$\rm ECE~445$

SENIOR DESIGN LABORATORY

FINAL REPORT

Smart Bruxism Treatment Device

Team #6

Edric Lin (edricl2@illinois.edu) Jaewoong (Justin) Song (js52@illinois.edu)

 $\underline{\mathrm{TA}}$: Mingjia Huo

December 7, 2022

Abstract

Bruxism (BRUK-siz-um) is a medical condition in which one unconsciously grinds and clenches their teeth. More specifically, bruxism can be separated into two major categories: awake bruxism and sleep bruxism. As the names suggest one occurs while the person is awake and the other while the person is asleep. With bruxism comes a wide array of potential issues including but not limited to damaged teeth (in the form of fractures and chips), increased tooth pain and sensitivity, worn enamel, tight jaw muscles, headaches, and sleep disruption. Current medical solutions aim to treat the consequences of bruxism rather than treat the root cause. As such, in this paper we propose a novel, one of a kind design for a treatment device designed to detect and treat the root cause of bruxism. This report goes into detail the process that went into the design, implementation, testing, and creation of the smart bruxism treatment device.

Contents

1	Intr	oduction	1
	1.1	Purpose	1
		1.1.1 Problem	1
		1.1.2 Solution	1
	1.2	Visual Aids	2
	1.3	High Level Requirements	3
	1.4	High Level Overview	4
		1.4.1 Block Diagram	4
		1.4.2 Physical Design	5
2	Des	ign	6
	2.1	Power Subsystem	6
		2.1.1 Battery Module Design	6
		2.1.2 Battery Module Verification	6
	2.2	Detection Subsystem	8
		2.2.1 EMG Module	8
		2.2.1.1 EMG Design	8
		2.2.1.2 EMG Verification	9
		2.2.2 Audio Detector Module	11
		2.2.2.1 Audio Detector Design	11
		2.2.2.2 Audio Detector Verification	11
	2.3	Control Subsystem	12
		2.3.1 Control Subsystem Design	12
		2.3.1.1 Microcontroller	12
		2.3.1.2 Ethernet Shield and MicroSD Slot	12
		2.3.2 Control Subsystem Verification	13
	2.4	Prevention Subsystem	14
		2.4.1 Alarm Module	14
		2.4.1.1 Alarm Design	14
		2.4.1.2 Alarm Verification	14
		2.4.2 TENS Unit	15
		2.4.2.1 TENS Unit Design	15
		2.4.2.2 TENS Unit Verification	15
3	Cos	t and Schedule	8
	3.1	Manual Labor	18
	3.2	Total Cost	18
	3.3	Schedule	18
4	Eth	ical Considerations	[9
	4.1	Overall Intentions	19
	4.2	Risk Mitigation Plans	20
		4.2.1 Biomedical Devices	20

		4.2.2 Batteries	0
5	Cor 5.1 5.2 5.3 5.4	clusion 21 Accomplishments 22 Uncertainties 22 Future Work 22 Acknowledgements 23	1 1 2 2 3
Re	efere	2^{4}	4
A	ppen A.1 A.2 A.3	lix A Biomedical Definitions 26 EMG 20 TENS 20 Targeted Muscle Area 20	6 6 6
A	ppen B.1 B.2 B.3 B.4 B.5	lix B Circuit Schematics 2' Power Subsystem 2' EMG 2' Audio Detector 2' Alarm Module 3' TENS Unit 3'	7 7 8 9 0
Aj	C.1 C.2 C.3 C.4 C.5	dix C PCB Layout & Physical Implementation 33 Power Subsystem 34 EMG 35 Audio Detector 37 Alarm Module 44 TENS Unit 44	2 2 5 7 0 2
Aj	ppen	lix D Parts List 44	4
A	ppen E.1 E.2 E.3 E.4 E.5 E.6	dix E Requirement and Verification Tables4'Power Subsystem4'EMG4'Audio Detector4'Control Subsystem5'Alarm5'TENS5'	7 7 8 9 0 1 2
A	ppen	lix F Software 53	3
A	ppen	lix G Schedule 54	4

1 Introduction

This section will go into the main motivation behind the problem statement, our proposed solution, visual aids for said proposed solution, as well as a high level overview of the project scope.

1.1 Purpose

1.1.1 Problem

Bruxism, more commonly known as tooth grinding, is a condition where one grinds or clenches their teeth unconsciously. To be more technical, bruxism "is a repetitive jaw muscle activity characterized by clenching or grinding of the teeth and/or by bracing or thrusting of the mandible during sleep" [1]. Depending on the particular study, up to 20% of the global population can be affected by this condition [2]. Should bruxism be severe and frequent enough, it can lead to jaw disorders, headaches, damaged teeth, and other problems. There is not one singular cause for bruxism and as such, current solutions act more as a temporary measure to minimize damage rather than address the issue itself. For example, common dental solutions include using a mouth guard and, in some cases, undergoing dental correction. Similar to treatments, medication serves mostly as a reactionary measure where they attempt to address issues and complications that arise from bruxism. For example, multiple sources propose "Local injections of botulinum toxin into masseter muscles to prevent dental and temporomandibular joint complications" [3]. The targeting of the masseter muscles heavily implies that the aforementioned muscle is one of the root causes and should be the main point of focus for the treatment.

1.1.2 Solution

Our proposed solution to bruxism is to develop a system that relaxes the muscles when the user is clenching their teeth. This will be done via a two part system: detection and prevention. The detection part will be outside of the mouth and focus on the jaw muscles and any noises made by the tooth grinding. It will consist of an EMG in conjunction with audio sensors. These signals will be transmitted into a control circuit that will save the data (via a MicroSD card) for later viewing, activate a TENS (transcutaneous electrical nerve stimulation) unit to relax the jaw muscles, and sound an alarm to serve as an audio indicator. Aside from electrodes for the EMG and TENS modules and an external audio detector, the entire device will be contained within a small portable box that can be placed, for example, upon a desk while one works.

1.2 Visual Aids



Figure 1: Simple visual of system. Second pair of TENS Electrodes omitted for clarity

1.3 High Level Requirements

Below are the high level requirements of our project. All items have been successfully attained except for the fourth requirement concerning the TENS unit. More details on why the requirement could not be met can be found in this section.

- Power section sends out ± 8 volts along with a reference ground
 - Both switches, when flipped on, activates the device
 - Current consumption of the device does not exceed 500mA
- Detection section detects teeth grinding and sends appropriate signals to control circuit
 - The EMG module will take EMG signals (up to 10 μ V) from the electrodes attached to the side of user's jaw. It will then output the filtered, rectified, and amplified analog signals (up to 5 volts) to the control subsystem.
 - The Audio Detector module will detect grinding and crunching noises. It will filter the audio and amplify the analog signal before then sending it to the control subsystem. Further data of the appropriate frequency range to filter and the allowable voltage range will need to be collected before more specific values can be given.
- Prevention section responds appropriately according to input from control circuit
 - The Alarm module will output an auditory notification at around 60 dB (± 10 dB) when the control subsystem gives the signal to do so. It will turn off and stay below 10 dB when the control subsystem gives the signal to do so.
 - The TENS unit will output square wave signals that are no more than 40 volts in magnitude and will give no more than 50 mA of current. The frequency of these signals will have a frequency of 100 Hz +/- 20 Hz. The pulse width of the signals are able to be adjusted, but must not exceed 1 millisecond in length.
- Data section collects data appropriately and allows for retrieval for later viewing
 - The data is to be collected via a flash memory device, presently proposed to be a MicroSD Card.
 - The microcontroller will write to the memory card via SPI.

