Electrical Muscular Stimulating Sleep Analyzer

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Superficial Muscular Stimulating Sleep Analyzer

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Abstract

Sleep is one of the most crucial components for optimal physical and mental health, and it plays a large role in ongoing bodily repair. However, despite the importance of sleep, an estimated 40 million people in the United States alone have some form of chronic sleep disorder annually [16]. Our product is designed to track a person's biometrics through a wearable armband for night use that will be able to detect the stages of sleep indirectly. The biofeedback from the device would then activate an electrical muscular stimulator that would release a current to force muscle contractions in order to wake a person up based off of inputted time set by the user and begin electrical stimulation as close to the input time as possible without going over a no later than time. The device acts as a non-invasive analyzer, and the device will detect a person's sleep cycle through skin resistance, muscle tension, and temperature. Despite the impressive advancements of wearable technology, there is no completely reliable, non-invasive commercial technology that is able detect the human sleep cycle. Our device would be a completely novel idea in this field of study.

Introduction

As stated by the Sleep Health Foundation, the reasons why people aren't getting enough sleep are because people are taking sleep for granted, shift work, eating and drinking late, not winding down before bed, sleep disorders, and stress [6]. By designing a device that records the amount of sleep you get each night, we are able to keep track of a person's sleep stages. In addition, our device is able to wake the user up while they are in the lightest stage of sleep (NREM 1), thus, assuring that the user gets the optimal and desired amount of sleep so that they wake up feeling well rested.

When we sleep, our body goes through four stages that make of the sleep cycles include - REM and NREM sleep (Figure 1). In NREM sleep there are three stages: stage 1,2, and 3. Stage 1 is the in-between stage of wakefulness and sleep. Stage 2 is the first stage of true sleep, and stage 3 is known as the deep, delta, or slow-wave sleep (SWS) [8]. REM sleep is the stage in which dreaming happens. An average sleep cycle lasts 90-120 minutes.

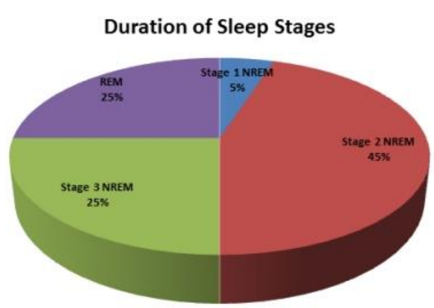

Figure 1

As college students, sleep is an extremely important necessity that unfortunately gets set aside due to school and work. Many students run on very little sleep and often have to wake up at odd hours. A device that could accurately track the user's sleep cycles and awaken the user at the most opportune time would allow for more wakefulness and an overall better mood during the day. However, there is currently no commercial product on the market that accurately tracks a person's sleep despite certain devices claiming they are able to. Current devices, such as; the Fitbit One, the Jawbone Up and Up3, claim that they are able to track sleep reliably; however, according to the Sleep Health Foundation, "of the few trackers on the market that says it can track REM sleep in addition to light and deep sleep. The device claims it can do this because it includes a heart rate monitor in addition to an accelerometer. However the research on which this claim is based has not been published as yet and so cannot be properly assessed." [5].

We hope that our device will not only improve users' lives, but also optimize individual efficiency. Getting sufficient sleep is very important for a plethora of things, as stated in "Sleep deprivation: Impact on cognitive performance," which states "Sleep is considered to be important to body restitution, like energy conservation, thermoregulation, and tissue recovery…sleep is essential for cognitive performance, especially memory consolidation" [4]. Harvard Medical School found, "Lack of sleep exacts a toll on perception and judgment. In the workplace, its effects can be seen in reduced efficiency and productivity, errors, and accidents. Sometimes the effects can even be deadly, as in the case of drowsy driving fatalities"[7]. Our device will allow the user to awaken at a time that is most beneficial to them, making them feel more rested and less groggy.

