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DreamTemp: A Platform For Sleep Monitoring and Improvement

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DreamTemp: A Platform For Sleep Monitoring and Improvement

By

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DreamTemp: A Platform For Sleep Monitoring and Improvement

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ABSTRACT

With 70 million Americans suffering from chronic sleep disorders and only 7500 board-certified sleep physicians, a clear logistical problem exists that technological solutions may be able to address. The proliferation of IoT devices in homes and on our person presents a unique opportunity to improve sleep quality by leveraging the data they produce, and the control they provide to us over our everyday lives. DreamTemp is a platform for sleep monitoring and improvement that aims to improve an individual's quality of sleep by dynamically adjusting the room temperature based on the user's sleep cycle using a smart wearable and thermostat. Through future studies that will investigate the effectiveness of our system in improving sleep quality, we hope to improve the health and quality of life of the population.

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List of Abbreviations

ACTH Adrenocorticotropic Hormone

API Application programming interface

BPM Beats Per Minute

CBT Cognitive Behavioral Therapy

CRP C-reactive Protein

EEG Electroencephalogram

HIPAA Health Insurance Portability and Accountability Act

HTTPS Hypertext transfer protocol secure

IL Interleukin

IoT Internet of Things

IRB Institutional review board

NREM Non-Rapid Eye Movement

REM Rapid Eye Movement

REST Representational State Transfer

SQL Structured Query Language

SSL Secure Sockets Layer

T2DM Type 2 Diabetes Mellitus

TNF Tumor Necrosis Factor

URL Uniform Resource Locator

Chapter 1

Introduction

1.1 Problem Statement

Almost everyone, at some point in their lives, has struggled to either fall asleep or wake up feeling refreshed. As we all know, a poor night's sleep dramatically affects our mental and physical health. In addition to the health risks caused by lack of sleep or lack of quality of sleep, no one wants to wake up feeling lethargic or in a bad mood. This is a growing problem with 70 million Americans currently suffering from chronic sleep disorders and one in three Americans reporting that they do not get the recommended amount of sleep.

Unfortunately, the existing solutions for improving sleep health are flawed. Getting treatment for a sleep disorder requires that you are first diagnosed by a board certified sleep physician. There currently are 7500 board certified sleep physicians and a population of 70 million and growing Americans suffering from chronic sleep disorders. Logistically, 7500 board certified sleep physicians cannot treat the 70 million cases of sleep disorders in the United States.

There is a plethora of sleep technology on the market ranging from affordable melatonin pills to more costly wearable smartwatches, and much more. However, sleep medication and supplements are not a viable long term solution and wearable technology only monitors your sleep and fails to provide you with an actual solution. In order to effectively diagnose and treat sleep disorders in the future, we must advance sleep technology in the future.

1.2 Project Purpose

As mentioned before, current sleep health solutions have flaws ranging from being inaccessible to providing information about your sleep but no way to improve it. However, we can clearly see that there exists a demand for solutions that improve sleep. Therefore, in order to improve the health of the population, our group sought to develop a system that could allowed people to take control and actually improve their sleep quality.

1.3 Proposed Solution

We have developed technology to optimize so many aspects of our lives and our group has decided to apply this is principle to improving people's sleep health. Wearable electronic sleep technologies such as the Oura ring, Fitbit, and others report data regarding how you slept and provide various analytics. However, these technologies only monitor sleep and fail to actually offer any solutions. To improve the quality of sleep achieved by individuals, we have to do more than just provide analytics. To investigate how to achieve this goal, we looked at the factors that affect sleep.

Many factors affect the length and quality of sleep that we actually achieve. For example, what you eat and drink, what medications you take, your screen time, and many other factors can affect your sleep. Most importantly, and central to our project, is the effect of ambient temperature on sleep quality. Most people intuitively understand this. Whether your room was too hot during the summer or too cold during the winter, we understand that there exists an ideal temperature that we can sleep at. Literature shows that there exists an ideal static temperature between 60 to 65 degrees Fahrenheit for adults. In our mission to improve the quality of sleep obtained by individuals, we leverage this known effect of temperature on sleep quality.

We call the proposed system DreamTemp. At a high level, DreamTemp is a platform for sleep monitoring and improvement. Using a smart wearable to determine sleep stage and a smart thermostat to control the temperature of the room, DreamTemp dynamically adjusts the room temperature based on a person's sleep stage with the goal to improve quality of sleep. DreamTemp uses a smart wearable to collect a user's heartbeat data as they sleep. Next, using a determining algorithm, we will convert this heartbeat data into the user's sleep stage. Then, our system interfaces with a smart thermostat to dynamically change the temperature of the room based on the user's sleep stage. By dynamically adjusting the ambient temperature in response to physiological markers, we hope to improve quality of sleep beyond the benefits of an ideal static temperature.

Chapter 2

Background and Significance

2.1 Effect of Sleep on Health

Disruptions in sleep can have significant short and long-term health consequences [1] [4].

