Muscle Highlighting Fitness Device

ECE 445 Design Document - Fall 2023

Project # 31

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Contents

1 Introduction

1.1 Problem

Many individuals find it challenging to engage and develop specific muscle groups during their workouts, especially if they are inexperienced with strength training. This is very common among beginners who may not have a strong mind-muscle connection. When individuals struggle to activate their target muscles, then they end up compensating by involving other muscle groups. For example, during a bicep curl, they may use their shoulders or back muscles instead of engaging their biceps. Due to inefficient muscle engagement, if the target muscles are not doing majority of the work during an exercise then the desired muscle growth or strength might be hard to achieve.

Form and techniques are vital parts of effective and safe workouts. Incorrect form can put excessive stress on joints and muscles, increasing the likelihood of strains, sprains and several other injuries. For example poor bicep curl form can cause bicep tendon rupture. What is even more unfortunate is that the majority of the people may not even realize that they have poor form. Without guidance, they may continue to perform exercises incorrectly. In addition to this, motivation and engagement are common challenges for many individuals when it comes to maintaining a consistent and effective fitness routine. It can be demotivating when individuals do not get to see visible results from their workouts and without real time feedback on their progress, individuals may question whether their efforts are paying off which can cause individuals to lose interest in their fitness routines.

Lastly, physical therapy and rehabilitation involves exercises and movements aimed at recovering from injuries or medical conditions. In traditional physical therapy settings, patients often perform exercises without immediate feedback which makes it challenging for them to fix their errors for faster healing to take place.

1.2 Solution

Our solution is to create a fitness device that specifically focuses on muscles in the arm including biceps(front of upper arms), triceps(back of upper arms) and forearms(lower arm). This device would be in the shape of a sleeve that the user would put on while working out their arms. This sleeve would contain multiple sensors throughout to detect various muscle activity. Additionally, each sensor would have an LED corresponding to it which would light up if the sensor recognizes muscle activity. The main goal would be for users to be able to recognize the muscles they are activating through the sleeve and to be able to make self adjustments if they realize they are not activating the correct muscles corresponding to the specific exercises they are performing.

In order to isolate which muscle is being targeted, we plan on placing EMG sensors and LEDs near the locations of different muscles. Our goal is to create a sleeve where muscles that are being contracted and used more, have a brighter illumination compared to muscles that may not be used as much during an exercise. For example, if someone is performing bicep curls, they would be contracting and using the bicep the most, but another muscle such as the tricep could also be used to a lesser extent. In this case, the EMG sensor near the bicep would provide a larger amplitude value compared to the EMG sensor near the tricep. The amplitude returned by the sensor defines the strength and intensity of the muscle being contracted. Using this amplitude value, the LED corresponding to the bicep EMG sensor would light up brighter than the LED corresponding to the tricep EMG sensor. This method provides the user with information regarding all muscles on the arm which are activated during the exercise as well as the intensity of which they are being used.

This device can thus provide real-time visual feedback to the users which would indicate which muscles are actively engaged during the different exercises. This will also help users develop a more efficient mind-muscle connection. Overall, this decision could educate users on the use of proper form and technique helping them prevent injury.