The overall objective for this project is to be able to design a marketable device that successfully tracks a user's sleep cycle, and help the user optimize their sleeping schedule.

Other objectives include:

1. distinguishing sleep stages using biofeedback
    a. Determine the differences of muscle tension, skin resistance, and temperature during different sleep cycles
2. detecting when the patient is asleep
    a. Determine the differences of muscle tension, skin resistance, and temperature when the user is awake as opposed to them being asleep
3. creating a safe electrical muscular stimulator that responds to feedback.
    a. Follow the FDA's standards for creating a safe EMS device

Description of the Design

Our approach to tracking sleep was chosen to be easily differentiable from current sleep trackers on the market. Current commercially available sleep trackers use an accelerometer at least in part to track whether or not one is asleep or awake [5]. These designs, however, are unable to accurately differentiate between different stages of sleep [5]. Our device does this by tracking several biometrics including, muscle tension, and skin resistance, and temperature because, these metrics demonstrate statistically significant change during different stages of sleep [1][2]. This also will allow it to track how much time the user spends in REM, and Non-REM stages 1, 2, and 3. Our device seeks to use an electromuscular stimulator to awaken the user during the 1st stage of Non-REM sleep, NREM 1 [8]. During NREM 1, the user will be at an in-between point of wakefulness and sleep, which we believe makes this the perfect stage to awaken the user [8].

Our group discussed many ideas in order to achieve our desired outcome. Originally, we wanted to create a device that one would wear around their wrist like a watch. This device would take the wearer's biometrics like temperature and skin resistance in order to decipher between sleep cycles. After further research on sleep cycles, we found that though heart rate changed; however, the change was not significant enough to use due to poor sensor code. However, blood pressure, muscle tension, and respiratory rate do change dramatically[1][2]. To make sure that the EMS device doesn't interfere with the sensors, we designed it so that the EMS band is on one arm and the sensor attachments are on the other.

Figure 2 depicts the muscle stimulator circuit that we used to wake up the wearer of the device. The arduino will be coded accordingly to set thresholds that will activate the EMS in order to wake the user up. Though the output voltage across the electrodes is high (approximately 38V), the output current will be very small (1.8mA), so there is no danger of a fatal electric shock.

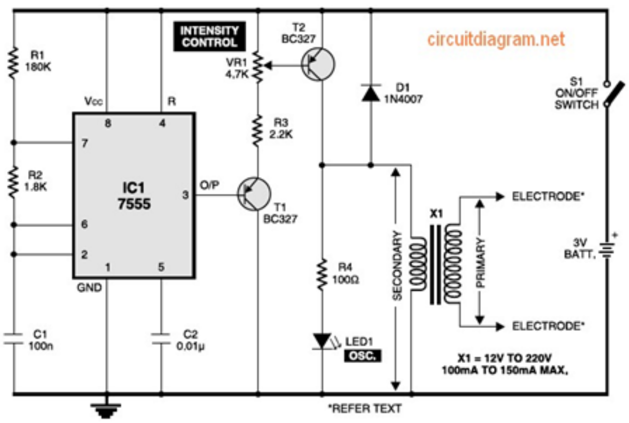

Figure 2: The muscle stimulation circuit [11]

We used an e-Health sensor shield as shown in Figure 3a to obtain the biometrics needed to determine what stage of sleep the user is in. Using sensor attachments made for the e-Health shield, we are able to measure the electrical activity of muscle and conductivity of skin, the amount of oxygen dissolved in the blood, and body temperature. In Figure 3b, we have our built EMS circuit prototype with our e-Health shield. To record the data gathered from the shield, we wrote a MATLAB code to plot the data in real time in Microsoft Excel. An example of the output data can be seen in Figure 4.