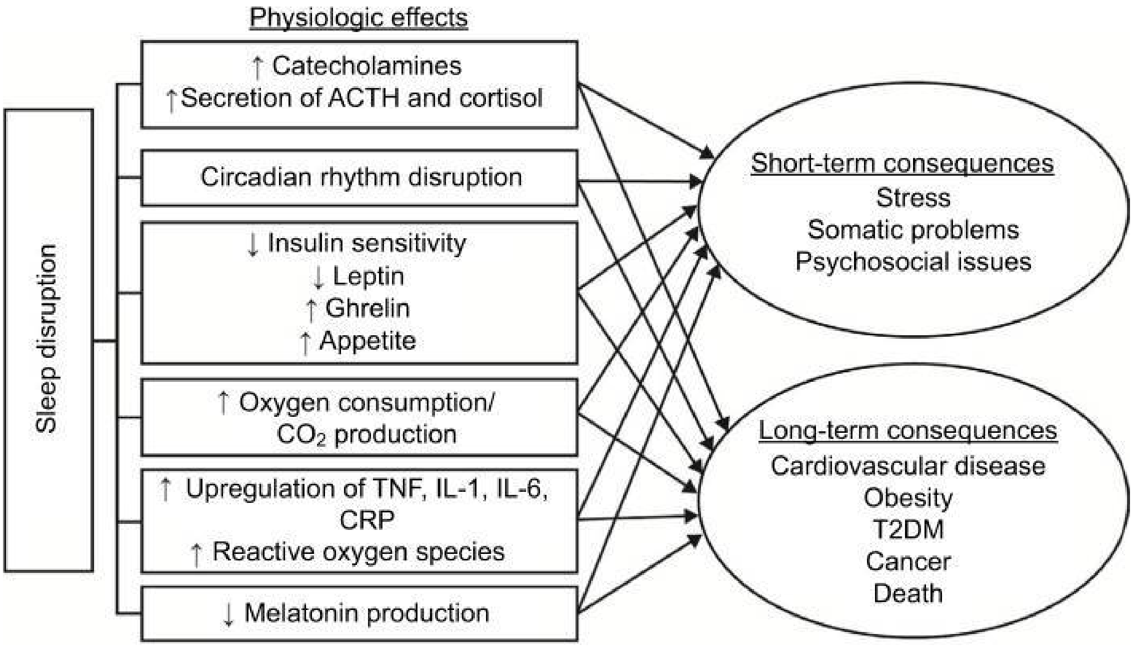

Fig. 2.1: Mechanisms for short-term and long-term consequences of sleep disruption [1].

Sleep also plays a critical role in our mental and physical health, impacting our systemic physiology. Mentally, a lack of sleep impairs higher-level reasoning, problem-solving, and attention to detail. Thus, it can affect your productivity and alertness, increasing the risk of accidents such as traffic accidents or falls. On top of affecting your ability to process information, it affects your overall mood and social health. Chronic sleep deficit can even put you at a greater risk for depression [5]. Physically, sleep impacts systemic physiology including metabolism, appetite regulation, immune system function, hormonal systems, and the cardiovascular system [1]. As such, sleep deficiency can lead to various chronic health conditions including heart disease, kidney disease, high blood pressure, diabetes, stroke, and obesity [6]. In the context of physical performance, sleep loss impairs a person's ability to recover after exercise, heightens fatigue, and decreases vigor [7]. As such, to improve the mental and physical health of the population, there exists a demand to improve the quality of sleep an individual receives.

2.2 Sleep

During sleep, the human body cycles between two major phases of sleep: rapid eye movement (REM) and non-rapid eye movement (NREM). NREM is further divided into three subphases named N1, N2, and N3. Stages N1 to N3 are a part of NREM sleep with each stage indicating a progressively deeper sleep. Approximately 75% of sleep is spent in NREM. The progression of sleep stages typically occurs in the order: N1, N2, N3, N2, REM. While the first REM period is short, as the night continues, the period spent in REM increases and time spent in NREM decreases [8].

Each sleep cycle stage varies in physiological markers such as muscle tone, brain activity, and eye movement. In a given night, the body will cycle through all of these stages 4-6 times with the average cycle length being 90 minutes [9]. The body's sleep-wake cycle is known as the circadian rhythm which is controlled by an internal clock. This internal clock follows an approximately 24-hour period and is controlled partially by ambient light to follow the rise and set of the sun [10].

An electroencephalogram (EEG) measures brain waves which are characterized

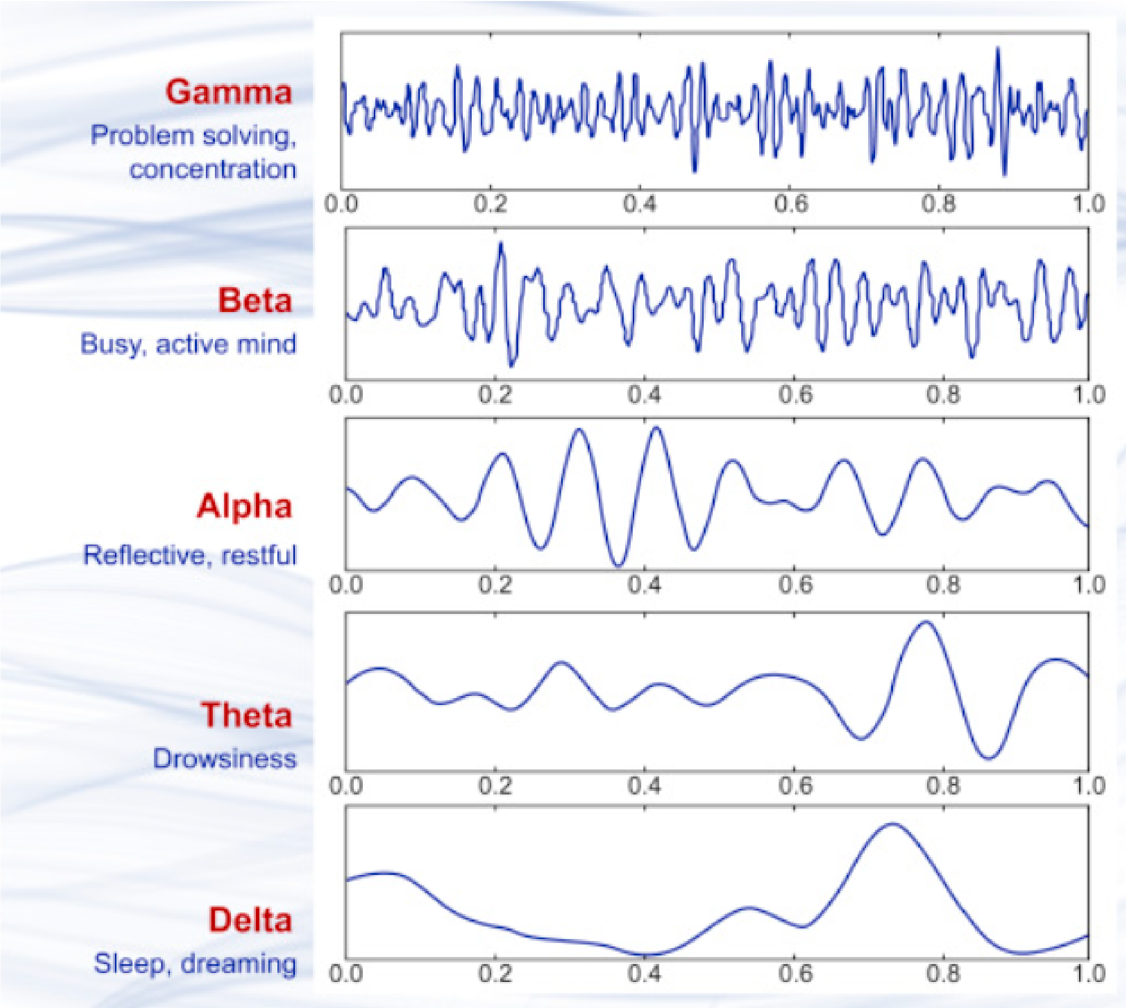

Fig. 2.2: Gamma, beta, alpha, theta, and delta frequency band examples from an EEG [2].