1.4 High Level Overview

1.4.1 Block Diagram



Figure 2: Block diagram of entire system.

This Bruxism Treatment Device consists of four separate subsystems: Power, Detection, Control, and Prevention. The Power subsystem is responsible for providing three stable DC voltages to the entire device: positive 8 volts, negative 8 volts, and 0 volts. It will consist of four Lithium-Ion batteries. It will also contain two switches that will act as on/off switches. One switch will enable the positive power line while the other will enable the negative power line. A ground line will be always connected to the entire system. The Detection subsystem will be responsible for detecting teeth grinding and sending the appropriate signals to the control subsystem. This subsystem will contain an EMG circuit and an Audio Detector circuit. Further detailed descriptions for both can be found here and here respectively. The Control subsystem will be responsible for processing the information input from the Detection subsystem and will output appropriate response signals to the Prevention subsystem. It will consist of a Micro-controller (details for which can be found here), an Ethernet Shield (details for which can be found here), and a MicroSD Card Slot. These will be discussed in further detail later. The Prevention subsystem will be responsible for preventing the user from grinding their teeth. It will consist of an Alarm Circuit and a TENS Unit Circuit (details for which can be found here and here respectively). The TENS Unit is not included in the block diagram for reasons that will be clear in the TENS Unit Subsection but if it were to be included, it would be in the Prevention subsystem.

1.4.2 Physical Design

The entirety of the smart bruxism treatment device is housed within a singular enclosure as detailed in Figures 3 and 4. The enclosure is divided into two sections. The first is a box that contains four lithium-ion batteries for the \pm 8 volts and 0 volts supplied to the entire system. The second is a box that contains all the PCBs that establishes the functionality of the system. On the top of the box are two switches with corresponding LED indicators. On the sides of the box are cut outs for the microSD card insert, the buzzer, wires for electrodes, and the microphone.

The device is designed to be small enough such that it lends itself well to portability. To that end, the entire system is battery operated. As this is a prototype design, the box in its current iteration can be minimized. For more details, please refer to the Future Work section.



Figure 3: Front view of box



Figure 4: Back view of box

2 Design

This section will go into detail the design portion of the project including but not limited to schematic design, design choices, and considerations.

2.1 Power Subsystem

2.1.1 Battery Module Design

The Battery Module of the Power Subsystem will be made out of four 2500 mAh 3.7volt Lithium-Ion rechargable batteries by TinyCircuits (part number ASR00050). Although listed as 3.7 volts, empirical testing reveals each to be 4 ± 0.02 volts in reality. They will be connected in series so that the module can provide the positive 8 volts and negative 8 volts DC voltages. The center node of the battery line provides 0 volt ground. The battery capacities are 2500 mAh each, resulting in 10000 mAh total. The batteries will be controlled by two mechanical switches to either connect or disconnect the battery module from the rest of the system. These switches will serve as the on/off buttons of the device. The switches will additionally power on LEDs to indicate that the supply voltage is turned on. We will use a blue LED to indicate that the positive 8 volt supply is connected and a yellow LED to indicate that the negative 8 volt supply is connected. For a visual reference, refer to Figure 3.

2.1.2 Battery Module Verification

The power supplied to a circuit can be found with the following formula:

$$P_{supplied} = I_{source} * V_{source}$$

As our system has two non-zero voltage sources, we needed to find the power supplied by each source to find the total power supplied by the Power Subsystem. This results in the following equation:

$$P_{total \ supplied} = P_{+8V} + V_{-8V}$$

To find the power of each voltage source, we utilized the lab's DC power supply to find the current each voltage source was supplying. We found that positive 8-volt supply was sourcing 150 mA, while the negative 8-volt supply was sourcing 1 mA. This gives us the following power consumption:

> $P_{+8V} = 8 * 0.150 = 1.2$ Watts $P_{-8V} = -8 * -0.001 = 0.008$ Watts $P_{total \ supplied} = 1.2 + 0.008 = 1.208$ Watts

When determining how long a device can be powered on by batteries before the batteries are depleted, one must use the following equation:

$$Lifetime = \frac{Battery Capacity in mAh}{Total Current Supplied in mA}$$

The Smart Bruxism Treatment Device draws a total current of 151 mA. The total lifetime is:

$$\text{Lifetime} = \frac{10000 \text{ mAh}}{151 \text{ mA}} = 66.23 \text{ hours}$$

It should be noted that these measurements and subsequent calculations were done without a functioning TENS unit. A fully functioning device may have very different power and lifetime ratings.

2.2 Detection Subsystem

2.2.1 EMG Module

2.2.1.1 EMG Design

The EMG is responsible for detecting muscle movement within the user's jaws and sending an amplified version of the signal to the control subsystem [4]. To detect the movement, the EMG uses non-invasive, surface electrodes (Covidien H124SG) that are placed upon the user's skin above their Masseter (jaw) muscles according to the figure below. Reasons for targeting the masseter muscle can be found here.



Figure 5: Placement of electrodes indicated by blue dots

The signal is then fed into an instrumentation amplifier (Analog Devices AD8221ARZ-R7) in the first stage signal boost. The input pins of the instrumentation amplifier connected to ground via diodes (Rectron FM4004-W) to protect the circuit from any high voltages (such as the TENS Unit's intended output voltage). This, however, also amplifies any voltage noise that accompanies the EMG signal. This is handled by a passive bandpass filter that filters out unwanted signals at various frequencies. A side effect of this is that the signal, while cleaner, is now weaker. This is solved with a second stage signal boost. Lastly, to read only positive voltages, a precision rectifier is utilized [5]. This module is powered by both the positive 8-volt and negative 8-volt supplies of the power subsystem, while ground is also supplied by the power subsystem. For a visual reference, refer to Figure 11.

2.2.1.2 EMG Verification

While doing research on EMG signal characteristics, we were led to believe that we ought to expect magnitudes of 5 to 15 mV before any amplification. However, empirical testing revealed that the Masseter muscles generate a peak voltage of 10 μ V. As such, a very high voltage gain is needed to obtain a usable voltage. While researching the design of other EMG circuits, a common circuit component used was the instrumentation amplifier. We decided to also utilize an instrumentation amplifier for its convenient usage (gain is dependent on only one resistor) and also its high input impedance. After comparing the latest instrumentation amplifiers in stock on Mouser, we decided to use Analog Device's AD8221ARZ-R7. The gain of the amplifier, according to its datasheet, is the following:

$$Gain = 1 + \frac{49.4k\Omega}{R_{gain}}$$

Moreover, the AD8221ARZ-R7 has low noise while its gain is between 100 and 1000 (once again from its datasheet). As we wanted to be safe and stay away from both extremes, we decided to utilize a gain of approximately 500. Setting gain to 500 gives us a resistor value of 99 Ω . We rounded up to 100 Ω , which gave us a gain of 495. This gave us a signal with an amplitude of approximately 5 mV.