Figure 3a: The e-Health shield over an arduino [12]

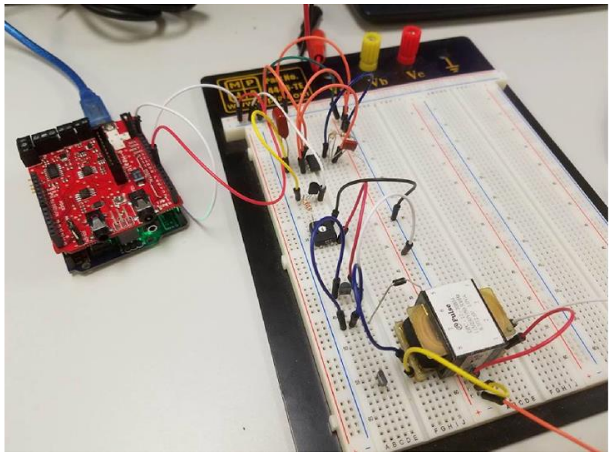
Figure 3b: Prototype muscle simulation circuit hooked up to the arduino and e-Health shield.

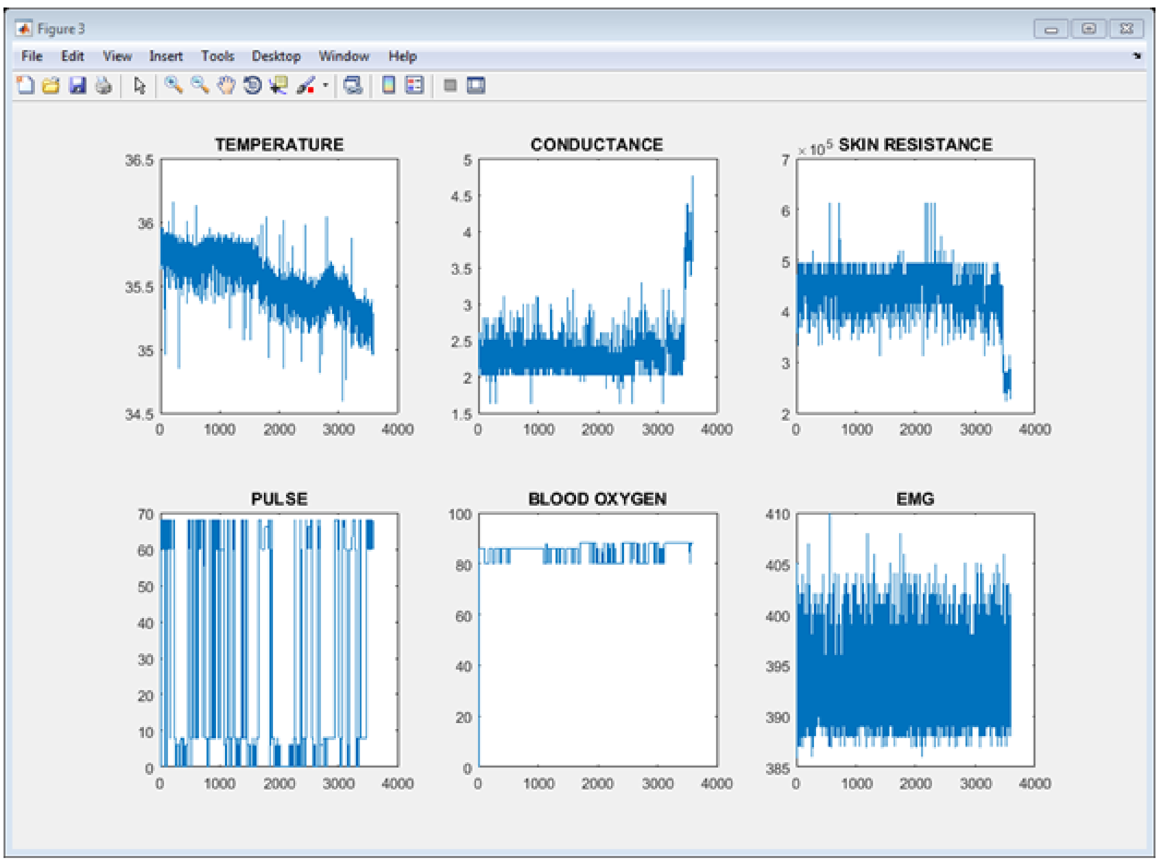

Figure 4: Plotted graphs of data gathered from a night of testing

<u>Measurement Methods and Measured and Simulated Results</u>

We allotted a two hour period per trial for the testing of our device. We chose this over a full night of sleep because from our research we know that a typical sleep cycle lasts anywhere from 90 to 120 minutes. In this time period we were able to collect data from our sensors of when the user is in NREM stages 1,2,3 and REM. By also using a four channel EEG with our prototype we were able to double check our data to confirm that a person is actually in said specific stage of sleep. For electrode application of our EEG we followed the 10-20 electrode system, Figure 5a, for placement of a frontal electrode Fz for detecting K-complexes, a central electrode C3 for spindles, and