by their frequency, separated into 5 frequency bands. Gamma waves (>35 Hz) indicate concentration, Beta waves (12-35 Hz) indicate a busy, active mind, Alpha waves (8-12 Hz) indicate relaxation, Theta waves (4-8 Hz) indicate deep relaxation and drowsiness, and Delta waves (0.5-4 Hz) indicate sleep [2]. The relative intensities of the frequency bands indicate the user's sleep stage. As described above, as the user falls asleep, the high frequency signals give way to lower frequency bands such as Theta and Delta waves. Sleep physicians use the information collected through EEGs to diagnose patients with sleep disorders.

2.3 Sleep Disorders

Sleep problems can include deficits in both the quantity and quality of sleep [1]. The recommended amount of sleep by the National Sleep Foundation depends on the individual's age. Young adults, aged 18-25, and adults, aged 26-64, should receive between 7 and 9 hours of sleep each night. Older adults, aged 65 and up, should receive between 7 and 8 hours of sleep each night [11]. According to the CDC, more than 1 out of 3 Americans do not report getting the recommended amount of sleep. Although short-term sleep struggles or irregularities such as a few days are fine, repeatedly going outside of the recommended hours can lead to serious health problems or exacerbate existing conditions [12].

In general, a sleep disorder is any condition that impairs someone's sleep or prevents them from getting restful sleep. Approximately 70 million Americans suffer from chronic sleep disorders [13]. Sleep disorders are characterized by persistent difficulty sleeping, sleepiness during the day despite obtaining the recommended amount of sleep, and/or reduced or impaired ability to perform regular daytime activities due to difficulties sleeping [14]. The International Classification of Sleep Disorders defines the following categories of sleep disorders: Insomnia, sleep-disordered breathing, central disorders of hypersomnolence, circadian rhythm sleep-wake disorders, parasomnias, and sleep-related movement disorders [15]. Sleep disorders result from various different causes with no one solution to the broad classification of diseases [15].

Sleep disorders are complex with various genetic, lifestyle, and environmental factors affecting an individual's risk. For example, consider Insomnia. Insomnia has several risk factors including advancing age, family history of insomnia, sex, lifestyle, increased stress or worry, and medical psychiatric disorders. Older individuals have a higher risk of insomnia. Genetics can influence your risk of insomnia, predisposing you to the disorder. Women are also more likely compared to men to have insomnia. Lifestyle factors such as drinking excessive caffeine or alcohol, consuming nicotine, long naps near bedtime, and having an irregular sleep schedule can also increase your risk of insomnia. Finally, medical disorders such as heart disease, asthma, or psychiatric disorders are associated with insomnia [16]. Interestingly, clinicians trying to assess sleep disorders can encounter challenges when ”untangling the causes and effects of bidirectional comorbidities” [17].

2.4 Existing Sleep Solutions

2.4.1 Clinical Solutions

To provide patients with clinical diagnoses and treatment, patients must see a board-certified sleep physician. Currently, there are only approximately 7,500 board-certified sleep physicians in the United States [18]. With 70 million people suffering from sleep disorders in the US and only 7500 board-certified sleep physicians, there exists an obvious logistical problem. Although doctors can diagnose some sleep disorders by collecting information from the patient and their relatives through questions, physicians will often turn to sleep studies and other medical tests to diagnose patients [19].

A sleep study, or polysomnogram, measures various different physiological markers during a patient's sleep cycles. Polysomnograms combine an ”electroencephalogram, electrooculogram, electromyogram, electrocardiogram, and pulse oximetry, as well as airflow and respiratory effort, to evaluate for underlying causes of sleep disturbances.” [20] Polysomnograms are considered the gold standard and are used to diagnose sleep-related breathing disorders, nocturnal seizures, narcolepsy, periodic limb movement disorder, and rapid eye movement sleep behavior disorder [20]. These sleep studies typically sleep centers and last overnight. Removable sensors are placed over a patient's body to record brain waves, heart rate, breathing rate and effort, oxygen levels, and muscle movements before, during, and after sleep [21]. Criticisms of sleep tests include that they do not accurately emulate a patient's actual sleep conditions due to the foreign environment and sleep conditions [22]. Although these studies are excellent at diagnosing sleep disorders, they do not represent an accessible solution to sleep issues. Clearly, there exists an opportunity for an accessible technological solution to easily monitor and improve sleep through DreamTemp. Although DreamTemp will not diagnose sleep disorders, our technology can nonetheless assist individuals in their goal to improve their quality of sleep and health.

2.4.2 Lifestyle Solutions

Although there is no replacing board-certified sleep physicians for diagnosis and treatment, there are nonclinical ways to improve the quality of your sleep. According to the AASM, your behaviors during the day, and especially at night, can affect your sleep quality. This includes your daily routines, what you eat and drink, what medications you take, etc [23]. To establish healthy sleep habits, the CDC recommends being consistent with when you wake up and fall asleep. It is also recommended to avoid large meals, caffeine, and alcohol before bedtime. Other ways to improve sleep include exercising during the day, removing electronic devices from your bedroom, and setting up a quiet, dark, relaxing, and comfortable temperature bedroom [24] [25] [26] [27]. Sleep experts also advise that your bed should only be sleeping to avoid psychological ties between being in bed and being awake. Cognitive behavioral therapy (CBT) has also been shown to combat insomnia, specifically a method called CBT-I. CBT-I includes multiple components such as sleep education, sleep restriction therapy, stimulus-control principles, cognitive therapy, and relaxation strategies [26]. These studies emphasize the ability of lifestyle changes to improve sleep quality.