As our research suggested that the most useful frequency range of an EMG signal is in between 50-150 Hz, we decided to utilize a passive bandpass filter which consisted of a high pass RC filter cascaded into a low pass RC filter. The formula used to calculate cutoff frequencies is the following:

frequency =
$$\frac{1}{2\pi RC}$$

After much time spent on adjusting the R and C values to be something reasonable and is within the market, we eventually settled on using 2.2 k Ω resistors for both the high pass RC filter and low pass RC filter. The low pass capacitance value needed was 470 nF, while the high pass capacitance value was 1.5 μ F. This gave us an actual pass range of 48 to 154 Hz. Further testing at this point revealed to us that the signal lost half of its strength after passing through the passive bandpass filter (i.e. the amplitude of the signal at this point was approximately 2.5 mV). As the microcontroller reads voltages up to 5 volts, we needed a further gain of 2,000. To do this, we utilized an inverting amplifier. The gain of an inverting amplifier can be found with the following formula:

$$Gain = \frac{-R_{feedback}}{R_{in}}$$

We selected the feedback resistor to have a value of $20k\Omega$ and the input resistor to have a value of 100Ω . The Op Amp used for the inverting amplifier is Texas Instruments' LM741. We also tested a non-inverting amplifier with the same gain, but it did not function at all. A reason why that may be is due to the input impedance of the amplifier configurations. A

non-inverting amplifier's relatively higher input impedance may be blocking all the current being fed into it. As such, it wouldn't "see" a voltage or signal to amplify.

Up to this point, the EMG signal is purely negative due to the inverting amplifier. As such, we decided to utilize a precision rectifier with the following circuit layout:



Figure 6: Precision Rectifier Circuit Used

The parts used in the final product are the same within Figure 6. Empirical testing of the rectifier circuit with a 5-volt amplitude sinusoidal input revealed a 0.8 volt drop within the circuit, resulting in a rectified sinusoidal output of 4.2 volts.

2.2.2 Audio Detector Module

2.2.2.1 Audio Detector Design

The Audio Detector is responsible for confirming that the user of the device is indeed grinding their teeth by detecting grinding audio, which has a frequency range of 1-2 kHz [6]. First, a microphone (Mallory Sonalert PMOF-6027WN-44KDQ) is used to pick up any audio made by the user's mouth and teeth. As the voltage output of the microphone is very low, a pre-amplifier is used to boost the signal's strength. This, however, also amplifies any unwanted signals at frequencies outside of the 1-2 kHz range. As such, a passive bandpass filter is used to obtain only the desired signal. To keep various resistors and capacitors of separate sub-modules from interferering from each other, a voltage buffer is used. Lastly, as the passive bandpass filter has weakened the audio signal, another amplifier is used to boost the signal so that it would be at a voltage that can be read by the microcontroller. This module is powered by both the positive 8-volt and negative 8-volt supplies of the power subsystem. For a reference, please refer to Figure 12.

2.2.2.2 Audio Detector Verification

Empirical testing of the audio signal after the pre-amplifier stage revealed that the voltage magnitude of the signal was about 3 volts. To filter out any unwanted noise from the signal, a passive bandpass filter is used, once again, implemented as a high pass RC filter cascaded into a low pass RC filter. Using the same formula in the EMG Verification for cutoff frequencies, we eventually found reasonable components in the market. 10 k Ω resistors are used for both filters. For the high pass filter, two 8.2 nF capacitors are put in parallel to make 16.4 nF, while the low pass filter only needs one 8.2 nF capacitor. This gives us an actual pass range of 983 - 1941 Hz. However, further testing with audio inputs at various frequencies revealed that the upper bound of the pass range was closer to 3.5 kHz. Although not desirable, we settled with this range in the end. We believe that the higher upper bound was due to other non-idealities introduced into the system from an op amp, as changing resistor and capacitor values to adjust the cutoff frequency had little effect.

As mentioned in the Audio Detector Design section, a voltage buffer is used to provide a separation of various resistors and capacitors from interfering from each other. Empirical testing at the point after the voltage buffer revealed to us that the audio signal has weakened to about half its strength from the pre-amplifier stage (i.e. the signal had a magnitude of approximately 1.5 volts). Once again, an inverting amplifier is used to boost the strength of the signal. Using the inverting amplifier gain equation mentioned in the EMG Verification section, we selected a gain of 3.3 to boost the magnitude of the signal to 4.95 V (just under 5 volts). This was done with a feedback resistor of 3.3 k Ω and an input resistor of 1 k Ω . A rectifier circuit was briefly considered to ensure that only positive voltage is read at the output, but simply grounding the negative power rail of the op amp had the same effect as was needed. To ensure that no DC voltage is read from this circuit, the output of this module has a 10 μ F capacitor to decouple the output from the inverting amplifier's output.

All op amps used in this module is Texas Instruments LM358DR.

2.3 Control Subsystem

2.3.1 Control Subsystem Design

2.3.1.1 Microcontroller

The Arduino Uno Rev3 SMD has been chosen as the microcontroller that will be used in the Control Subsystem. The microcontroller will take in analog inputs from the EMG and the audio detector. Within the logic of the microcontroller, once both are above a certain threshold (i.e. taking the logical AND of the two signals), then the microcontroller will send signals to both the alarm and the TENS unit in the Prevention Subsystem to activate both of them. It will be powered at 8 volts supplied by the power subsystem. A control flow of the written software code can be found in Figure 27 at the Software Appendix.

The analog input pins, which take in the outputs of the EMG and the audio detector, provide 10 bits of resolution with a voltage read range of 0 to 5 V by default (which is the configuration the system uses). As such, in order to correctly translate the binary value to the voltage being read, the following formula must be used:

$$Voltage = 5 * \frac{Binary value}{1024}$$

It is important to note that in the software code, float values must be used rather than integers in order to preserve the added precision of decimal points.

2.3.1.2 Ethernet Shield and MicroSD Slot

The Ethernet Shield is primarily used for its MicroSD Card slot, which will serve as a way for the user to export their data in a convenient way. Additionally, the shield allows for future feature expansion in the sense that the data can be exported wirelessly via Ethernet. It will be powered by the Arduino.

The data (referenced in Table 8) will consist of moments in time when the device detected teeth grinding (the method of which is described in the Prevention Subsystem section). The protocol for writing to MicroSD cards are done through the (SPI) Serial Peripheral Interface, which is a synchronous serial communication interface specification. When the necessary conditions are satisfied (as outlined in the Microcontroller Subsection), the microSD card will be written to. The data written to the microSD card will include the relative, local time, the voltage level of the EMG, and the voltage level of the audio detector. The latter two will be read in through the analog ports of the microcontroller.