1.3 Visual Aid

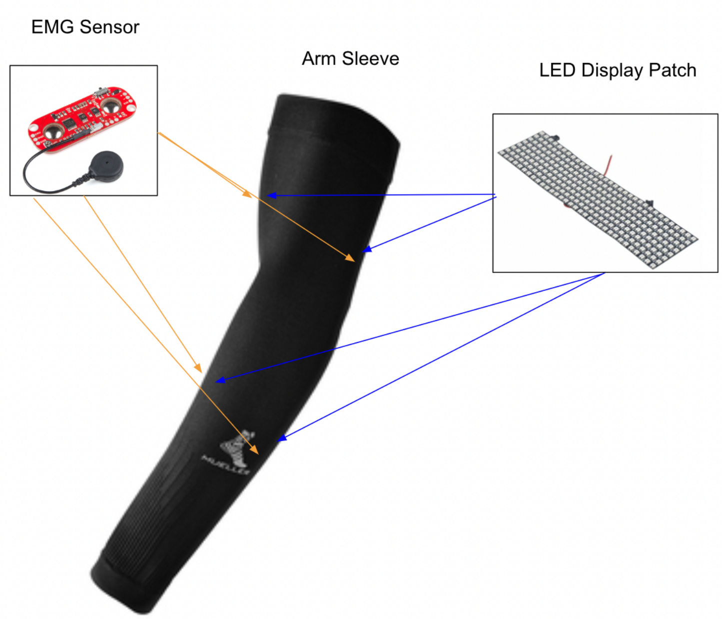


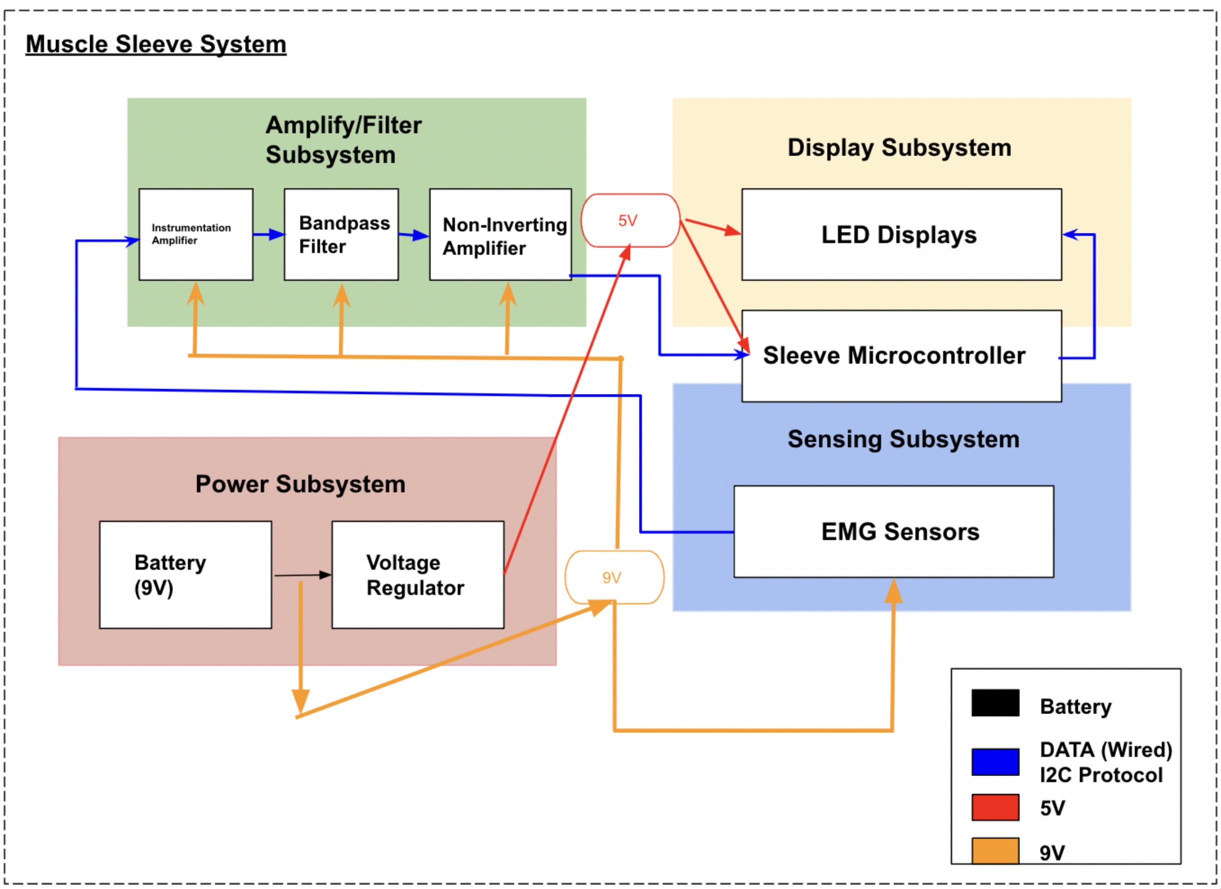
Figure 1: Image of the arm sleeve integrated with LED display and EMG sensors