2.4.3 Technological Solutions

Of course, in addition to lifestyle changes, medical and technological advances can also improve sleep. Melatonin supplements are commonly used to help individuals fall asleep [28]. Melatonin is a hormone produced by the pineal gland during dark hours and plays an important role in the regulation of the sleep-wake cycle. Exogenously administered melatonin supplements (AKA edible melatonin supplements) have been shown to be beneficial in treating certain types of insomnia [29]. Several other supplements can be used individually or in parallel with other strategies to improve sleep including lavender, L-theanine, magnesium, valerian root, glycine, and ginkgo biloba. However, some techniques are not recommended for daily use or need more research to understand their complete effects and benefits [28]. Technologies that can improve sleep include the Oura ring, blue-light-blocking glasses, cooling headbands, and an array of other technologies [30]. Most of these technologies, particularly wearable electronic sleep technologies, only monitor sleep and fail to offer solutions. Meanwhile, DreamTemp presents itself as a solution that can both monitor and improve sleep.

2.5 Effect of Temperature on Sleep

According to Alon Avidan, director of the UCLA Sleep Disorder Center, the ideal thermostat temperature is between 60 - 65 degrees Fahrenheit for adults [28] [31] [32]. This ideal temperature ranges from person to person [32]. For example, as we age, our body temperature, melatonin release, and cortisol decrease which may change the ideal temperature for sleep. Meanwhile, the ideal temperature for babies is slightly higher compared to adults, sitting at an ideal temperature between 65 - 70 degrees Fahrenheit. This is partly attributed to babies not being able to regulate their body temperature as well as adults and their smaller bodies being more sensitive to changes in ambient temperature [32] [33]. The ideal temperature is also affected by different amounts of thermal insulation on the person (bedding, clothing, etc). As such, existing literature suggests a wide range of ideal temperatures anywhere from 68 degrees Fahrenheit (covered subjects) to 90 degrees Fahrenheit (naked subjects) [3] [34]. Importantly, this means that we must account for differences in patients' thermal insulation when designing the temperature optimization algorithm.

The ambient temperature of someone's bedroom can cause sleep disturbances because our circadian rhythm can be affected by the core temperature of the body [35]. The human body's core temperature sits around 98.6 degrees Fahrenheit, fluctuating by 2 degrees Fahrenheit throughout the night. As the body prepares for sleep, the body releases melatonin, coinciding with a drop in body temperature. Broadly, this decrease in temperature continues throughout the night and reaches a low point in the early morning and then gradually increases as the morning progresses [36]. More finely, it has been established that the body,Äôs core temperature fluctuates during different stages of sleep. The body's core temperature decreases as the person falls asleep and gradually rises as they reach deep sleep [37]. According to Ngarambe et al., ”This implies that, to achieve a sufficient quality of sleep, the body’s core temperature must be maintained at a level appropriate to each sleep stage” [3]. Utilizing this information, our solution aims to dynamically adjust the temperature of the room based on the user’s sleep cycle.

The body’s temperature can affect sleep onset, sleep quality, and time spent in different sleep stages. One study showed that having a higher core body temperature can lead to reduced amounts of restorative slow-wave sleep and decreased subjective sleep quality [38]. During REM sleep, the body stops most temperature regulation such as sweating or shivering [39]. This leaves the body more sensitive to changes in ambient temperature. Additionally, high ambient temperatures also appear to lessen the time spent in REM sleep and increases in core body temperature or ambient temperature promote wakefulness [40] [22] [41]. Ambient temperatures above or below thermoneutrality had similar effects on sleep patterns, with the most extreme cold temperature conditions being more disruptive than the extreme warm ambient temperatures [42]. However, a mild to moderate increase in ambient temperature during deep sleep has been shown to increase the length of deep sleep and can be used in our study [43] [44]. Ultimately, the above information outlines the various effects of temperature on sleep. From the information above, we can conclude that ambient temperature can impact someone’s sleep cycle and we can use this to promote high quality sleep by dynamic adjustments to the ambient temperature.

2.6 Heartrate to Sleep Stage

Literature has also shown that a person's sleep cycle can be determined by their heart rate data alone, bypassing the need for an EEG as used in traditional sleep studies. One study noted that the average heart rates for each sleep cycle are statistically different [45]. The same study noted a more dramatic difference between REM and NREM. Because heart rates are different depending on the sleep cycle, particularly between REM and NREM, we will theoretically be able to determine sleep stage from heart rate data alone. Another study presented a method to determine sleep stages using only an electrocardiogram (ECG) data using machine learning [46]. Although Fitbit,Äôs ability to be used as an ECG appears limited, this presents itself as a consideration for future work [47].

2.7 Related Work

Ngarambe et al. developed a system that investigated the effects of dynamically changing the ambient temperature based on the user's sleep stage [3]. They used an IoT based thermostat system and sensors placed beneath the mattress to detect movement and determine the subject's sleep stage. Ultimately, Ngarambe et al. determined a positive effect on subjective sleep quality using the dynamic ambient temperature condition over the static temperature condition. To evaluate subjective sleep quality, participants completed a questionnaire after waking up. Our project builds upon this study by using a smart wearable instead of a seniors placed under a mattress. Using a smart wearable is a much more user-friendly option as the user simply has to wear the smart wearable instead of setting up multiple sensors. This option is also cheaper, aligning with our goal to develop an accessible solution to improve sleep quality.

Chapter 3

Design and Implementation

3.1 Application Architecture

At a high level, our application can be thought of as having a Front End, and a Back End. Figure 3.1 shows the overall system architecture. The Back End is served to the client via an NGINX reverse proxy.

The Front End (See 3.2 is responsible for all user interactions including new user account creation and controlling the temperature optimization system for their account. This includes responsibilities like interacting with the Fitbit and Nest APIs for account creation, and interacting with the Back End server to indicate when the user goes to sleep and wakes up.

The Back End (See 3.3) is responsible for running the optimization algorithm on users and has features designed to accomplish that end. It exposes a set of APIs used for new user onboarding, and for controlling the optimization of those users. It is also responsible for storing user data in persistent storage through the user of a relational database. The NGINX reverse proxy is responsible for encrypting content and serving the server's SSL certificate to ensure user data is protected and in compliance with HIPAA guidelines.