2.3.2 Control Subsystem Verification

The control subsystem was verified piece by piece, component by component. Each component was tested in isolation with the control subsystem and then slowly integrated with other components until all the connections were built up. As evidenced by Figure 2, there are five major connections to the microcontroller. For all testing procedures, the Ethernet shield was always attached to the main Arduino Uno Rev 3 SMD. This configuration was done from the beginning so as to avoid the possibility that something worked only on the microcontroller but not on the microcontroller + shield combination.

First and foremost, we verified that the microcontroller could be powered on independent of a host computer powering it. Given that the datasheet of the microcontroller we used specified a recommended input voltage of 7-12 V, we supplied the microcontroller with 7.4-8V. As was expected, the microcontroller operated just fine.

The alarm module was ultimately conditionally powered by the microcontroller. In order to verify correct operation, the buzzer was attached to one of the digital out pins of the microcontroller and was then powered on. Various tones, frequencies, and lengths were played in order to determine optimal values for our use case.

The next verification item of interest was the analog input pins. Both the EMG and audio detector output would eventually feed into the analog input pins because, by definition, both circuits outputted analog voltages. In order to verify correct reading, the voltages being read in on the microcontroller were serially printed on the host computer. At the same time, the same voltages being read were also probed with an oscilloscope. The two reading types were compared and evaluated to determine accuracy.

Once it was determined that the analog input pins were working functionally as expected, the alarm module was tested in conjunction with the analog inputs separately (i.e. the EMG with the alarm and then the audio detector with the alarm). In both testing scenarios, when the analog input voltage pin crossed a specified voltage threshold, the alarm module was turned on. Expected operation was obtained.

Writing to the microSD card was then tested. In terms of the software, there was serial and SD setup done for the required libraries for writing to a microSD card. Then a file to host the captured data was created. After that, a variety of things were written to the microSD card including but not limited to strings, variables, relative local time, etc.

2.4 Prevention Subsystem

2.4.1 Alarm Module

2.4.1.1 Alarm Design

The Alarm Module will be responsible for alerting the user that they are grinding their teeth. It is simply a buzzer (CUI Devices CPT-2305-90PM) that is powered and controlled by the microcontroller of the device. For reference, please refer to Figure 13.

2.4.1.2 Alarm Verification

The testing and verification of this module was conducted in conjunction with the microcontroller. The microcontroller sends a square wave pulse train with an amplitude of 5 volts at a desired frequency to make the buzzer sound off. The buzzer's sound intensity is dependent on the frequency. We measured this with a decibel meter (Sound Meter phone application) and concluded that a frequency of 800 Hz was sufficient. It does not fall within the frequency range of the Audio Detector module (1-3.5 kHz) and it had a sound intensity of 58.9 dB at one foot away from the device. This satisfied our requirement of having an intensity of 60 dB \pm 10 dB at one foot away from the device. For further testing related to the Alarm Module, please refer to the Control Subsystem Verification.

2.4.2 TENS Unit

2.4.2.1 TENS Unit Design

The TENS Unit is responsible for generating and delivering the voltage impulses to the user's Masseter muscles to counteract the jaw muscles' clenches. It is controlled by the microcontroller, but is powered by the positive 8-volt supply from the battery subsystem when turned on. The target output of 40 volts is done by a step up transformer. This design is not an original design. The original source of this design was found online [7], [8]. For reference, please refer to Figure 14.

2.4.2.2 TENS Unit Verification

We began our testing with simulations in LTSpice. Our initial results seemed promising.



Figure 7: Circuit simulated in LTSpice. Output resistor of 1 k Ω is typical resistance of skin.



Figure 8: LTSpice Simulation Results. Blue trace is pre-transformer voltage. Red trace is overall output voltage.

Although the output voltage was not at our target of 40 volts, we believed that we would find a solution after breadboard testing and seeing the actual behavior of the circuit. After satisfactory results from breadboard testing, we proceeded to create the PCB version. PCB tests at the pre-transformer voltage revealed that the waveform was near the desired waveform: a square wave pulse with a frequency of 117 Hz, an amplitude of 4.79 volts, and an adjustable pulse length that never exceeded 1 millisecond.



Figure 9: Pre-transformer voltage of the TENS unit.

The voltage amplitude was higher than expected, but we believed that some would be lost across the transformer and would result in a lower effective voltage. Thus, we then connected our transformer to the PCB. Unfortunately, it did not work. After consulting Professor Andrew Stillwell, we decided to unit test the transformer with inputs at various frequencies. We found that the transformer we have only functioned at frequencies at 10 kHz or above. A possible solution for this problem is to instead find a line frequency transformer with the same voltage and power ratings. As it was too late into the semester to implement this solution, the TENS unit unfortunately remains incomplete.

Another problem to resolve is the placement of the TENS Units' electrodes. As the device is intended to deliver electric pulses to the Masseter muscles, the electrodes would overlap with the EMG's electrodes and cause interference. This would affect the EMG's signal acquisition and lead to inaccurate readings. We had no solutions to this predicament, and believe that an entirely different treatment may be needed in the end. For these solutions, please refer to Future Work.

3 Cost and Schedule

This section will go into the cost and schedule of this project.

3.1 Manual Labor

Calculations for manual labor are below. The following numbers are assumed (on a per person basis):

- Hourly Wage: \$40
- Hours of Work Per Week: 10 $\frac{\text{hours}}{\text{week}}$
- Total Weeks Worked: 16 weeks

With two people on this team:

$$(2 \text{ people}) * \left(\frac{\$40}{\text{hour}}\right) * \left(\frac{10 \text{ hours}}{\text{week}}\right) * 16 \text{ weeks} = \$12800$$

3.2 Total Cost

As referenced in Appendix C, the total material costs for the parts is \$172.89. As such, the total cost is \$12920.08. The calculations are as follows:

Total cost = Total Material Cost + Total Labor Cost
=
$$$172.89 + $12800$$

= $$12972.89$

3.3 Schedule

The schedule can be found in Appendix G. The initially proposed schedule from the design document, while created in good faith, was not entirely accurate. Due to a variety of events, a large portion of the work was actually done during in the two weeks leading into Fall Break as well as Fall Break itself. Part of the reason why this happened is that there was an extended amount of unexpected time wasted while waiting on PCBs to be delivered. This fact, that we had no control over, unfortunately pushed back and delayed our proposed schedule by several weeks.

4 Ethical Considerations

This section will go into the ethical and safety considerations associated with this project as well as risk mitigation plans put in place.

4.1 Overall Intentions

Overall, we intend to follow the IEEE Code of Ethics and the ACM Code of Ethics and Professional Conduct.

This project contains an element of human testing that should be scrutinized over for the safety of the user. As such, we intend to uphold §7.8.I.1 of the IEEE Code of Ethics wherein we "hold paramount the safety, health, and welfare". §7.8.I.2 of the IEEE Code of Ethics also applies to us, as we go through the stages of designing and testing our project [9]. Many TENS devices have received FDA approval, which says something about the safety of such devices. However, this fact will not decrease the caution taken when using, testing, and integrating the device into our system.