1.4 High Level Requirements

- The device should function for at least one hour during workout
- The arm sleeve is able to display all muscles being activated even if some muscles may not be used as much as others
- The EMG sensor data that would be analyzed using an oscilloscope, its voltage ranging from 3.3-5 V and frequencies ranging from 0 - 500 Hz

2 Design

2.1 Block Diagram



2.2 Subsystem Overview

The power subsystem provides the voltage to turn on all the other subsystems with 9V. The EMG sensors are the main starting point of the overall design. Once voltage is circulating, the EMG sensors detect muscle activity and generate a real time signal which is then sent to the amplifying/filtering subsystem. This subsystem first amplifies the given signal from the EMG sensors to a max of 9V, and then runs a bandpass filter on the generated amplified signal to remove any noise. This filtered signal is then sent to the microcontroller where it will then perform a ranking of the amplitudes of the signal and then take the percentage difference between each ranking pair. Once these values are determined, the microcontroller will provide an input to each LED corresponding to a specific EMG sensor and light up based on a ratio compared to the input from other EMG sensors.

2.3 Subsystem Descriptions

2.3.1 Filter Subsystem

For this device, using a bandpass filter can be a useful technique in order to filter out the noise in the EMG muscle activity sensor system.

We learned that EMG signals are low in amplitude and therefore, they can be susceptible to a lot of interference and noise due to people's movements in a workout environment. This bandpass filter can help us improve the accuracy of the EMG signals. We learned that EMG signals range from 20 Hz to 500 Hz, with the most relevant information that we would require falling between the frequencies of 20 Hz and 250 Hz. Thus, we would be using the bandpass filter to focus on this specific frequency range within the EMG signal and cutoff frequencies to capture the relevant signal components. We would be using real time filtering which is applied as the signals are acquired. Lastly, after filtering, these signals would be processed by the microcontrollers on the sleeves so that the LED displays would be illuminated with the intensity level corresponding to the muscle that is getting worked out the most.

We decided to use a bandpass filter over a Lowpass filter as a Lowpass filter would allow frequencies under a certain cutoff frequency. This would not be ideal for data collection using an EMG sensor as most of the relevant information that we would receive from the muscle activity is in the higher frequency range(20Hz - 250Hz). In contrast, a BandPass filter can allow us to fine tune the frequency settings of the filter and help us target the specific arm muscles we would be monitoring.

Requirement	**Verification**
• We learned that the frequency range of EMG sensor signals is usually around 20 Hz - 500 Hz. Bandpass filter is able to retain information for frequencies ranging from 20 Hz - 250 Hz attenuating the other unwanted frequencies	• In order to test this system, we would attach the arm sleeve on one of our teammates during a bicep curl exercise. • We could ensure that the teammate performs bicep curls with 5 pounds by creating lots of unnecessary noise such as excessive movement of the arms and moving the arm sleeve up and down. This way, the EMG signals should be able to cover a range of frequencies that the BandPass filter we would use should be able to pass • The Bandpass filter should be able to retain important information, attenuating the other unwanted frequencies which we could verify by using an oscilloscope or microcontroller in order to visualize the filtered signal

2.3.2 Amplifying Subsystem

We believe that we would require some special techniques in order to eliminate the noise in the system and to amplify the relevant information we obtain from the sensors. It could happen that, due to excess noise from the movement during workouts we are unable to eliminate noise from the signal and are not able to accurately access the muscle activity taking place.