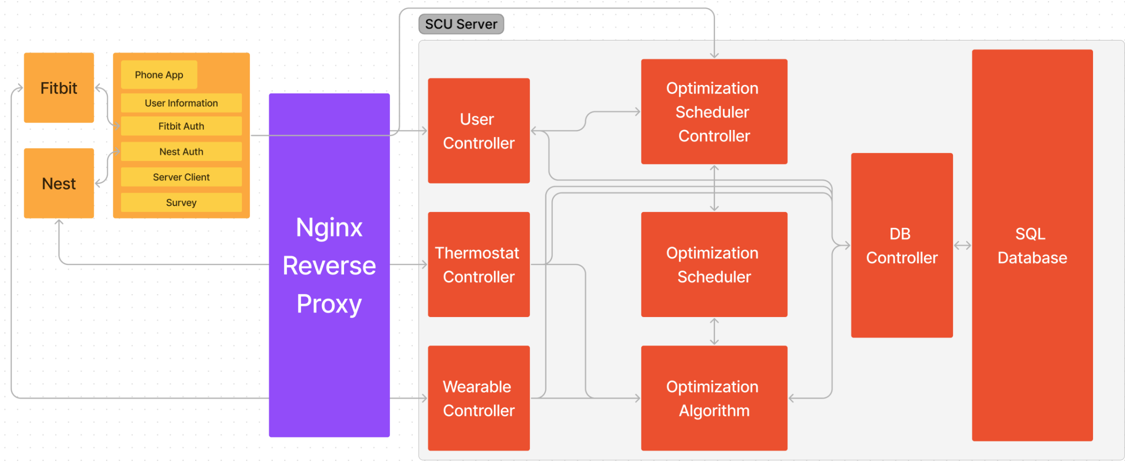

Fig. 3.1: Overall system architecture.

3.2 Frontend

3.2.1 Design Rationale

Aside from using the smart wearable, there are additional times when the user will need to interact with the system. Some only take place once like creating a user id and linking themselves to the appropriate smart wearable and thermostat. Others are repeated aspects of using the system such as signaling when they've gone to sleep and submitting sleep quality surveys when they wake up.

DreamTemp uses a mobile app for the user to interact with the system. This was decided because it would be more convenient to access than a web app. In addition, the study conducted by Ngarambe et al. required a system of multiple sensors that would have been quite difficult for the average user to set up and use, so ease of set up and use were heavily taken into consideration during the design of our system, especially in regards to user experience.

The first screen the user will see on the mobile app is the sign up page. In order to comply with HIPAA and IRB standards, each user creates their own user

ID that all their data is linked to. The user ID data is anonymous, complying with ethical standards of privacy. In addition, once the user Id is created, it is stored permanently on the local disk of the user's device so that the user does not have to keep logging in repeatedly. The app then goes through the process of linking the user's account to the proper smart wearable and thermostat so that the system is communicating with the correct devices. We will go further in depth regarding this process in the next section. From there the use of the app turns into a cycle. There is a page with a sleep button that you hit when you go to sleep. Then a feature called a sleep loading page that has a wake up button will appear. This page stays for five minutes and if the user clicks the wake up button within these five minutes, they will be redirected back to the page with the sleep button. Otherwise if five minutes have passed without the user hitting the button, the page will transition into a sleep survey that the user can take once they wake up. Submitting the survey essentially sets the user as awake in our system and we can stop heartbeat collection and temperature optimization. Once the user submits the survey, the page with the sleep button appears and the cycle begins again. The purpose of the sleep loading page is for instances where a user either hits the sleep button but can't fall asleep or they accidentally clicked the sleep button and didn't mean to. We wanted the user to be able to wake themselves back up in the system without having to submit a survey with false answers regarding a portion of time in which they didn't actually sleep. In addition, just as how submitting the survey in the morning stops the system's heartbeat collection and temperature optimization, we begin both of these processes when the sleep loading page transitions into the sleep quality surveys. This means that when the transition happens, a message is sent to the backend indicating that the user has fallen asleep. This helps us to avoid the scenario where the system begins heartbeat collection and temperature optimization just to find out that a user accidentally hit the sleep button.

3.2.2 Implementation

For the front end of our project we decided to use the Flutter framework because it is cross compatible with both IoS and Android, thus allowing us to develop for both platforms with a single code base. For our smart wearable we decided to use a Fitbit because when we were looking at other smart wearable such as Apple watches and Oura rings, Fitbit was the only one that had a real time heartbeat collection API. For our smart thermostat, we decided to use a Google Nest Learning thermostat because of the substantial developer support that already exists for it.

Fitbit Authentication

We utilized a Flutter package called Fitbitter to assist us with authentication. After the user has created their user ID, they are redirected away from the app and to a browser where the user is prompted to sign into their Fitbit account. Once the user has signed in, Fitbitter returns an access and refresh token that we can use to communicate with the user's Fitbit. We then send this access token to our backend where it is stored in a database with the user's corresponding user ID. This process essentially links the user to their Fitbit and ensures that we will be analyzing heartbeat data from the correct device. Afterwards, the user is redirect back to the app. This was accomplished using deep links to create a custom URL for our app that was used as our redirect URL.

Nest Authentication

After linking the user and their Fitbit, we follow a similar process in order to link the user and their Nest Thermostat. We use Google authentication APIs that redirect the user from the app to a browser that prompts the user to sign into the Google account associated with their Nest Thermostat. This returns an authorization token. In order to get the access token needed to communicate with the thermostat, we needed to make projects both on Google's Cloud Console and their Device Access Console. This provides us with client secrets and other various IDs that, combined with the authorization code, allow us to acquire the access token from Google. We followed the same process of sending the access token to our backend so that it could be stored in our database with the user's corresponding user ID. Afterwards, the user is redirect back to the app.

3.3 Backend

3.3.1 API Endpoints

UserDataController Component

The *UserDataController* component is used to transmit user data between the phones of each user and the server. The core APIs for this component are described in Table 3.1. First, the *UserDataController* provides a set of APIs to simplify the process of creating and receiving information from the participants of the study. The *UserDataController* is then responsible for processing and storing the relevant data through interaction with the *DatabaseController*.

The AddUser endpoint is the first step in user creation and is passed a user id,

Table 3.1: UserDataController APIs

UserData/	**HTTP Method**	**Description**
`AddUser`	POST	Adds a new user to the system.
`LinkFitbit`	PUT	Link's a user's fitbit account to their user account
`LinkNest`	PUT	Link's a user's nest account to their user account
`GetUserIds`	GET	returns a list of all valid user ids
`UserExists`	GET	returns true if the user exists or false if the user does not exist
`SubmitSurvey`	POST	Submit the user's sleep survey to end their nights sleep

the user's age, and the user's sex. This information is stored in the users table by the *DatabaseController*. The user creation is not completed until that user has also linked a supported wearable and thermostat to their account.