As this project may carry risks that may be more than minimal risk in testing and showcasing the final product, we followed up with the University of Illinois Office for the Protection of Research Subjects guidelines. Namely, we have contacted the office to determine whether or not Institutional Review Board approval will be needed. After contacting the IRB, we have been notified that if it is a class project, then it is not considered to be human subjects research and as such, do not require IRB approval to proceed. We also do not intend to seek out other test subjects besides ourselves.

Regarding data collection and usage, we will follow $\S1.6 - 1.7$ of the ACM Code of Ethics and Professional Conduct [10]. There will be no identifying information related to the user other than the actual teeth grinding data. The data will be directly written to a MicroSD Card that the user provides. The data will not be saved or shared with any parties or entities without the explicit consent of the user nor will it contain any personally identifying information.

4.2 Risk Mitigation Plans

4.2.1 Biomedical Devices

While both the EMG and the TENS unit interacted with humans for testing, only the TENS posed potential risk. The EMG has a very low risk of endangering or harming the subject.

For the TENS unit, all testing phases were first read through an oscilloscope first prior to testing on a human. Furthermore, the power supplied to the circuit was sourced from a power supply rather than the batteries to reduce the risk of any unexpected events occurring. After it was determined that the output was suitably safe, only then were surface electrodes attached to the human subject and connected to the TENS unit circuit. Additionally, all testing and simulation was first done on a breadboard as a safety check. After testing on the breadboard was determined to be safe, then testing was moved onto the PCB platform.

4.2.2 Batteries

Dealing with Lithium-Ion batteries can be potentially hazardous when misused. Precise care was taken when using the batteries. When the batteries were used, the heat of the batteries were constantly checked and the batteries were monitored for any signs of heating and/or smoking. Additionally, most of the testing of the system was done on the power supply in the lab. Batteries were only tested after the completion of major milestons and even then was the testing time limited.

5 Conclusion

This section summarizes the accomplishments of this senior design project and provides suggestions for future work.

5.1 Accomplishments

Overall, the final product was a major success. With the exception of the TENS Unit (details found in the Uncertainties Subsection and in the TENS subsection), all other portions of the final system were successfully completed as outlined in the Design Section. The final product operation is as follows:

- 1. User attaches electrodes on targeted area, the masseter muscles (details here).
- 2. User flips on both power switches to turn on the device.
- 3. User waits and ensures that start up tone from the alarm module is played.
- 4. If user were to grind or clench their teeth loud enough, the following events would happen:
 - (a) The alarm module plays a tone.
 - (b) The teeth grinding/clenching event is logged by recording the relative time occurred, the voltage recorded by the EMG, and the voltage recorded by the audio detector.

Looking at the overall system from a subsystem perspective, all of the subsystems (with exception of the TENS unit module contained within the detection subsystem) were successfully implemented. Finer details on implementations can be found in the Design Section.

5.2 Uncertainties

The most difficult module to implement by far was the TENS unit namely because successful operation was not obtained by the deadline (in comparison to that of the other modules, which were successfully completed). Specific details are described in the TENS Unit Design subsection as well as the TENS Unit Verification subsection.

To summarize the main difficulty associated with the TENS unit design, the step-up transformer did not function as expected. While initial results through simulation were encouraging, testing on the breadboard and PCB revealed unexpected issues.

First and foremost, while expected operation was observed at the node right before the transformer (see here for the circuit schematic), the output right after the node was not what was desired. After thorough testing and consulting Professor Stillwell, it was found that the particular transformer that was purchased required a minimum operating frequency of 10kHz. In contrast with our desired frequency closer to 100Hz (a magnitude factor of 100 difference), it was clear that unless a more appropriate transformer was acquired, the TENS unit would not work. Unfortunately, due to timing and scheduling restrictions, sourcing the appropriate part, testing, and debugging was not possible. As such, the TENS unit was not included in the final design.

5.3 Future Work

There exists many different avenues one can take to improve upon this project. A brief summary list can be found below.

- Ethernet or WiFi capabilities
- Integration with smartphone application
- User adjustments via mechanical knobs
- Alternative to TENS module
- More detailed statistics of data recorded into the microSD card by the microcontroller
- Wall powered functionality rather than battery dependence
- Further downsizing

The first and foremost factor that can be improved is to implement a working TENS device. As described here, some issues prevented the successful completion of the TENS unit. Further work, testing, and prototyping can lead to a working TENS unit. Another approach one could take is to research alternatives to the TENS unit, such as ultrasonic muscle therapy.

As the system currently hosts a Ethernet Shield (as described here), primarily for its convenient microSD card slot, there exists potential improvements to be made for the data portion of the system. Rather than relying purely on the microSD card, the system can be upgraded to include a wireless solution, either via Ethernet or WiFi, to transmit the data to an edge computing device. In the same vein of reasoning, a smartphone application can be developed and deployed to host the data with more detailed time and data statistics.

Currently, the device primarily records the relative time when the user grinds their teeth as well as the voltage levels of the EMG and audio detector. For a second iteration of this product, more accurate time keeping as well as detailed statistics can be included such as graphs as well as trends over multiple days or weeks.

More fine-tuned controls for precision can also be implemented. For example, the TENS unit's pulse length is able to be adjusted with a potentiometer. A more user-friendly device may have a mechanical knob for the user to determine their preferred pulse length. In addition, some circuitry can be implemented to adjust the noise levels of the alarm module, which can ultimately include another outward facing mechanical knob for fine adjustment.

Currently the device is powered by four batteries as discussed here. Future iterations of this device can be powered through a wall adapter to increase the operating time of the device.

Overall, the entire system can be minimized. Due to the prototyping nature as well as some other factors discussed earlier, the PCBs were split up in order to accommodate modular testing. A more finalized version of the system can host all of the circuitry onto a single PCB so as to minimize the amount of area consumed. This decrease of area can be attributed to the fact that each PCB needed specially designed mounting holes and relative spacing between each PCB to properly accommodate each other. Having a single PCB can decrease the overall volume that the system consumes. All of the described approaches are potential improvements that can be made to the device.

5.4 Acknowledgements

The following thanks and acknowledgements are made.

- Mingjia Huo (our TA) for her support and attentiveness to our project
- Professor Joseph Irudayaraj (Professor in Bioengineering) for early advice
- Alexander Bom (Bioengineering student and our friend) for electrode guidance
- Professor Andrew Stillwell (Professor in ECE) for transformer advice
- Greggory Bennet and Skee Aldrich (Staff at Machine Shop) for building our container
- The rest of the ECE 445 Staff for running the course