an occipital electrode O1 for alpha waves all with reference to A1 [13]. Electrodes were placed on the subjects head according to Figure 5b and secured down with an EEG cap pre measured with the electrode placement locations.

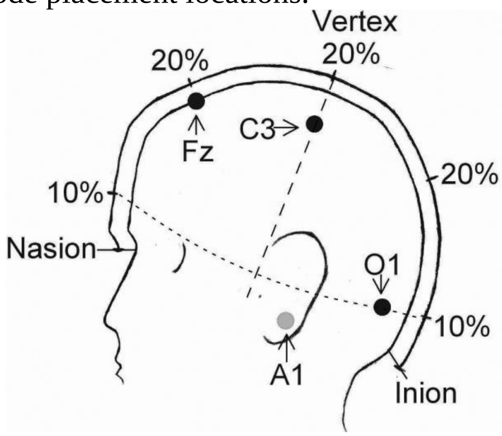

Figure 5a: Electrode placement following the standard 10-20 system of electrodes at Fz, C3, and O1 with reference to A1 [13]

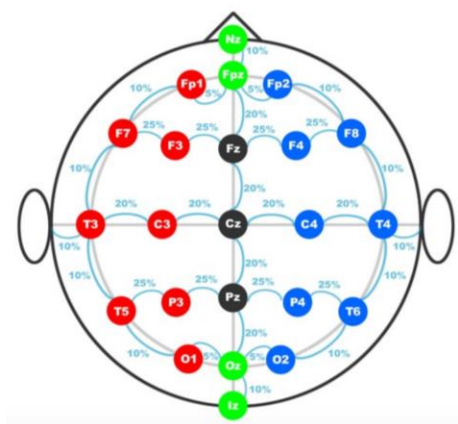

Figure 5b: 10-20 System electrode distances [15]

During those two hours we monitored the EEG output and compared it to our biometrics. Figure 6 shows the expected brain wave patterns seen during NREM and REM sleep. We specifically looked for theta waves because NREM 1 is the sleep stage in which we would like to wake the user up. Figure 7 shows our resulting EEG output from our overnight testing. Channel 1 was the output of the electrode at Fz, Channel 2 was the output of the electrode at M1, Channel 3 was the output of the electrode at C3, and Channel 4 was the output of the electrode at O1.

