ECE 445

Senior Design Laboratory

Final Report - Fall 2023

Muscle Highlighting Fitness Device

Team # 31

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1 Introduction

1.1 Problem

Many individuals find it challenging to engage and develop specific muscle groups during their fitness training. This is very common among beginners who may not have a strong mind-muscle connection. When individuals struggle to activate their target muscle groups during their workout then, they end up compensating by involving other muscle groups. This means that if the target muscle group is not doing most of the work during a workout exercise then the desired muscle growth would be difficult to achieve.

In addition to this, we know that form and technique are crucial parts of a safe workout and this incorrect technique could lead to injuries and sprains from excessive stress on joints and muscles. An unfortunate truth about this issue is that due to lack of guidance, several individuals do not realize that they have incorrect form and technique. It can also be discouraging for individuals to not be able to see visible results from their workouts and without real time feedback on their progress, they may 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

The solution that our group came up with was to create a fitness device in the form of an arm sleeve that would have surface electrodes all throughout the sleeve. The purpose of these sensing surface electrodes would be to measure the muscle activity through electrical signals produced solely by the arm muscles including biceps and triceps. Additionally, each of the sensors would have an LED corresponding to it which would illuminate if the surface electrodes detect muscle activity. The main goal would be for individuals to be able to recognize the muscle that they are activating during their fitness exercise through their 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. A simple example that shows the functionality of the fitness device would be if an individual is performing bicep curls, then the arm muscle that they would be contracting the most would be the bicep. However, another arm muscle such as the tricep could also be used but to a lesser extent. In this scenario, the surface electrodes near the bicep would sense higher muscle electrical activity and this would provide a larger amplitude value compared to the surface electrodes placed 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 sensor would light up brighter than the LED corresponding to the tricep sensor.

1.3 Visual Aid

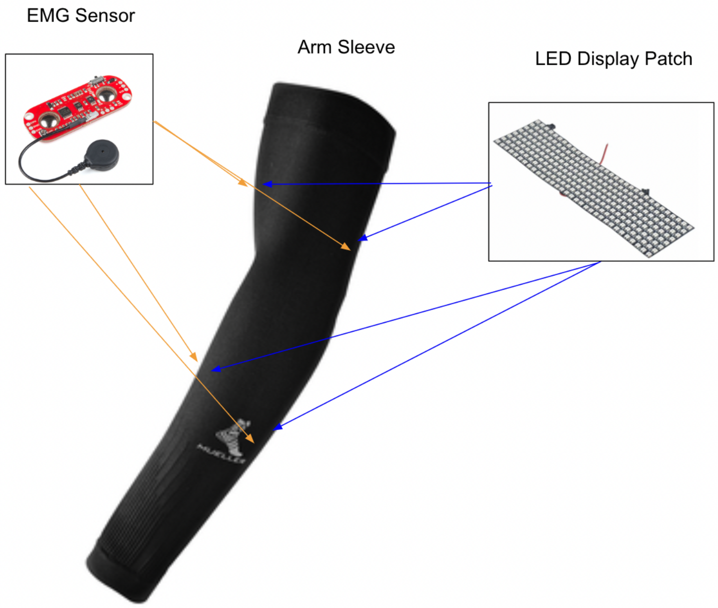

Figure 1: Image of the arm sleeve integrated with LED display and surface electrode sensors

1.4 High Level Requirements

1. The device should function for minimum one hour while performing fitness exercises
2. The intensity of muscle contractions should be appropriately displayed through the LED's for each muscle group
3. Muscle contractions are able to be detected by the arm sleeve and produce a signal ranging from 0-5 V peak to peak and frequencies ranging from 10 - 500 Hz