References

- F. Lobbezoo, K. Koyano, D. A. Paesani, and D. Manfredini, "Chapter 145 sleep bruxism: Diagnostic considerations," in *Principles and Practice of Sleep Medicine (Sixth Edition)*, M. Kryger, T. Roth, and W. C. Dement, Eds., Sixth Edition, Elsevier, 2017, 1427–1434.e4, ISBN: 978-0-323-24288-2. DOI: https://doi.org/10.1016/B978-0-323-24288-2.00145-8. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780323242882001458.
- [2] S. Shetty, V. Pitti, C. L. Satish Babu, G. P. Surendra Kumar, and B. C. Deepthi, "Bruxism: A literature review," en, *J Indian Prosthodont Soc*, vol. 10, no. 3, pp. 141– 148, Jan. 2011.
- [3] F. F. Ferri, "Ferri's Clinical Advisor 2022". Elsevier, 2021.
- [4] Megcircuitsprojects. ""EMG Sensing Circuit"." (2019), [Online]. Available: https://www.instructables.com/EMG-Sensing-Circuit/ (visited on 09/29/2022).
- [5] A. D. Wiki. "Activity: Precision Rectifiers, Absolute value circuits, For ADALM1000"."
 (2021), [Online]. Available: https://wiki.analog.com/university/courses/alm1k/ circuits1/alm-cir-precision-rectifier (visited on 09/29/2022).
- [6] C. Spence, "Eating with our ears: Assessing the importance of the sounds of consumption on our perception and enjoyment of multisensory flavour experiences," *Flavour*, vol. 4, no. 1, p. 3, Mar. 2015, ISSN: 2044-7248. DOI: 10.1186/2044-7248-4-3. [Online]. Available: https://doi.org/10.1186/2044-7248-4-3.
- [7] K. Rohwer. ""Transcutaneous electrical nerve stimulator (TENS) circuit diagram"."
 (), [Online]. Available: https://www.learningelectronics.net/circuits/transcutaneouselectrical-nerve_03.html (visited on 09/29/2022).
- [8] S. Gozani, "TENS Under the Hood: Maximum Voltage". Quell, 2020.
- [9] IEEE. ""IEEE Code of Ethics"." (2016), [Online]. Available: https://www.ieee.org/ about/corporate/governance/p7-8.html (visited on 02/08/2020).
- [10] A. for Computing Machinery. ""ACM Code of Ethics and Professional Conduct"." (2018), [Online]. Available: https://www.acm.org/code-of-ethics (visited on 09/29/2022).
- M. B. I. Reaz, M. S. Hussain, and F. Mohd-Yasin, "Techniques of emg signal analysis: Detection, processing, classification and applications," *Biological Procedures Online*, vol. 8, no. 1, pp. 11–35, Dec. 2006, ISSN: 1480-9222. DOI: 10.1251/bpo115. [Online]. Available: https://doi.org/10.1251/bpo115.
- [12] R. Martinek, M. Ladrova, M. Sidikova, et al., "Advanced bioelectrical signal processing methods: Past, present, and future approach—part iii: Other biosignals," Sensors, vol. 21, no. 18, 2021, ISSN: 1424-8220. DOI: 10.3390/s21186064. [Online]. Available: https://www.mdpi.com/1424-8220/21/18/6064.
- [13] U. Food, D. A. C. for Devices, and R. Health. ""Electronic muscle stimulators"." (2017), [Online]. Available: https://www.fda.gov/medical-devices/consumer-products/ electronic-muscle-stimulators (visited on 09/29/2022).
- [14] "Front matter," in Functional Occlusion in Restorative Dentistry and Prosthodontics,
 I. Klineberg and S. E. Eckert, Eds., Mosby, 2016, pp. i–iii, ISBN: 978-0-7234-3809-0.
 DOI: https://doi.org/10.1016/B978-0-7234-3809-0.00023-1. [Online]. Available:
 https://www.sciencedirect.com/science/article/pii/B9780723438090000231.

- [15] "Acknowledgment," in Functional Occlusion in Restorative Dentistry and Prosthodontics, I. Klineberg and S. E. Eckert, Eds., Mosby, 2016, p. ix, ISBN: 978-0-7234-3809-0.
 DOI: https://doi.org/10.1016/B978-0-7234-3809-0.00031-0. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780723438090000310.
- [16] A. Au, M. Bakke, G. E. Carlsson, et al., "Contributors," in Functional Occlusion in Restorative Dentistry and Prosthodontics, I. Klineberg and S. E. Eckert, Eds., Mosby, 2016, pp. x-xi, ISBN: 978-0-7234-3809-0. DOI: https://doi.org/10.1016/B978-0-7234-3809-0.00029-2. [Online]. Available: https://www.sciencedirect.com/science/article/ pii/B9780723438090000292.
- I. Klineberg and S. E. Eckert, "Preface and introduction," in Functional Occlusion in Restorative Dentistry and Prosthodontics, I. Klineberg and S. E. Eckert, Eds., Mosby, 2016, pp. vii–viii, ISBN: 978-0-7234-3809-0. DOI: https://doi.org/10.1016/B978-0-7234-3809-0.00027-9. [Online]. Available: https://www.sciencedirect.com/science/article/ pii/B9780723438090000279.
- [18] "Copyright," in Functional Occlusion in Restorative Dentistry and Prosthodontics, I. Klineberg and S. E. Eckert, Eds., Mosby, 2016, p. iv, ISBN: 978-0-7234-3809-0. DOI: https://doi.org/10.1016/B978-0-7234-3809-0.00024-3. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780723438090000243.
- G. Zarb, "Foreword," in Functional Occlusion in Restorative Dentistry and Prosthodontics, I. Klineberg and S. E. Eckert, Eds., Mosby, 2016, p. vi, ISBN: 978-0-7234-3809-0.
 DOI: https://doi.org/10.1016/B978-0-7234-3809-0.00026-7. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780723438090000267.
- [20] S. Direct. "Jaw Muscle an overview"." (2016), [Online]. Available: https://www.sciencedirect.com/topics/neuroscience/jaw-muscle (visited on 11/02/2022).

Appendix A Biomedical Definitions

A.1 EMG

EMG stands for "electromyography" and detects electrical activity within muscles. EMGs are widely used in the medical industry for its diagonistic procedures [11], [12].

A.2 TENS

TENS stands for "Transcutaneous Electrical Nerve Stimulation". TENS units are devices designed for pain relief and muscle stimulation/relaxation using electrical impulses. The electrical pulses are deployed through surface contact electrodes attached to the muscle area of interest. They are widely regarded to be safe and a multitude of devices employing the use of TENS units have received FDA approval [13].

A.3 Targeted Muscle Area

There are three main muscle groups associated with bruxism as described in Table 1. Many doctors have reason to believe that "by manipulating these muscles while a person lies still, they can reduce the person's tendency to grind" [14]–[19].

Muscle Names	Function
temporalis and masseter muscles	Closes the jaw
lateral pterygoid muscles	Moves the jaw side to side
lateral pterygoid and digastric	Jaw opening

Table 1: Muscle groups associated with bruxism [20].

Out of the muscles listed above, the masseter is one of the largest ones. There are also other reasons for targeting the masseter discussed in the Introduction. It is optimal to target larger muscle groups as not only is the EMG is more likely to pick up on the muscle activity, but there will also be a larger contrast between activity and the lack thereof.