The LinkFitbit endpoint is used to link a Fitbit wearable to the user to be used for heartbeat data collection. It is passed a user id, fitbit id, access token, and refresh token. This information is stored in the fitbitUsers table by the *DatabaseController*. Attempting to call LinkFitbit on an invalid user id will return a 400 bad request response.

The LinkNest endpoint is used to link a Nest Thermostat to the user to be used for temperature data collection and adjustment. It is passed a user id, access token, refresh token, and token expiration time. This information is stored in the nestUsers table by the *DatabaseController*. Attempting to call LinkNest on an invalid user id will return a 400 bad request response.

The GetUserIds endpoint is used to obtain a list of all current valid user IDs. This endpoint was created for development purposes and is not directly used by the final product.

The UserExists endpoint is used to check if a given user id is a valid user in the

Table 3.2: SleepOptimizationManagerController APIs

Manager/	**HTTP Method**	**Description**
`Sleep`	PUT	Set the given user to be asleep
`Wake`	PUT	Set the given user to be awake

system. It can be used by the client to ensure that their user is configured correctly.

The SubmitSurvey endpoint is used to submit a sleep survey in the morning after a user optimizes their sleep. These surveys are used to validate the effectiveness of the sleep optimization system. The client must pass a user id, and answers to the questions q1, q2, q3, q4, q5, q6, and q7. The client must also pass the waketime of when the user woke up. Attempting to call SubmitSurvey on an invalid user id will return a 400 bad request response.

SleepOptimizationManagerController Component

The *SleepOptimizationManagerController* component is used to control the sleep state of the current users. The core APIs for this component are described in Table 3.2.

The Sleep endpoint is used to tell the system to mark a given user as being asleep. Calling Sleep on a user that is already sleeping will return a 400 status code.

The Wake endpoint is used to tell the system to mark a given user as being awake. Calling wake on a user that is already awake will return a 400 status code.

Both of these endpoints work with the *OptimizationScheduler* (See 3.3.5) to control which users are asleep and which are awake.

Table 3.3: HealthController APIs

Health/	**HTTP Method**	**Description**
/	GET	Returns 200 OK response code

HealthController Component

The *HealthController* component is used to validate the the server is running and measure it's uptime. The APIs for this component are described in Table 3.3.

The Health/ endpoint is used to logging and to ensure that the backend is running properly. In a production environment this endpoint would be hit every minute, and an on call engineer would be notified if it did not respond with a success status code.

3.3.2 Database Abstraction

DatabaseController

The platform uses the *DatabaseController* component to manage all database queries. This layer exists to protect the information in the database and comply with HIPPA standards, and increases the overall testablity of the code by separating the actual database calls from the functions that need their data. The core APIs of this component are described in Table 3.4.

DatabaseReader

The database calls are managed using a custom database reader written to accommodate this project's needs. It provides a layer of abstraction around dealing with the direct database calls, and greatly simplifies the process of making database calls.

Table 3.4: DatabaseController APIs

Method	**Description**
`addUser()`	Add a user to the database including all relevant information for that user
`linkFitbitToUser()`	Link a user's fitbit account to their user account in the database
`linkNestToUser()`	Link a user's nest account to their user account in the database
`refreshFitbitUserAuth()`	Update a user's fitbit credentials in the database
`refreshNestUserAuth()`	Update a user's nest credentials in the database
`addSurvey()`	Stores a user's sleep survey in the database
`getUsers()`	Get a list of all users from the database
`getUser()`	Retrieves a specific user from the database
`getSleepSession()`	Returns a user's most recent completed sleep Session
`submitSleepPacket()`	Submit a user's sleep state data to the database

By using disposable database reader objects, the backend uses only a single database connection across all database calls. It is constructed by taking in the database connection, and the type, T, of the object being used for the database transaction. The databaseRead method takes in the sql command to be executed as a string, and a function that can process the datatable result into a list of type T. The databaseWrite method takes in a function that converts an object of type T to a sql command, and the object of type T to be written.

Both of these methods execute the database transactions safely, and roll back the transaction should any errors occur. They both also manage the database connection and check the status of the connection before executing.

3.3.3 Wearable Controller

The wearable controller is a generic component that is used to retrieve heartbeat data from a user.

The interface used has only one method, getHeartbeatData(). It returns a promise to a generic heartbeat data packet.

Fitbit Controller

The Fitbit controller is a wearable controller that is used to read data from a Fitbit. It implements the getHeartBeatData() method and reads the most up to date heartbeat data for the user. It is the only wearable controller currently implemented.

The Fitbit controller relies on a FitbitAuthenticator object created for this project in order to manage user api credentials. Fitbit implements a verion of the OAuth2.0 security standard, and the FitbitAuthenticator manages and adheres to those standards. It has one public method, checkAuth(). The checkAuth method ensures that the given user has a valid access token for the Fitbit API, if the token is expired, it requests a new token before returning.

3.3.4 Thermostat Controller

The thermostat controller is a generic component that is used to get and set the temperature of a user.

The interface has two methods, getTemperature, and setTemperature. The getTemperature method returns the current ambient temperature of a user in celcius. The setTemperature method sets the temperature of a user's thermostat to the given temperature in celcius.

Nest Controller

The Nest Controller is a thermostat controller used to get and set the temperature of a Nest Thermostat.

The nest controller relies on a NestAuthenticator object created for this project in order to manage user api credentials. Nest implements a verion of the OAuth2.0 security standard, and the NestAuthenticator manages and adheres to those standards. It has one public method, checkAuth(). The checkAuth method ensures that the given user has a valid access token for the Nest API, if the token is expired, it requests a new token before returning.

3.3.5 Optimization Scheduler

The Optimization Scheduler is responsible for keeping track of which users are sleeping and which are awake. It is also responsible for running a given optimization on those users.

The methods of this class are outlined in Table 3.5.

Table 3.5: OptimizationController Methods

Method	**Description**
`wakeUser()`	Indicates a user is awake and stops optimizing their temperature
`sleepUser()`	Indicates a user is asleep and starts optimizing their temperature
`optimizeUserSleep()`	Optimizes the temperature of all sleeping users periodically.

The wakeUser method is called by the SleepOptimizationManagerController (See 3.3.1) and is responsible for ending a user's temperature optimization at the end of their sleep.

The sleepUser method is called by the SleepOptimizationManagerController (See 3.3.1) and is responsible for starting a user's temperature optimization at the start of their sleep session.