Due to this, we would be using an instrumentation amplifier which is a circuit with high impedance which amplifies the difference between two input signals. Because skin has high output impedance, its voltage is easily understood by thinking of the skin impedance and circuit impedance as resistors in a voltage divider. If both resistors are of equal value, only half of the input voltage will be measured across the circuit impedance. As the circuit impedance is increased above the skin impedance, more voltage will be applied across the circuit. We want to maximize the voltage going into the circuit. After the signal then goes through the BandPass filter with the cutoff frequencies between 20 - 500 Hz, we can increase the output signal to be read on an oscilloscope by using a non-inverting amplifier.

We learned that the EMG signals are typically very low in amplitude in the range of .5 mV. We need to amplify the overall signal to around 5 V so this would mean that there needs to be two separate amplifying systems with each having an amplification factor of 100. If we put together the 100x100 amplification, then it could lead to discomfort, harm to the device as well as bring in excessive and unnecessary noise into the filter subsystem and very high amplification in one system could also lead to greater susceptibility to electrical interference. Therefore we need to amplify it twice to perform an amplification without generating noise or ruin the device.

For this project we decided to use instrumentation and non-inverting amplifiers over operational amplifiers as we realized that they might not have the ideal input impedance needed for EMG sensors. We learned that EMG sensors require high impedance so that they avoid loading the electrodes. However, op-amps could degrade the EMG signal quality due to their lower input impedance compared to instrumentation amplifiers.

Requirement	Verification
• The instrumentation amplifier as well as the inverting amplifier should have a factor of 100 combined so that the amplified EMG sensor signals fall within the range 3.3-5V.	• In order to test this system, we would attach the arm sleeve on one of our teammates during a bicep curl exercise. We choose an amplification factor of 100 so that the amplified EMG sensor signals fall within the range 3.3-5V. We could ensure that one of our teammates is performing bicep curls using a 5 pound weight so that we are able to use a multimeter in order to compare the EMG signal input to its amplified output signal value in order to confirm that it has reached the desired voltage before it is passed through the BandPass filter.

2.3.3 EMG Sensor Subsystem

The electromyogram (EMG) sensor is used to detect electrical activity from a muscle using conductive pads that are placed directly on the skin. It is able to capture muscle contractions.

For this device, we plan on creating a sleeve where we would be placing EMG sensors on the main muscles of the arm such as the biceps(front of upper arms), triceps(back of upper arms) and forearms(lower arm) so that it is able to detect muscles being contracted while people work out those specific muscles in the arm using surface electrodes. The sensor would be able to clearly show significant differences in electrical activity when different weights are used. Electrical activity that is detected by the EMG sensors is displayed on an oscilloscope. In standby mode, the output voltage is close to 0V however, once muscle activity is detected, the output signal rises up and the maximum voltage is .5mV without amplification and 5V with amplification. Additionally, the most relevant information required from the sensors would fall between the frequencies of 20 Hz and 250 Hz. The EMG circuit would require three electrodes: positive input, negative input and ground. For example, in order to measure the activity of the bicep, the elbow would be a suitable placement for ground and the positive and negative electrodes should be placed on the upper arm. Using the data that is provided to us by each sensor, the microcontroller would be used to rank their outputs based on amplitude value from greatest to least so that we are able to understand the order of intensity in which the muscles are being worked out.

A EMG sensor model used is DEV-18425 from MYOWARE because it provides a rectified signal which will be effective to reduce the noise while it is compatible with 5V. Moreover, it is suitable for wearable projects since it has a great portability compared to other models. We decided to use EMG sensors over other sensors such as accelerometers because we learned that accelerometers function based on the detection of changes in motion, that is, they primarily detect changes in velocity over time. However, muscle activity is measured through muscle contractions that generate electrical signals which are best measured using EMG sensors.