2 Design

2.1 Block Diagram

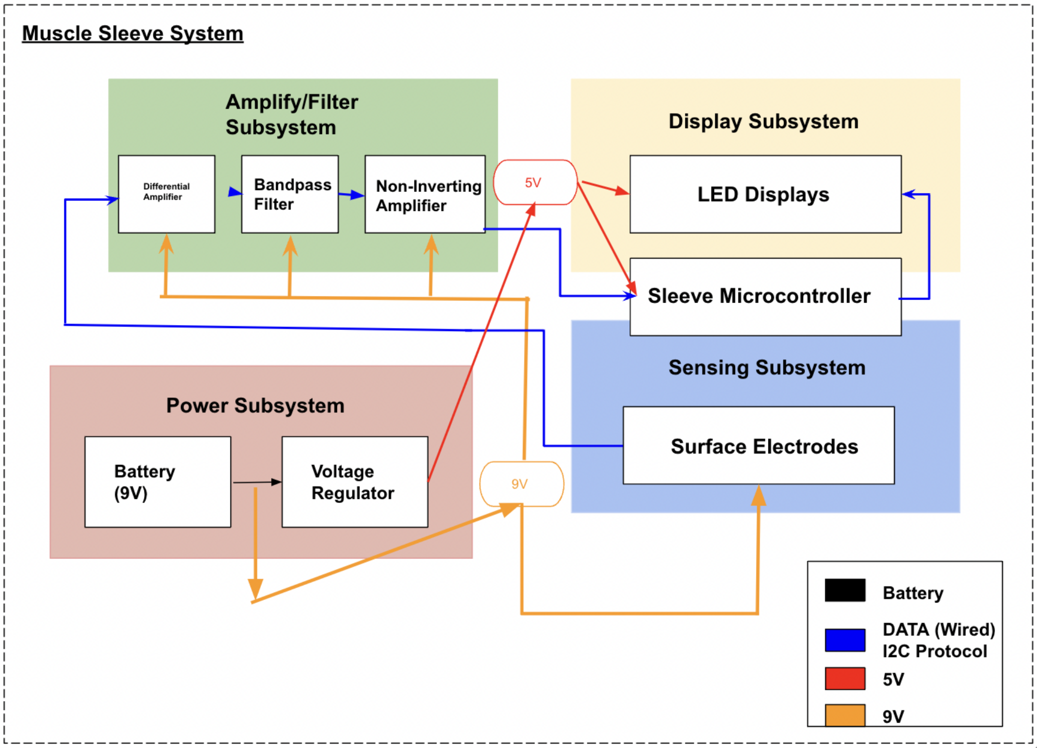

Figure 2: Block Diagram

The block diagram shows the four major subsystems for the arm sleeve system. The power subsystem consists of two 9V batteries which are also connected to a linear regulator to generate a voltage of 5V. The 5V is used to power the display subsystem and microcontroller while the 9V is used for the sensing and amplifying/filter subsystems. The sensing subsystem contains surface electrodes which read in a small signal generated by the muscles when active. This signal is sent to the amplification and filtering subsystem. The small signal is first passed through a differential amplifier which amplifies the signal to a usable amplitude. Then the bandpass filter removes any noise generated and keeps the frequency ranges which have the relevant signal information. Finally, the non-inverting amplifier amplifies the signal further to be able to send the signals to the microcontroller. The microcontroller takes the signals in as input and performs software on these inputs to then produce a voltage output which is sent to the display subsystem to illuminate the LEDs.

2.2 Amplifying Subsystem

2.2.1 Description

The amplifying subsystem plays a significant role in filtering noises from our signals. We have two separate parts to the amplification subsystem: one before filtering and one after filtering. The reason behind this structure is that this structure can make filtering more efficient and accurate. More specifically, the amplifying subsystem before filtering is necessary for accurate filtering because the initial amplitude of the signal from the sensing subsystem is too small, so to filter out noise accurately, the amplitude should be amplified. Moreover, the amplifying subsystem after filtering is also necessary to filter out noise efficiently. After the filtering subsystem, any signals with frequencies outside the range of the filter are attenuated, however, this does not mean these signals are completely removed. Therefore, in order to generate a larger gap in amplitude for better differentiation between the noise and useful signal, the second step of amplification is necessary.