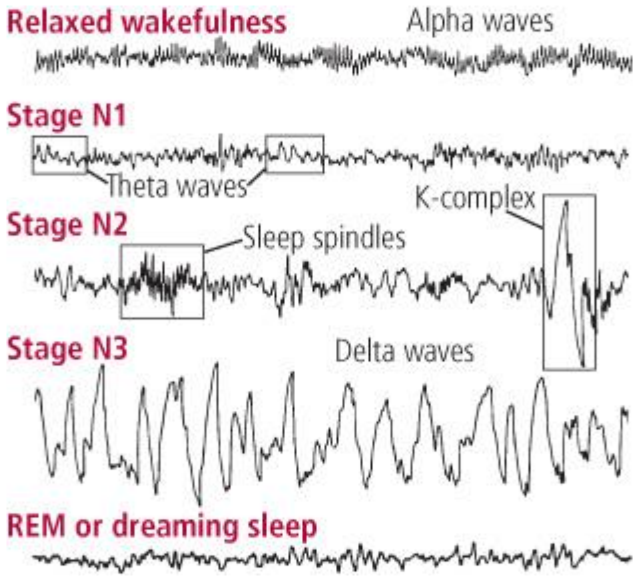

Figure 6: Brain wave patterns during sleep [14]

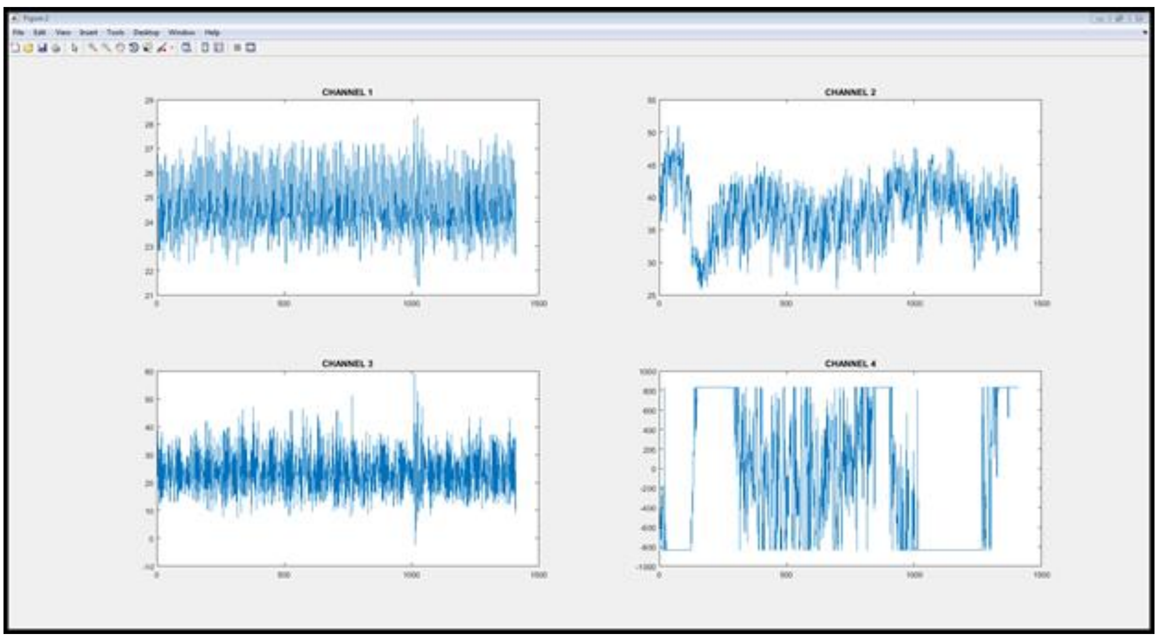

Figure 7: EEG data gathered from overnight testing

In total our device tracks body temperature, conductance, skin resistance, and muscle tension using individual sensors to. We compared the data from these sensors to laboratory data to determine how sensitive they are. We used that information to set parameters to determine NREM 1; which will allow us to set parameters to wake the user up during that stage. We will additionally utilize data collected from the sensors to determine whether the prototype tracks sleep stages properly.

Timeline and Milestones

Key Tasks: Finalize Biometrics, Specify Circuits, Construct Circuits, Determine EMS Specifications, Construct EMS, Code Feedback Loop, Assemble Model, Trouble Shoot

For this project we used a Gantt chart as a reference for when we should have each key task finished.We budgeted our time for this project over a 6 month period. For the finalized biometrics we had chosen a body temperature sensor, pulse detector, GSR sensor, and an electromyograph. The only circuit that we had built for this project was our EMS circuit and the only codes we created were for the sensors and importing data from the shield into excel. Figure 8 is the Gantt chart we referenced, for each task we assigned a minimum of two people. For the larger tasks, such as circuit construction and coding, the entire team partook in.