Appendix B Circuit Schematics



B.1 Power Subsystem

Figure 10: Schematic of the Power Subsystem

B.2 EMG



Figure 11: Schematic of the EMG module

B.3 Audio Detector



Figure 12: Schematic of the Audio Detector module

B.4 Alarm Module

[F	r.	o	m	-	Ar	rd	U	ìr	10		X									-	1			i I) 27	: 7-1			
-	•	•	•	•	•	•	•	•	•	-	•	•	•	•	•	•	•	•				2			E	31	JZ	Z	er	
-										-				•					н 1	-				-			-	•		
-										•				•		•				7			· ·				-	•		
-	•	•	•	•	•	•	•	•	•	-	•	•	•	:	•	•	•	•	GN	1D					•	•	-	•		

Figure 13: Schematic of the Alarm Circuit

B.5 TENS Unit



Figure 14: Schematic of the TENS Unit

Appendix C PCB Layout & Physical Implementation

C.1 Power Subsystem



Figure 15: PCB Layout of the Power Subsystem PCB.



Figure 16: Back view of the container. The black box is the battery box. The switches and LEDs of the Power Subsystem is located on top of the gray box.



Figure 17: Inside of box. Power PCB is top left PCB (in yellow rectangle).

C.2 EMG



Figure 18: Intended PCB Layout of the EMG module.



Figure 19: Physical implementation of EMG Circuit. Improvised PCB/breadboard hybrid design.

C.3 Audio Detector



Figure 20: PCB Layout of the Audio Detector module.



Figure 21: Physical implementation of Audio Detector module.



Figure 22: Inside of box. Audio Detector PCB is left PCB (in yellow rectangle).

C.4 Alarm Module



Figure 23: Buzzer with the microcontroller.



Figure 24: Buzzer located on side of Box.

C.5 TENS Unit



Figure 25: PCB layout of TENS Unit.



Figure 26: Physical implementation of TENS Unit.

Part Description	Manufacturer	Part Number	#	Unit Cost (\$)	Total Cost (\$)
$10 \ \mu F \ SMD$ Capacitor	Samsung	CL21A106KOQNNNG	3	0.10	0.30
$\begin{array}{c} 100 \ \Omega \ \text{SMD} \\ \text{Resistor} \end{array}$	KOA	RK73B2ATTDD101J	1	0.10	0.10
Instrumentation Amplifier (SMD)	Analog Devices	AD8221ARZ-R7	1	8.28	8.28
$\begin{array}{c} 2.2 \text{ k}\Omega \text{ SMD} \\ \text{Resistor} \end{array}$	YAGEO	RC0805FR-132K2L	2	0.10	0.20
470 nF Thru-Hole Capacitor	Samsung	ESL474M063AC3AA	1	0.24	0.24
$1.5 \ \mu F \ SMD$ Capacitor	Wurth Elektronik	885012207023	1	0.22	0.22
$\begin{array}{c} 0.1 \ \mu F \ SMD \\ Capacitor \end{array}$	Samsung	CL21B104KBCNNND	8	0.10	0.80
Microphone	Mallory Sonalert	PMOF-6027WN-44KDQ	1	3.05	3.05
Blue LED	CREE LED	C5SMF-BJF-CR0U0451	1	0.19	0.19
Yellow LED	Wurth Elektronik	151034YS03000	1	0.17	0.17
Mechanical Switch	E-Switch	100SP3T1B2M2QE	2	3.23	6.46
$\begin{array}{c} 10 \text{ k}\Omega \text{ SMD} \\ \text{Resistor} \end{array}$	KOA	RK73B2ATTD103J	6	0.10	0.60
10 kΩ Thru-Hole Potentiometer	Bourns	3306P-1-103	1	0.49	0.49
Operational Amplifiers	Texas Instruments	LM358DR	2	0.37	0.74
Buzzer	CUI Devices	CPT-2305-90PM	1	1.29	1.29
$\begin{array}{c} 100 \ \mu F \ SMD \\ Capacitor \end{array}$	Murata	GRM31CR61A107MEA8L	1	0.51	0.51
100 kΩ SMD Resistor	КОА	RK73H2ATTD1003F	2	0.10	0.20

Appendix D Parts List

$\begin{array}{c} 47 \ \Omega \ \text{SMD} \\ \text{Resistor} \end{array}$	КОА	RK73H2ATTD47R0F	1	0.10	0.10
10 nF SMD Capacitor	Wurth Elektronik	885012207039	1	0.10	0.10
4.7 nF SMD Capacitor	Wurth Elektronik	885342207004	1	0.10	0.10
PNP BJT	Nexperia	BCW29	1	0.10	0.10
SMD Diode	Rectron	FM4004-W	3	0.28	0.84
SMD IC555 Timer	Texas Instruments	NE555DRE4	1	0.38	0.38
Transformer	Wurth Elektronik	750311681	1	4.40	4.40
SMD NMOS Switch	Toshiba	T2N7002AK	1	0.16	0.16
Arduino Uno	Arduino	Rev3 SMD	1	26.30	26.30
Arduino Shield	Arduino	Ethernet Shield 2	1	29.80	29.80
Electrodes	Covidien	H124SG	6	0.825	4.95
3.7 Volt Batteries	TinyCircuits	ASR00050	4	4.47	17.88
0 Ω SMD Resistor	YAGEO	RC0805JR-130RL	2	0.10	0.20
Header Pins	Samtec	TSW-101-08-L-D	26	0.244	6.34
Battery Holders	Keystone Electronics	1043	4	2.48	9.92
$\begin{array}{c} 1 \ \mathrm{k}\Omega \ \mathrm{SMD} \\ \mathrm{Resistor} \end{array}$	YAGEO	RC0805FR-131KL	2	0.10	0.20
3.3 kΩ SMD Resistor	КОА	RK73B2ATTD332J	1	0.10	0.10
8.2 nF SMD Capacitor	YAGEO	CC0805KRX7R9BB822	3	0.12	0.36
100 Ω Thru-Hole Resistor	YAGEO	CFR-25JB-52-100R	1	0.10	0.10
10k Ω Thru-Hole Resistor	YAGEO	CFR25SJT-26-10K	7	0.10	0.70

2.2k Ω Thru-Hole Resistor	YAGEO	FMP100JTF52-2K2	2	0.22	0.44
Thru-Hole Diodes	onsemi	1N4148-T50A	2	0.10	0.20
Thru-Hole Op Amps	Texas Instruments	LM741CN/NOPB	3	0.90	2.70
6.8 kΩ SMD Resistor	KOA	RK73H2ATTD6801F	1	0.10	0.10
General Box	Polycase	WH-14 Hinged NEMA	1	31.53	31.53
Battery Box	Polycase	DC-47F	1	11.05	11.05
					172.89

Table 2: Material costs for all parts.

Appendix E Requirement and Verification Tables

E.1 Power Subsystem

#	Requirements	Verifications
1	Supply $\pm 8.5 \pm 1.5$ V	Probe 8.5 V and -8.5 V nodes with respect to ground node with voltmeter while connected to full system.
2	Overall system should not draw more than 500 mA from power subsystem.	Hook DC power supply set to 8 V and -8 V to overall system. Read current supplied.
3	Blue LED turns on when supplied +8 V with respect to ground and turns off when supplied 0 V.	Supply DC +8 V to the Blue LED. Verify it shines. Ground input of the Blue LED. Verify it doesn't shine.
4	Yellow LED turns on when supplied -8 V with respect to ground and turns off when supplied 0 V.	Supply DC -8 V to the Yellow LED. Verify it shines. Ground input of the Yellow LED. Verify it doesn't shine.