2.2.2 Design Decisions

For the first part of the amplification subsystem, we would be using a differential amplifier which would serve the purpose of taking the difference between the two signals measured by the surface electrodes. The reason why we are using the difference between the two signals rather than one electrode is that using the difference of two signals can effectively filter out the noise from the environment or other muscles. Next, the differential amplifier would make this difference in voltage and amplify it by a gain of 10. To figure out resistor values for gain of 10, we used the equation of gain below.

$$\text{Gain} = \frac{R\_ref}{R\_n}$$

Since we want to get a gain of 10, we set R_ref to 1 MOhms while R_n to 100 kOhms.

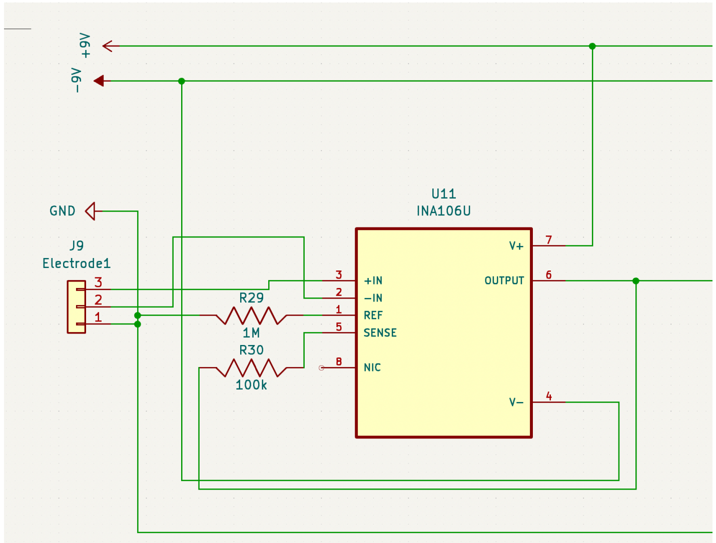

Figure 3: Amplifying Subsystem using Differential Amplifier Schematic

The next part of the amplification subsystem would be a non-inverting amplifier. In this case, the output signal would be a non-inverted(in terms of phase) signal which is an amplifier version of the input signal with a gain of 5. To figure out resistor values to use, we used the gain equation for non-inverting amplifiers below.

$$\text{Gain} = \frac{R\_ref}{R\_n} + 1$$

Since we want to get a gain of 5, R_ref/R_n = 4, so we set R_ref to 370 kOhms and R_n to 100 kOhms which makes R_ref/R_n = 3.7 close to 4.

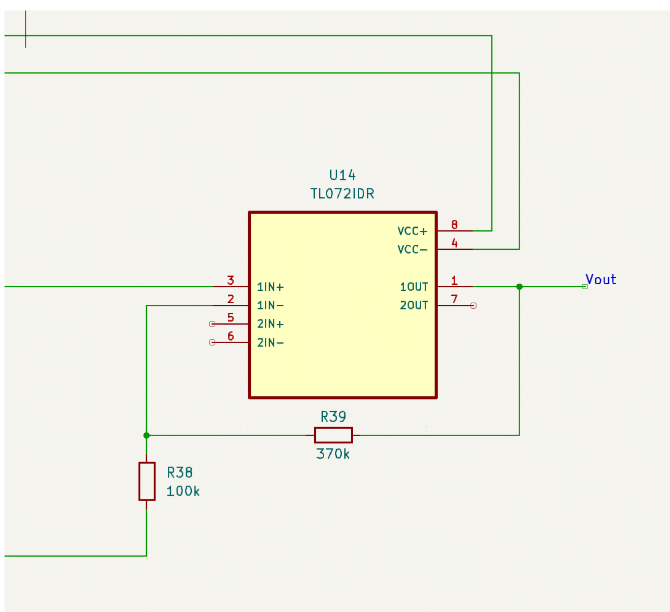

Figure 4: Amplifying System using Non-Inverting Amplifier Schematic

After the signal is passed through the differential amplifier and before it is passed through the non-inverting amplifier, the signal goes through the BandPass filter with the cutoff frequencies between 10 - 500 Hz. As the raw signal amplitude from the surface electrodes is in the range of 0 - 50 mV, the amplification subsystem amplifies the amplitude to a maximum value of 2.5 V so that we are able to analyze it through the oscilloscope.

