely the camera placement in regard to the bed and the users.

Single Person		Two People	
Total Time:	8 hours 0 minutes	Total Time:	8 hours 0 minutes
Sleep Time:	7 hours 3 minutes	Sleep Time:	7 hours 22 minutes
Active Time:	0 hours 57 minutes	Active Time:	0 hours 38 minutes
Total Time:	8 hours 0 minutes	Total Time:	8 hours 0 minutes
Sleep Time:	6 hours 48 minutes	Sleep Time:	6 hours 57 minutes
Active Time:	1 hours 12 minutes	Active Time:	1 hours 3 minutes
Total Time:	8 hours 0 minutes	Total Time:	8 hours 0 minutes
Sleep Time:	7 hours 17 minutes	Sleep Time:	7 hours 6 minutes
Active Time:	0 hours 43 minutes	Active Time:	0 hours 54 minutes

Figure 8. Sleep Data

5. RELATED WORK

Students at the University of Washington conducted a study on what they believe to be the best recommendations for developing something to improve sleep health. They surveyed 87 and interviewed 12 people currently using a sleep improvement device, as well as interviews with five sleep experts. Their solution was to use the SATED test to give a sleep score. The stated test accounts for five different sleep health measurements. Satisfaction, Alertness, Timing, Efficiency, and Duration. These five variables would calculate a sleep score, allowing users to attempt to change their modifiable behaviors. They also emphasize the use of a log or journal to document how they feel about a night's sleep. Their hope is to encourage users to diagnose changes in their lives affecting their sleep. Doctors could also reference the log to help make a diagnosis [11]. This idea seems to be decently effective in terms of giving users a score and allowing them to reflect on variables that might be affecting their sleep.

The issue with using the SATED test could be that users might subconsciously modify how they feel about a night's sleep to improve their sleep score. The test also could have issues with its test-retest reliability, meaning that if the user took the test one hundred times, how reliable out of the hundred would the test be [10]? They also did not account for environmental variables such as temperature, time of year, humidity, etc.… By not taking this into account, it could affect the users' data by misleading them to believe a modifiable behavior could be to blame, when truly it was an environmental variable. We account for these environmental variables and even offer sleep health suggestions based on these variables. We also offer visualization of subjective sleep trends through our log, which displays little markers on the calendar to show visible sleep trends.
Another problem we aim to solve is allowing users to connect through the community page to suggest sleep health improvements not already given by our system. A study done by a social support group in a virtual community aimed to solve this same problem. They had a relatively effective solution, although there were some negative problems to address. They paid participants $25 for their 12-month assessment, which was then run through social support behavior code to categorize the content into five different categories. The five categories were information support, esteem support, network support, emotional support, and instrumental support. From this data, they were able to analyze and come up with the effectiveness of their community support app [12].

Some of the negative feedback was some people perceived posts as too much complaining, attacking others, sharing information, or excluding other users. It took users approximately ten to fifteen minutes to get the hang of their app. However, our app has a very user-friendly and simple interface that allows users to quickly get the hang of it and not get left behind due to technological difficulties. We have also added a profanity filter to help block out negative comments directed toward other users and a flag function to give users the opportunity to alert us of any antagonistic behavior. In terms of feeling left out, our users have access to every post done on the community page that they have not personally blocked, disabling users from privately messaging or leaving other users out.

One way people tend to track their sleep health is through a systematic process called polysomnography. A polysomnography is an extensive and inconvenient means to monitor sleep health. A patient is connected to an electroencephalogram, electrooculogram, electrocardiogram, and pulse oximetry [14]. Using all of these sensors, we are able to get quantitative data on our sleep habits and disorders. Polysomnography is one of the best ways to measure sleep habits due to its accuracy and precision. However, it is not only extremely expensive, averaging in the U.S. to be around $3000. It is also very inconvenient to use compared to a sleep sensor paired with a smartphone app. Supporters of the test might overlook its accessibility in developing countries. Smartphones, however, are extremely obtainable in today's economy. A study found that in the U.S., more children are likely to have a smartphone than a book. That same study also noted the Malaysian growing smartphone population, rising to eighty-five percent of adult residents owning a phone [15]. Being obtainable on both Android and IOS platforms, anyone with a phone is able to download the app and track their sleep data. Furthermore, the icons and suggestions on the app help us to navigate to the flow and data quickly, which makes the app easier to use compared to the polysomnography. The free app largely reduces the cost for us to get access to our sleep data. Even for users who cannot use polysomnography to track their sleep.

6. CONCLUSIONS

Some limitations of this sleep health tracker are that it lacks the hardware and functionality to determine when a user enters deep sleep and other categories of sleep. Users also cannot manually enter sleep data if they do not have the hardware. Some other issues could be that users cannot delete a sleep day if they accidentally create a sleep session or delete a log. In order to fix these issues, we would have to implement a new sensor to track different bodily rates, such as breathing or pulse to determine when a user enters deep sleep. A program would then have to be written to capture and analyze that data and send it to our database. In order to delete logs and nights, we would have to implement a way for users to select and delete a night or log, we would also have to get the reference to that log for the database. This adds a layer of complexity with deleting data nodes from Firebase [16].

Sleep health is integral to a person's happiness and ability to function. People for years have been attempting to analyze and improve their sleep health. This application provides an easy way to track, store, and analyze sleep data. Some suggestions will help users improve their environmental variables to support better sleep. A log and community also add more functionality to the user, allowing them to help others and to identify sleep health trends according to the data acquired for their sleep.

Our experiments aimed to test the recording device's reliability and the data displayed on the app. The first aimed to test the functionality of the frame differencing algorithm on a swinging camera or a camera with motion, and the second to test the reliability with two users in the frame. The first experiment was set up by recording data with a swinging camera, a still camera, and a video recording to analyze by hand. To test two users, we experimented with one and two users over six nights to determine sleep trends. As was expected, the swinging camera was less accurate. It was, in fact, extremely unreliable, while the still camera showed very accurate data, only varying by a few percent of the hand-calculated value. This is because frame differencing compares pixels from one frame to the next; if the camera is swinging, all the pixels have changed from their original position. The second experiment had results that we did not intend to see. Sleep with two users showed better sleep health and less time spent active. There were likely two reasons for that. First, the camera was positioned so that part of the second user could have been blocked by the first user, thus providing lower values than expected. Second, the users may have suppressed motion to not wake the other person up.

Other groups have tried to tackle the issue of sleep monitoring to improve sleep health. One of the methodologies we researched was utilizing the SATED method to give a sleep score to each user in order to improve that score [13]. A community was also added to help users to reach out and communicate with others with the goal of uplifting, providing solutions, and having someone to talk to. Lastly, polysomnography aims for accuracy but with the price of high cost and inconvenience. Each method came with its own bit of criticism. First, that we subconsciously want to raise our sleep score, even if lowering the accuracy of the data. On top of that, some people in the virtual community felt they were being left out, attacked, or other online issues. The best measure of sleep health is polysomnography, being too expensive and hard to access. We aimed to solve the issues we researched here. Our app gives users real-time suggestions based on their actual sleep data, so there is no way to subconsciously or consciously get better sleep without changing an environmental or personal variable to improve sleep. We then took a step towards helping the virtual community feel less left out by removing direct messaging, private groups and adding an anonymous username for those who chose not to make their information public. Lastly, adding a profanity filter keeps the feeling of being attacked as low as possible. With all of these functions, the app remains at a low cost and is even usable without the sensors required to get environmental sleep data.

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