Requirement	**Verification**
● We plan on taking the percentage difference from each pair ranking and using that to determine the LED intensity output. For example, in the exercise: a close grip chin up both the bicep and tricep muscles are activated. The bicep sensor data through the EMG shows a frequency of about 80 Hz whereas the tricep sensor data	● We would test the frequency percentage difference displayed on the sleeve during a bicep curl exercise ● For this, we would place the sleeve on one of our teammates arms and as we would place the ground electrode on the elbow, and the positive, negative electrodes on the upper arm.

through the EMG shows a frequency of about 100 Hz. Their percentage difference is 22% so, the LED illumination for the tricep would be 22% more intense than for the bicep	● We would read the electrical activity displayed on the oscilloscope while one of our teammates performs a bicep curl using a 5 pound weight vs when the same teammate performs a bicep curl using a 10 pound weight. ● We should verify whether we are able to observe the most electrical activity from the electrodes connected to the bicep in comparison to the other arm muscles such as the tricep or the forearms ● In addition to this, we should be able to check that regardless of the weight the teammate is lifting during the exercise, the percentage difference between the bicep and tricep frequency when the teammate is lifting 5 pounds vs 10 pounds should be the same.
● Must send the real time signal to the microcontroller through Filter and Amplifying subsystems after filtering the raw .5mV EMG sensor signal to have an amplification to 5V and filtering all the frequency values to obtain values between 20 Hz - 250 Hz	● Must send the real time signal to the microcontroller through Filter and Amplifying subsystems: ● We would test and verify the amplification of the EMG sensor signals and the filtering of the unwanted noise frequencies outside of the EMG signal range. ● We could check periodically the output of the EMG sensor using an

	oscilloscope so that we are able to observe real time filtered and amplified electrical signals from the electrodes attached to the arm muscles. ● In order to confirm amplification of the EMG signals, we would be comparing the input vs output signals in real time.

2.2.4 LED Display Subsystem

For this device, we wanted to use an LED illumination display for the users to be able to recognize the muscles they are activating through the sleeve and to be able to make self adjustments if they realize that they are not activating the correct muscles corresponding to the specific arm exercises they are performing.

The signal from the EMG would be sent to the microcontroller. As mentioned above, the microcontroller would be programmed to rank the outputs of the sensors of the different arm muscles based on their amplitude value from greatest to least. In order to provide an accurate illumination for the LEDs for each sensor, we plan on taking the percentage difference from each pair ranking and using that to determine the LED intensity output. For example, in the exercise: a close grip chin up both the bicep and tricep muscles are activated. The bicep sensor data through the EMG shows a frequency of about 80 Hz whereas the tricep sensor data through the EMG shows a frequency of about 100 Hz. Their percentage difference is 22% so, the LED illumination for the tricep would be 22% more intense than for the bicep.

Using Digital Potentiometer to manipulate the brightness by software since we have to sort the order of the muscle parts by activation intensity. We are using Digital Potentiometer instead of other methods such as giving delay to the LED because delay to a LED will cause some delay to other LEDs as well, causing the delay of the whole system. Equation for

Resistance for each LED: R = Minimum Resistance * (Max Frequency/Each Frequency)

Requirement	**Verification**
• Digital Potentiometer should change resistance by software.	• As the voltage flowing to the LED increases which means the resistance decreases, the brightness of the LED will be more intense. Confirm the voltage is increased using a multimeter.
• Digital Potentiometer should change resistance as the frequency of the signal from the EMG sensor changes.	• As the frequency of the signal from the EMG sensor increases, the brightness of the LED should increase as the resistance decreases.

2.3.5 Power Subsystem

The power subsystem interacts with all other components in other subsystems as it provides a constant voltage of 9V to the rest of the device. We plan to use a linear regulator to regulate the voltage to 5V as some subsystems such as the microcontroller and LED Display require 5V input voltage and not 9V.