Table 3: Requirements and Verifications for battery module.

- 1. Batteries supplied 7.89 V and -7.95 V.
- 2. Total supplied current was 151 mA.
- 3. Functions as expected
- 4. Functions as expected

E.2 EMG

#	Requirements	Verifications
1	Electrodes must be able to detect EMG signals within range of 5 mV – 15 mV	The electrodes' output will be placed in parallel with a load resistor. The resistor is probed with an oscilloscope to verify the amplitude.
2	The bandpass filter must filter signals that have frequencies outside the range of 50 - 150 Hz. An error of 10 Hz on each extreme is allowed.	Probe the output of the bandpass filter with a spectrum analyzer.
3	The precision full wave rectifier must be able to invert the negative half of the AC input signal that has a maximum peak voltage of 5V.	Use a signal generator to input a 10 V peak-to-peak sinusoidal wave into the precision full wave rectifier. Probing the output should result in the full-wave rectified version of the input with ~1V error.

Table 4: Requirements and Verifications for EMG module.

- 1. EMG signals had magnitude 0.1 10 $\mu \rm V$ range. Made design changes accordingly.
- 2. Functioned as expected. Most pronounced frequency range was within 50 150 Hz.
- 3. Functioned as expected. Peak output voltage was 4.2 V.

E.3 Audio Detector

#	Requirements	Verifications
1	Bandpass filter must have pass range of 1 kHz – 2 kHz.	Probe the output of the bandpass filter with a spectrum analyzer.
2	Overall subsystem must be able to produce voltage between 0.5 V – 5 V range.	Play tone within 1 kHz – 2 kHz range. Probe output with oscilloscope.

Table 5: Requirements and Verifications for audio detector module.

- 1. Functions as expected during testing. Later empirical testing had complications.
- 2. Output voltage typically ranged from 0 V to 3.5 V. Sometimes had spikes of up to 4.5 V.

E.4 Control Subsystem

#	Requirements	Verifications
1	Receives data from two analog sources and performs analog to digital conversion to a digital signal.	Feed 2 analog signals from 2 signal generators (one sinusoidal, one square, both with 3-volt magnitudes) into 2 analog pins of the Arduino. After iterating though code that performs analog to digital conversion, it will output a digital signal (0 V or 3.3 ± 0.3 V) that can be probed with an oscilloscope.
2	Process analog EMG signals into digital data to be stored on microSD card.	A continuation of number 1. The sinusoidal signal will be processed as digital data and be saved as a text file to be written into a microSD card.
3	Can receive data from Arduino. The data will be moments in time when the device detected teeth grinding.	Run code that outputs a success message when data from Arduino is received while testing in conjunction with Arduino.
4	Can write data to SD card with a targeted maximum latency of approximately 1 second. The data will be moments in time when the device detected teeth grinding.	Same as number one but output message when successfully storing data on SD card. Will also verify by reading microSD card on external computer system.

Table 6: Requirements and Verifications for microcontroller.

- 1. Functions as expected.
- 2. Functions as expected.
- 3. Functions as expected.
- 4. Latency was minimal (magnitude of degree less than the original 1 second target). Exceeded expectations.

E.5 Alarm

#	Requirements	Verifications
1	Sound intensity should be within 60 ± 10 dB within 1 feet of device.	Feed code with Arduino to make buzzer play. Measure sound intensity at 1 feet away with decibel meter.

Table 7: Requirements and Verifications for alarm module.

Notes for each item:

1. Buzzer has sound intensity of 58 dB at 1 feet

E.6 TENS

#	Requirements	Verifications
1	Turns on and off accordingly.	Connect circuit's voltage controlled switch to 5 V and 0 V of a power supply one at a time. Probe output of IC555 with oscilloscope.
2	Output voltage of IC555 timer has max of 4 V. It also produces square wave signal with max frequency 120 Hz.	Probe primary transformer coil with oscilloscope.
3	Output voltage square wave pulse length can be adjusted. It does not exceed 1 millisecond in width.	Probe primary transformer coil with oscilloscope while adjusting potentiometer.
4	Output current is no more than 50 mA. Output voltage is no more than 40 V.	Continuation of number 2. Attach secondary transformer coil leads to 1000 Ω load (resistance of human skin). Measure current and voltage with multimeter.

Table 8: Requirements and Verifications for TENS unit.

- 1. Functions as expected.
- 2. Max frequency was 117 Hz. Max voltage was 4.7 V. Would have taken steps to reduce voltage down to 4 V.
- 3. Functioned as expected. Max pulse width length was 900 μ s.
- 4. Could not test. Design flaw in transformer of circuit.

Appendix F Software



Figure 27: The overall control flow of the microcontroller.

Week	Important	Edric	Justin
0 (9/26)	_	Footprints and PCB Design of Power and Detection Subsystems Research teeth grinding audio characteristics	Footprints and PCB Design of Control and Prevention Subsystems Research proper usage and positioning of electrodes
1 (10/3)	Design Review PCB Board Review	Fix PCB Design Order parts Begin physical dimensions planning	Fix PCB Design Order parts Research how electrodes work in relation to our design
2 (10/10)	_	Continue week 1 work Talk to machine shop Begin breadboard testing on circuits of concern	Continue week 1 work Talk to machine shop Begin breadboard testing for relevant circuits Create 3D models of physical implementation for PCBs placement
$3 \\ (10/17)$	-	Continue 10/10 work Order boxes for machine shop Simulate TENS Unit	Continue week 2 work Order box from machine shop
4 (10/24)	PCB orders arrive	Begin soldering and testing PCBs that have arrived Fix Audio Detector design Breadboard TENS Unit	Begin soldering and testing PCBs as they arrive
5 (10/31)	Second Round PCB Orders	2nd PCB order of Audio Detector Fix EMG design Order new EMG PCB independently Order new TENS Unit PCB	2nd PCB order of Audio Detector Debug and test EMG PCB Create and run software test code for EMG and microSD card

Appendix G Schedule

independently

6 (11/7)	_	Finalize Audio Detector design and PCB Order new Audio Detector PCB Build and test Power Subsystem Fix EMG design again Order new EMG PCB independently Finalize internals of container boxes with machine shop	Verify and touch up Audio Detector layout Purchase new Audio Detector PCB Tested power PCB Finalize design and picked up physical box from machine shop Create and test EMG + alarm + microcontroller code
7 (11/14)	Mock Demo	Integrate feedback from mock demo Begin integration of subsystems Fix EMG design again Test TENS Unit PCB Test Audio Detector PCB	Integrate feedback from mock demo Begin integration of subsystems Tested new EMG PCB Continue software testing as subsystems are integrated
8 (11/21)	Fall Break	Finalize EMG fixes Continue integration of subsystems Test integrated product	Final EMG design Finish integration of subsystems Create and test final version of software code
$9 \\ (11/28)$	Final Demo	Create and prepare presentation Begin final paper	Create and prepare presentation and final paper
10 (12/5)	Final Presentation Final Paper	Last check for final submission	Last check for final submission

Table 9: Week by week overall tasks and assigned responsibilities.