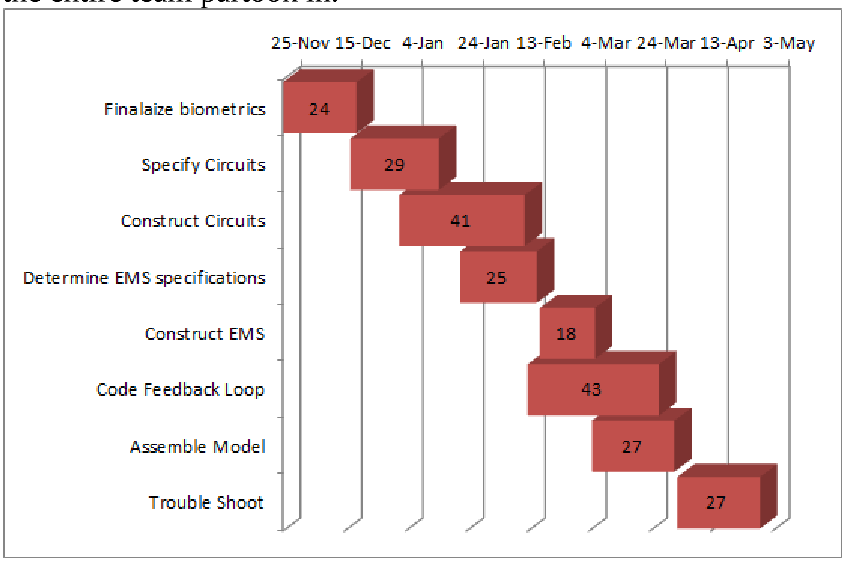

Figure 8. Gantt Chart

<u>Budget and Funding</u>

To build our prototype we spent approximately $339 (Table 1) from personal funds. As a team we decided that we need the following parts: an arduino, a Breadboard, EEG, e-Health Shield with sensors, Conductive Gel and EEG Electrodes, and our EMS circuit. By also having four skilled team members, were able to rely on each other's expertise and knowledge to design a prototype.

For funding of our senior design project we primarily used personal finances. We funded our project as a group due to the shield and sensors being sold by an overseas manufacturer. After having issues ordering our parts internationally through the NIU Electrical Engineering Department, we were able to split the costs amongst ourselves and personally finance our prototype.

Table 1 Project Budget

Supplies	Price
Arduino	$0 - Owned
Breadboard	$0 - Owned
EEG	$0 - Borrowed
e-Health Shield with Sensors	$270
Conductive Gel and EEG Electrodes	$60
EMS Circuit Components	~$9
Total Budget = ~$339	

Critical evaluation of design and summary

Initially, our group did a patent search prior to finalizing the decision on our project. Many patents have been issued for wearable devices that measure biometrics such as heart rate, body temperature, etc. Patent US7608041 B2 is a device that has the same end goal of our device, but it goes about it in a different way. It receives input from the user to approximate sleep cycle times, and then wakes the user up at the appropriate time in the cycle [8]. Patent US20130018284 A1 monitors a user's movements during sleep to try and determine where they are in their sleep cycle, and when would be the best time to wake them up [9].

Many other patents do similar things, but none monitor biometrics to determine the current sleep cycle or use electrostimulation to wake up the user. The final design is well positioned in the niche market for sleep trackers. With that in mind, it is bulkier and currently more expensive than existing sleep trackers due to the additional sensors.