2.2.3 Requirement and Verification

Details of the requirements and verification steps can be found in Appendix A Table 6.

We successfully verified the requirement in Appendix A Table 6. We not only tested the sample in our requirement table, but other samples as well. The result is in Table 1 below. As we can see, every value in the Amplifying 1 column is around 20 times the values in the "Difference" column which means that the amplitude of the amplified signal has around 10 times the values in the "Difference" column. On the other hand, every value in the Amplifying 2 column is around 5 times the value in Amplifying 1 column. Therefore, our requirement in the requirement table has been met.

Input 1	Input 2	Difference	Amplifying 1 (peak-to-peak)	Amplifying 2 (peak-to-peak)
50 mV	10 mV	40 mV	833.186 mV	4.259 V
40 mV	10 mV	30 mV	617.291 mV	3.091 V
50 mV	30 mV	20 mV	412.721 mV	2.132 V
40 mV	30 mV	10 mV	208.121 mV	1.188 V

Table 1: Amplification Subsystem Results

2.3 Sensing Subsystem

2.3.1 Description

The sensing subsystem detects electrical activity from a muscle using surface electrodes that are placed directly on the skin. It is able to capture muscle contractions. The signal generated by each electrode would have an amplitude ranging from 0 to 50 mV while the frequency would range from 10 to 500 Hz based on the muscle contraction it has detected. More specifically, if an electrode detects light muscle contraction, then the signal generated by the electrode would have amplitude close to 0 mV and frequency close to 10 Hz. On the other hand, if an electrode detected heavy muscle contraction, then the signal generated by the electrode would have an amplitude close to 50 mV and frequency close to 500 Hz. These signals will be an input to the amplification and filtering system. A picture of the electrodes attached on the arm can be found in Figure 5.

2.3.2 Design Decisions

For this device, we plan on creating a sleeve where we would be placing surface electrodes on the main muscles of the arm such as the biceps(front of upper arms) and triceps(back of upper arms), so that the surface electrodes are able to detect muscles being contracted while people work out those specific muscles in the arm. The sensor would be able to clearly show significant differences in electrical activity when different weights are used.

In more detail, we will use three electrodes to detect each muscle part: one is for negative signal and is attached on the beginning of the muscle part, one is for positive signal and is attached on the middle of the muscle, and one is for reference and is attached on the elbow where no muscle exists. 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. The reason why we generate two signals on one muscle is because we want to use the difference between amplitudes of two signals instead of using just one signal to reduce the noise from environment or other muscle parts.