The optimizeUserSleep method is called when the object is created during the bootup of the backend. It calls the optimizeTemp method on the optimizer passed to it on every sleeping user once per minute. It does this for all users that have been asleep for longer that 5 minutes. The optimizer runs the optimization for each user in parallel, using an async await pattern to ensure that none of the IO done by the optimization blocks the main thread.

3.3.6 Design Rational

The Back End was designed with a number of design best practices in mind. Separation of concerns, Dependency inversion, Encapsulation, Single responsibility, and Don't Repeat Yourself (DRY)

Separation of Concerns [48] is a design principle that says software should be separated based on the kind of work it does. This principle can be seen at play in the existence of the many components of the Back End, and how related components perform related tasks.

The Dependency inversion [48] principle states that the direction of dependency within the application should be in line with the direction of abstraction, and not the direction of implementation. Essentially, a given class should never directly depend on a different class, only ever an interface of that class. Doing this decouples the two objects and makes them both more maintainable and testable. Making a change to the implementation of a particular object will not require any changes to the objects that depend on it. This principle is used extensively in the Back End for every object that has dependencies. Notably, the optimization scheduler can use any object that implements a generic optimization interface, and use any wearable or thermostat that implements their respective interfaces.

Encapsulation [48] is a principle of object oriented programming that says different parts of the application should be insulated from the other parts of the program. Changing the implementation details of a particular method should not impact any calls to that method. Properly following this principle can lead to more loosely coupled objects and generally makes code more readable. The calling object should not need to worry about the implementation of how a method works to use it correctly. This principle was closely followed, especially as it relates to database calls and the OAuth2.0 authentication workflows for the Fitbit and Nest APIs

The Single Responsibility Principle states that "objects should have only one responsibility and that they should have only one reason to change" [48]. For example, the FitbitAuthenticator object is only responsible for managing the OAuth2.0 authentication for a Fitbit. The OptimizationScheduler is only responsible for managing when the optimization runs. That sort of thing.

The Don't Repeat Yourself, or DRY, principle means that everything said in your code should only be written once [48]. It is very important for the maintainability of code because it means that any code to be updated only needs to be updated once. It is important to note that behavior that is only repetitive by coincidence should still exist separately in case the design constraints of one section of the code should change but not the other.

3.3.7 Technologies Used

The Back end of the project is using an ASP.Net 6.0 webserver written in C#. We are also self hosting a MySql server locally to store participant data. The webserver is used to interact with the participants phones via REST API calls, store data in the database, and control the temperature of each of the participantś nest devices. We chose to use C# because of our familiarity with the language, the amount of documentation and support that exists around the language, and for the extensive amount of libraries build to create REST APIs with the language.

We chose to use a relational database because of the highly relational nature of the data. Due to the way heatbeat and temperature data will be returned to our system, we are forced to join these datasets via a series of keys, which is not an easy operation to perform in a NoSql database. We will also need to run large aggregation queries on this data, which is again difficult when dealing with a document based database. For these reasons we chose to implement a relational database for our platform. We chose MySql because it is free, and easy to configure on our local machine.

Chapter 4

Test Plan

Using the above system and devices, we will perform our study. Participants will have the Nest thermostats installed in their residences and will wear a Fitbit for the duration of the night. After pressing the "Go to Sleep" button on the mobile app, our system will begin collecting their heartbeat data using Fitbit APIs. This anonymized data will be sent to our backend where we will use the data to determine their sleep cycle. Using this information, we will then use the temperature optimization algorithm to determine the ideal temperature based on the subject's test condition. The test conditions are: 1) No temperature control condition, 2) Ideal literature temperature, 3) Test condition.

In the no temperature control condition, we will not control the temperature of the individual's room. In the ideal literature temperature condition, we will set the room's temperature to the ideal literature temperature between 60-65 degrees Fahrenheit. In the third condition, our experimental condition, we will implement our dynamically controlled temperature algorithm based on the person's sleep cycle. This study design will allow us to test if the temperature control algorithm improves the quality of sleep over the no temperature condition, but also test if the temperature control algorithm performed better than the ideal literature temperature condition. By cycling participants through these three conditions depending on the night, we can get equal amounts of data for each condition. This design also allows us to test multiple different temperature optimization algorithms to determine the best dynamically controlled temperature algorithm. The flexibility of our system that allows for this testing is one of our strengths.

Our system will continue to adjust the temperature of the participant's room depending on their current test condition until they press the "Wake Up" button on the mobile app. This will prompt the participant to complete the sleep quality survey. We will use a subjective questionnaire to evaluate the quality of sleep of our participants. The self-rating Scale for Sleep and Awakening Quality questionnaire can be seen below.

Questions	Score
1. How well did you sleep?	1 (Poor) 2 3 4 5 6 7 (Very good)
2. Did you sleep well?	1 (Not at all) 2 3 4 (Very much)
3. Did you have deep sleep?	1 (Not at all) 2 3 4 (Very much)
4. Did you have difficulty in falling asleep?	1 (Not at all) 2 3 4 (Very much)
5. Did you have difficulty staying asleep?	1 (Not at all) 2 3 4 (Very much)
6. Do you feel refreshed after sleeping?	1 (Not at all) 2 3 4 (Very much)
7. How many times did you wake up during the night?	0 (Never) 1 2 3 4 5 (5 times)

Fig. 4.1: Scale for Sleep and Awakening Quality questionnaire questions [3].

Using the data we collect, we will be able to perform various analyses including comparing sleep quality based on the ambient temperature condition, the lag time between setting a temperature using the optimization algorithm and the room reaching that desired temperature, and other tests we may be interested in. Because we did not receive IRB approval for our system yet, we were unable to test our system on any subjects. We also lacked the ability to test the system on ourselves because our residences were incompatible with a Nest Thermostat. However, we were able still collect heartbeat and sleep stage data from our group members. The beats per minute data was collected in real time and the sleep stage data was collecting retroactively from Fitbit.