Requirement	**Verification**
• Confirm battery is able to run throughout the duration of a workout which is currently defined as one hour. Battery must reach 1 hour minimum	• Run the battery with all components for an hour. Periodically check the voltage across each subsystem to confirm there is a constant voltage being supplied throughout using a multimeter.

2.4 Tolerance Analysis

One subsystem that poses a risk for successful completion is the sensor subsystem. When the EMG sensors are stand alone with no muscle detection, they output a voltage around 0V, and when the muscle is activated they detect a voltage of about 0.5mV. If the sensors do not detect a proper muscle activation even when one is occurring, there can be a failure in the product working as the LEDs may not light up accordingly. Considering 0.5mV is the maximum output of the sensors when it does detect muscle activation, we can say that there is a 10% tolerance on the sensor output to check if a muscle is activated. This means any output within 0.49-0.5mV is considered muscle activity.

Another subsystem to take into consideration is the power subsystem. We require the battery to provide power for one hour, the length of an average workout. Below are the calculations for the total power and voltage required for the overall system:

- 9V * 1µA (max current from data sheet) * 64 (# of led for each pad) * 3 (# of pads) = 1.728 mW
- Power needs for EMG sensor: 9V * 9mA(current from data sheet) * 3 (count) = 243 mW
- Power needs for Amplifier: 9 V * 0.3 mA (Quiescent current per amplifier) * 1 (count) = 2.7 mW
- Power needs for Filter: 0 W since it does not use power.
- Power needs for Linear Voltage Regulator: ΔV * I = (9-5) * 10mA (current from data sheet) = 4 * 10 mA = 40 mW
- **Total power needed:** (1.728 + 243 + 2.7 + 40) mW * 1hr = 287.428 mW
- **Total Voltage/Current needed:** 9V at 0.0274 amps

Thermal Tolerance:

- Current Output from Voltage Regulator: 800 mA
- Voltage Output from Voltage Regulator: 5 V
- Power Supply from Voltage Regulator: 5 * 800 mA = 4 W
- The maximum heat generated by a microcontroller, which has the lowest thermal tolerance in those parts, is 4W since the power supplied from Voltage Regulator, which can increase up to 20 celsius degrees. Since the microcontroller has an operating temperature of -40~85 degrees Celsius,

the maximum temperature of the environment is 65 degrees Celsius which is too high. Therefore, the thermal tolerance for a microcontroller is safe for any environment.

Additionally, the material that repels water will be used to protect the electrode from the sweating, so it can reduce the noise caused by sweat.

3 Cost Analysis

Based on research, $59/hour is reasonable. $59 * 2.5 * 72 hours = $10,620 per person.

The total parts below come out to $104.19. Therefore the overall cost is going to be $31.964.19.

3.1 Parts Table

Parts	Manufacturer	Part #	Quantity	Cost per Unit	Description	Links
2.2k ohms Resistor	YAGEO	13-RC1206FR-102K2LTR-ND	1	$0.10	RES 2.2K OHM 1% 1/4W 1206	Link
1 k ohms Resistor	ROYAL OHM	1210W2J0102T5E	1	$0.04	RES 1K OHM 5% 1/2W 1210	Link
220nF Capacitor	KEMET	C0805X224K3RECAUTO	1	$0.30	CAP CER 0805 220NF 25V X7R 10%	Link
600nF Capacitor	KEMET	CKC33C604KWGLCTU	1	$1.68	Multilayer Ceramic Capacitors MLCC - SMD/SMT 650V 0.6uF 3640 KCLINK KONNEKT	Link
Instrumentation Amplifier	Texas Instruments	LM258DRG4	1	$0.42	IC OPAMP GP 2 CIRCUIT	Link