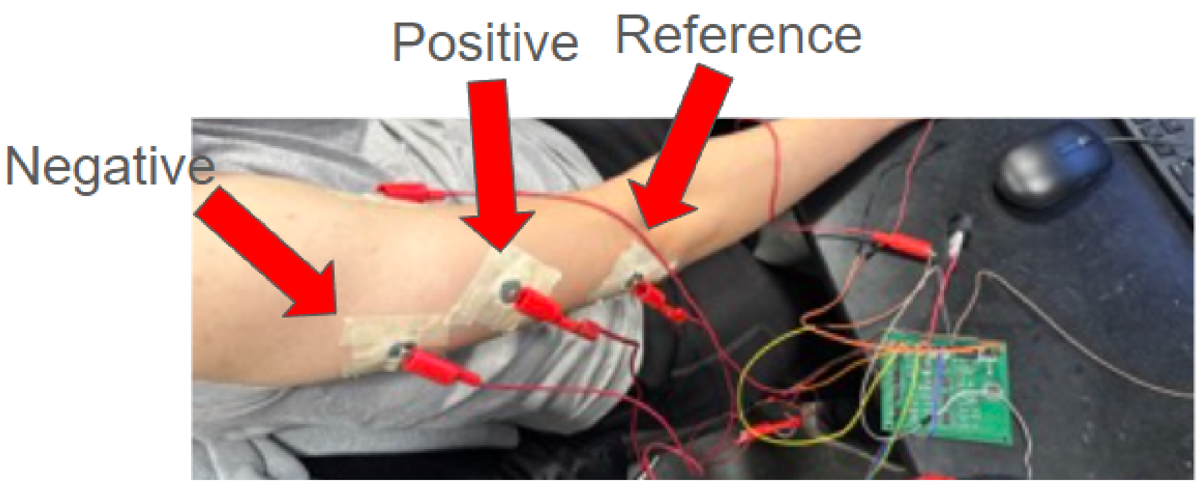

Figure 5: Attached Electrodes on the Arm

Once muscle activity is detected, the difference of amplitudes of the signal rises up and the maximum difference is 50 mV without amplification and 5V peak to peak with amplification. Additionally, the most relevant information required from the sensors would fall between the frequencies of 10 Hz and 500 Hz. 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.

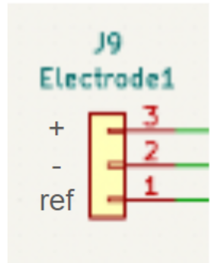

Figure 6: Electrodes Input in Schematic

2.3.3 Requirement and Verification

Our requirements and verification on the sensing subsystem focused on whether our electrodes are correctly detecting muscle contractions. Details regarding the verification can be found in Appendix A Table 7.

Unfortunately, we were not able to verify requirements for the sensing subsystem directly because our low quality electrodes burnt out faster than we expected. As a result, before we could record data, all ordered electrodes burnt out while we were testing the sensing subsystem with our amplifying and filtering subsystem. Since we still needed input from the electrodes, we instead used a signal generator to replicate the electrode input.

2.4 LED Display Subsystem

2.4.1 Description

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. In the LED display subsystem, the signals from the amplifying and filtering subsystems would be sent to the microcontroller, and the microcontroller should manipulate the brightness of the LEDs depending on the amplitude of the corresponding signals. More specifically, if one input signal has higher amplitude than the other, the LED matched with this signal will be brighter than the other.

2.4.2 Design Decisions

For the display subsystem, we use the ATMega32u4 microcontroller which is used in Arduino Leonardo to manipulate the brightness of LEDs. While breadboarding, we used the Arduino Leonardo development board to test and realized that the microcontroller used on the development board, the ATMega32u4, would also work for our design. Furthermore, this microcontroller has additional input and output pins which would make it convenient for us to extend our arm sleeve to include more muscles in the future.

LEDs are connected to the PWM pins of the microcontroller via 1k resistors to protect the LEDs from the high current. Since the maximum voltage supplied by a microcontroller is 5V, the maximum current that can be made is 5V/ 1 kOhms = 5 mA while the maximum current for LED is 20 mA, so there will be no risk of burning out LEDs.