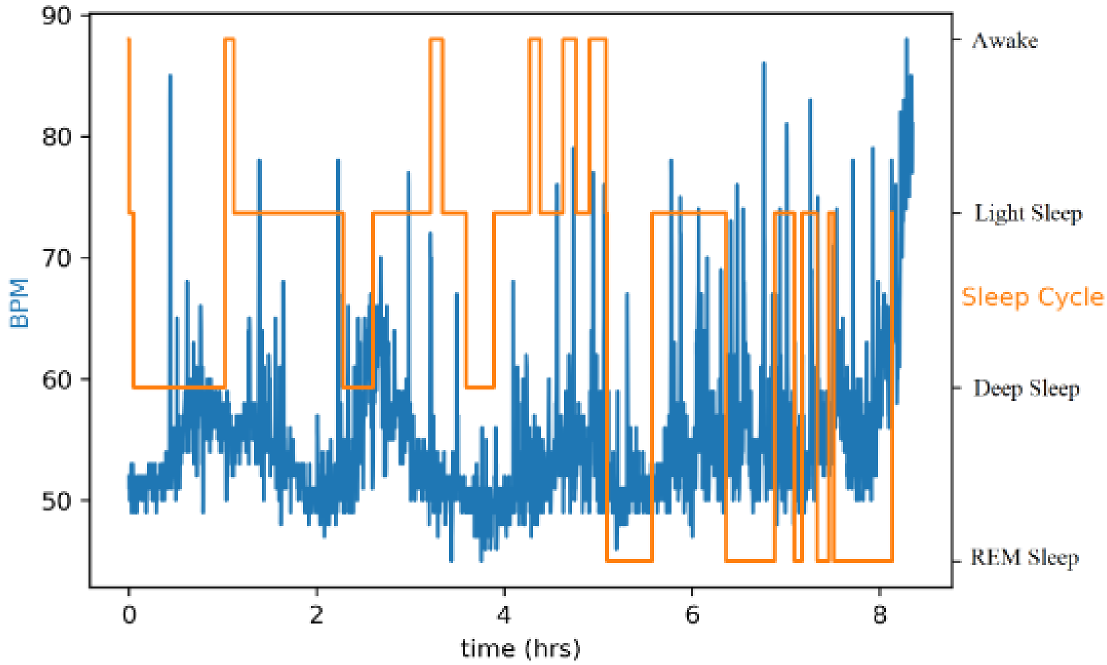

Fig. 4.2: Beats Per Minute (BPM) and Sleep Stage during a night's sleep

Despite the challenges we encountered in testing our system's effect on sleep quality, we successfully developed the front-end and back-end which integrated the Fitbit and Nest Thermostat to allow for these experiments to be performed by future groups.

Chapter 5

Societal Components

5.1 Ethical Concerns

Privacy is one of the primary ethical concerns present in our project. Because heartbeat data is classified as protected health information, we designed our solution to be compliant with HIPAA standards. In addition to extensively testing our backend for security risks, we anonymize the data that we receive. This ensures that our solution is HIPAA compliant. Through these measures, we are privacy and security of protected health information.

5.2 Social Justice

Developing technology to monitor and improve sleep will not only improve the health of the general population, but it will also help promote social justice and equality. Studies have shown that poor sleep takes a disproportionately large toll on people of color. Specifically, the studies noted that people of color are more likely to take longer to fall asleep, wake up during the night, and spend less time in deep sleep. Furthermore, sleep disorders are twice as common in people of color [49]. Directed towards improving the sleep quality of all, DreamTemp strives to address this healthcare inequality by developing an accessible solution.

5.3 Sustainability and Environmental Impact

It is important to note that heating and cooling rooms comes with high energy demands. As such, dynamically changing the temperature of a room using DreamTemp can present difficulties. Despite the initial concerns, DreamTemp could offer energy savings. Instead of changing your thermostat temperature manually to find the perfect temperature, DreamTemp could offer energy savings by immediately bringing your room to the ideal temperature. This environmental impact of our technology should be investigated to understand the differences in energy demand between a dynamically adjusted temperature condition to a static temperature condition.

5.4 Scalability and Consumer Adoption

It is important when looking at the future of this project to consider the scalability of the system. This version of the project was designed for research purposes and does not scale to accommodate an infinite number of users. Because of the Back End's monolithic structure, our project only scales to accommodate as many users as our one machine can serve. If this project were to be made available to a consumer audience, the main factor to consider would be synchronizing data across machines. We would advise that the core functionality is containerized and managed with Kubernetes, and the storage is separated to use a distributed or cloud-based storage solution for user data. Each container could be responsible for optimizing a subset of users.

5.5 Usability

Our system is designed to be easy to set up and use. The user simply needs to set up their Fitbit and Nest and then from then on everything is on the app. We wanted our app to be intuitive to use. We have minimal distractions and large buttons and text to make it more accessible to all people.

Chapter 6

Conclusion

We have created a powerful platform that allows people to take their sleep into their own hands. DreamTemp is capable of reading user's heartbeat data in real time and controlling the ambient temperature of their sleeping environment. It effectively utilizes technology to both monitor and improve user's sleep health. DreamTemp also presents itself as an secure, accessible, and easy to use system. The combination of these features sets DreamTemp apart from other existing sleep aid solutions on the market. The use of our technology could hopefully revolutionize the way we manage our sleep.

There were many lessons learned during the development of the DreamTemp platform. Both the Back End and Front End designs underwent many architecture iterations before landing at our current implementation. The process of reiteration emphasized the importance of various software engineering best practices outlined in our design rational. Through the practice of these skills, we are better prepared to build more powerful systems and provide service to our communities through engineering efforts.

In building a system to comply with HIPAA data privacy standards, we learned a great deal about information security and how to build a robust, secure system. This involved learning about HTTPS internet transfer, OAuth2.0 authentication, and protecting a database against SQL injections.

We also learned a significant amount of information regarding sleep and its effects on health. We also learned about the disparities in sleep health found in the population and are motivated address this social inequity in the future through our work as engineers and through the dissemination of sleep health education. Due to our goal to reduce social inequities, we remained dedicated to building an accessible solution to improve quality of sleep.

Overall, we believe that the platform we created has a huge potential to impact people's well-being. Future work will allow us to test our systems benefit and develop the optimal temperature optimization algorithm. As the system matures, we would also love to hear from customers regarding their user experience to refine our UI. We are proud to have developed a system that has the potential to positively impact the population and we look forward to our future contributions as engineers to a more just, sustainable, and healthy world.

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Signature for Inter Thesis- DreamTemp

Final Audit Report 2023-06-20

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By:	Jean Tsai (ctsai2@scu.edu)
Status:	Signed
Transaction ID:	CBJCHBCAABAAJlhiYnNWLur9Rm7puy-OixboIzQnVtZd

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