This design offers the primary benefit of not relying solely on an accelerometer to track whether a person is awake or asleep. We were able to successfully create a device that can track biometrics in real time. In addition, the EMS circuit that was constructed is able to work effectively and efficiently in conjunction with the arduino and eHealth shield. Due to the limitations of our sensors and the various problems we had with the EEG we were not able to successfully construct a device that distinguishes all of different sleep cycles. However, we are able to differentiate between a state of awakeness and sleep with the eHealth shield and sensors. We are also able to determine when REM occurs and NREM1; which are the most important phases specifically for our project.

The device itself is quite cumbersome to prepare and requires a decent amount of time to set up. One of the causes for this setback is that the various sensors are currently separate of each other. The circuitry was meant to be condensed to be comfortable for the user. Trying to integrate the circuitry and sensors into a comfortable, wearable device proved difficult. A way of alleviating this problem is to construct a sleeve with the sensors embedded within it.

After going through our constructed failure mode analysis (Appendix A), we determined that the most serious problems that could occur would result from the EMS part of the entire project. The EMS could cause pain, minor burns and discomfort if the circuit fails due to error. Circuitry failures could cause electrocution or superficial burns to the user. However, due to the fact that the device runs at a low voltage, any injuries received would not be severe in an individual with good health. The device should not be used in conjunction with an individual who has a pacemaker or a heart condition, as well as by pregnant women.

A concern that we initially had when designing our device was not being able to be complete it in the time given due to budget issues within the department. Although we completed our design in time, we felt that we did not have sufficient equipment or space to test our device. Typically in a sleep study a 10 or 20 channel EEG is used, being limited by an 8 channel EEG we had to carefully choose where we wanted to place our electrodes so that we could still be able to accurately determine the sleep cycle the user is in. We were also limited in the space for testing our device. Because we could only use a specific computer in the Engineering building for the EEG we had to test our device in a location which was not ideal. The device does not work completely as intended; however, we understand that theoretically it should work with the various data in research.

Conclusion

Overall, our project was successful. We had difficulty testing our project due to access of only less than optimal quality testing devices. The EEG that we used was very old and only worked on Windows XP, and it picked up a lot of signal noise.

Our group learned many important lessons during the design and testing of our project. The most critical and important lesson was communication. If we had not been in constant communication with every group member as well as our mentor, Dr. Kocanda, it would have been close to impossible to have completed our project in the time allotted. All group members took responsibility for their specified tasks of the project and kept the others up-to-date, allowing for the project work to flow smoothly. We were not afraid to let our group members know if we were not satisfied with their performance and what they needed to do to improve their work. Another important lesson that we learned, was deciding when to take initiative. We tried buying the e-Health shield through the NIU Electrical Engineering Department, and our request was held up for almost a month before we decided to cancel it and use our own funds. We were unsure of the amount of time required for our request to go through, and it was possible that we would not have received the most vital part of our project in time.

The group has compiled a list of goals to pursue if we choose to continue expanding on our idea. The main thing that we would focus on is obtaining better equipment to test our device. We would like to consolidate the arduino, e-Health shield, and sensors into a sturdy wearable armband, and possibly make it wireless for ease of use. It would also be an added perk to create a phone app to show the user their biometrics in the form of data or multiple graphs in real time.

Acknowledgments

We’d like to thank Dr. Kocanda for letting us use his lab and Dr. Demir for guiding us throughout our project

Appendix A

Failure Mode Analysis Chart:

Failure Mode	Cause	Impact	S	F	Detect	D	RPN	Follow-up Action	S	F	D	RPN
User Injury	Circuit Shorting	Human injury, possible unsafe circuit	4	3	User detection	1	12	First aid kit	4	3	1	12
Unable to finish project in allotted time	Sleep stage analysis takes too much time	Project not complete	5	1	Schedule	3	15	Focus project on analyzing sleep stages only	2	1	3	6
Unable to finish project in allotted time	Sleep Stage analysis isn't accurate enough	Project not complete	5	1	Schedule	2	10	Focus project on determining awake or asleep	2	1	2	4

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