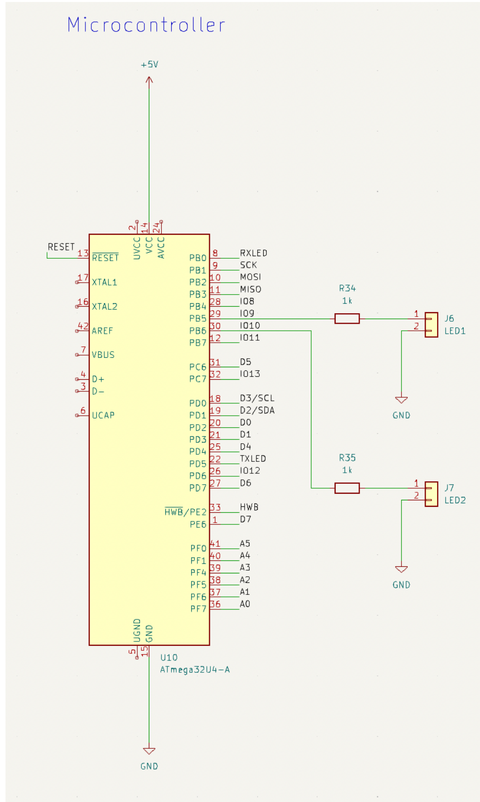

Figure 7: Display Subsystem Schematic

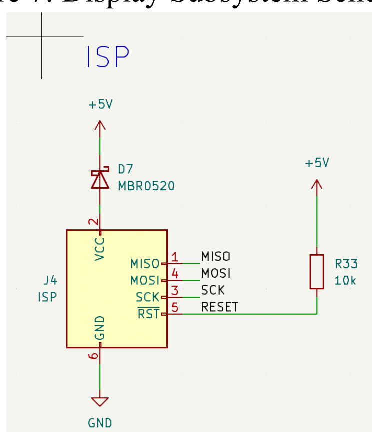

Figure 8: Schematic of ISP for Microcontroller

The microcontroller in this system will manipulate the brightness by supplying different amounts of voltage. The microcontroller computes the voltage to supply for LEDs depending on the amplitudes of signals, so the signal with highest amplitude can supply the highest voltage value. To implement this, instead of sorting the signals depending on amplitude, we were using the equation below for faster runtime.

$$V\_n = V\_max * \left(\frac{\text{Amplitude\_n}}{\text{Max Amplitude}}\right)^2$$

We squared the ratio instead of using a simple ratio, so the brightness of LEDs are more distinguishable. For example, when the electrode on bicep generates the signal with amplitude of

1 V while the electrode on tricep generates the signal with amplitude of 2.5 V, the microcontroller will provide the LED on tricep with 5 V since the maximum voltage that can be generated by microcontroller is 5 V, and provide the LED on bicep with 5 V * (1/2.5)^2 V = 0.8 V. Since the resistor values are the same on LEDs, the current on bicep LED which is directly related to the LEDs' brightness is only 16% of current on tricep LED. As a result, the brightness of the bicep LED will be only 16% of the brightness of the tricep LED.

2.4.3 Requirement and Verification

Details of the requirements and verification steps can be found in Appendix A Table 8. Unfortunately, our microcontroller system was not working, so we tested the software with an Arduino Leonardo board and the breadboard, and this test result is reliable since we are using a microcontroller used in the Arduino Leonardo board.

To verify our requirements, we used a signal generator to create two signals which replicate the input of the electrodes: one with the amplitude of 1 V while the other with amplitude of 2.5 V. We connected these two signals into the Arduino Leonardo with our software program, then connected the outputs from the Arduino Leonardo to the LED via resistors. Then, we can simply observe whether the LED matched with a signal with 2.5 V amplitude is brighter than the other. The pictures below show our results.

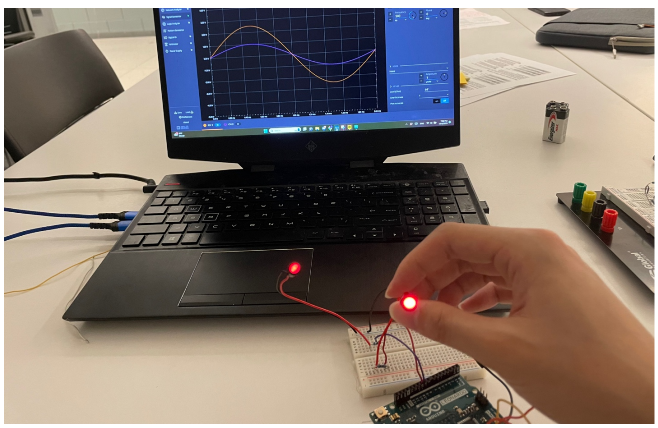

Figure 9: Display Subsystem Demo (Right: 2.5V, Left: 1 V)