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Surface EMG Electrode(10 pack)	SparkFun Electronics	SEN-129 69	1	$8.95	BIOMEDIC AL SENSOR PAD (10 PACK)	Link
Reference Cable(3 pack)	SparkFun Electronics	CAB-129 70	2	$5.69	SENSOR CABLE - ELECTROD E PADS (3	Link
9.0V Battery	Amazon	6LR61	1	$5.50	Amazon Basics 9 Volt Alkaline Performance All-Purpose Batteries	Link
Voltage Regulator	Texas Instruments	LM337K CSE3	1	$1.00	IC REG LIN NEG ADJ 1.5A TO220-3	Link
Arm Sleeve	EGOFLEX		1	$6.79		Link
LED Display	LOAMLIN	PL0056	1	$9.66	*Voltage: DC 12V *SMD Type: High Quality 5050 Diodes (super bright) *Qty of SMD: Each LED has 48 SMD in total. *Color: White	Link

					*Power:12V *0.36A *Lumens:58 0LM	
Microcontroller	Microchip Technology	ATMEGA32U4-AU	1	$5.29	IC MCU 8BIT 32KB FLASH 44TQFP	Link
Non-inverting Amplifier	Microchip Technology	MCP616-I/P	1	$1.12	IC OPAMP GP 1 CIRCUIT 8DIP	Link
Switch	DaierTek	KCD1-101	1	$7.99	Mini Rocker Switch 12V 20A T85 2 Pin SPST Small ON Off Switch 120V 10A ON and Off Rocker Toggle KCD1	Link

4 Schedule

Week	Task/Person
9/25 - 10/2	**Sangyun:** Design Power and Microcontroller on PCB using kiCAD **Sreyas:** Design Bandpass Filter and Amplifying subsystem on PCB using kiCAD **Anushka:** Design Sensing and Display Subsystem on PCB using kiCAD **Everyone:** Look into what components are included in kits and what needs to be ordered
10/2 - 10/9	**Everyone:** Work on combining the subsystems into one PCB design, including creating the necessary routes

	between subsystems. Order parts that are needed.
10/16 - 10/23	**Everyone:** Get PCB design reviewed and work on any changes for respective subsystems. Perform research into ideal locations for sensors on the arm sleeve.
10/23 - 10/30	**Sreyas:** Work on creating necessary holes in arm sleeve and how to place sensors and PCB in overall design **Sangyun/Anushka:** Start initial software implementation for sensor data and LED display **Everyone:** Order PCB after finalizing design
10/30 - 11/6	**Everyone:** Solder respective subsystem components on PCB. Confirm soldered parts are working through verification and testing.
11/6 - 11/13	**Anushka/Sangyun:** Finalize code implementation and perform testing of code on the different subsystems. **Sreyas:** Continue testing and debugging PCB components. Stitch sensors and LED displays into the arm sleeve.
11/13 - 11/20	**Everyone:** Finalize overall design and perform testing to make sure design is working.

5 Ethics and Safety

The IEEE Code of Ethics details how there should be a responsible and respective working environment during professional activities. As a group we will make sure to follow this guideline by respecting each other's opinions and treating everyone equally. Additionally, we will be mindful of each other's schedules and make sure to create a good working environment so we can all feel welcome. Our project requires us to solder which means we will need to use the senior design lab a couple of times. During these scenarios, we plan to keep each other accountable and work together when soldering.

The added material to reduce the noise caused by sweating would also contribute to safety by preventing electrocution when sweating. Also, to prevent burning skin by electrodes, it would be tested using the thermometer before it is attached on the skin. To prevent exposure of battery or circuit, the circuit and battery will be fixed tightly, and to prevent exposure when they fall apart, encapsulation of the circuit and battery will be required.

6 Citations

"IEEE Code of Ethics." *IEEE*, www.ieee.org/about/corporate/governance/p7-8.html. Accessed 26 Sept. 2023.

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"Industry-Standard Dual Operational Amplifiers", Texas Instruments, https://rocelec.widen.net/view/pdf/x9qyuxflz9/lm158.pdf?t.download=true&u=5oefqw

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