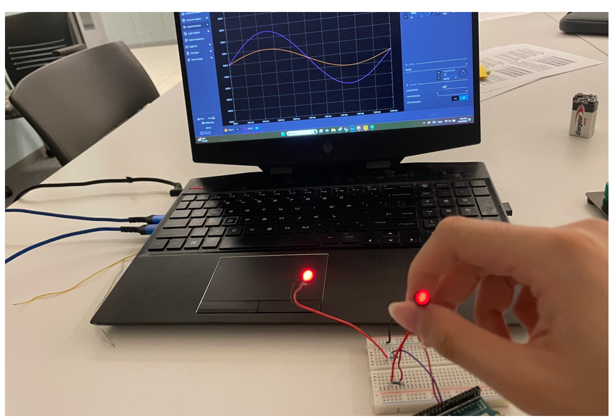

Figure 10: Display Subsystem Demo (Flipped Amplitudes)

For accurate verification using quantitative data, we measured the voltage value supplied by the microcontroller to LED via resistors on the breadboard. From these measurements, we got

4.8~5.0 V from the output of the Arduino board that is matched with the signal with amplitude of 2.5 V while the output that is matched with the signal with amplitude of 1 V is measured between 0.7 ~ 1.0 V. If we calculate the current from these values, then we get: Current on LED matched with the signal with amplitude of 2.5V: 4.8/1 kOhms ~ 5.0 V/ 1 kOhms = 4.8 ~ 5.0 mA, Current on LED matched with the signal with amplitude of 1 V: 0.7/1 kOhms ~ 1.0 V/1kOhms = 0.7 ~ 1.0 mA.

From these results, we can conclude that current on LEDs matched with the signal with 1 V amplitude is only 14.5 ~ 20% of the current on other LEDs. Since the current is a direct factor of the brightness of LEDs, we can confirm that our requirement on this system has been met.

2.5 Filtering Subsystem

2.5.1 Description

For our fitness device, we decided to use a BandPass filter in order to filter out the excessive and unnecessary noise in the muscle activity sensor subsystem. While analyzing the raw signals detected by the surface electrodes on the arm muscles, we observed that they are low in amplitude, ranging from 0 - 50 mV and therefore, can be susceptible to a lot of interference and noise due to people's movements in a workout environment. The purpose of the BandPass filter would be to improve the accuracy of the signals detected by the surface electrodes by keeping the most relevant information in the range of 10 Hz - 500 Hz.

2.5.2 Design Decisions

From the differential amplifier, the input signal goes through the filtering subsystem which consists of a high pass filter followed by a low pass filter. The high pass filter has the goal of setting a lower bound frequency cutoff and the low pass filter has the goal of setting a higher bound frequency cutoff. For our design, the most relevant information that is detected by the surface electrodes through the muscle activity is within the range 10 - 500 Hz and thus, the lower bound set by the high pass filter would be 10 Hz and the upper bound set by the low pass filter would be 500 Hz. These bounds were determined by using the equation:

$$\frac{1}{2\pi \cdot R \cdot C}$$

where R represents the resistance value and C represents the Capacitance value. For the high pass filter in our design, we used a resistance value of 159k Ohms and a capacitance value of 0.1 uF and for the low pass filter in our design, we used a resistance value of 318k Ohms and a capacitance value of 1000 pF. Additionally, we placed the high pass filter first as it would allow the higher frequencies to pass through, followed by the low pass filter, which would further refine the frequencies. Thus, placing the high pass filter initially would help attenuate unwanted low frequency components of the signal more effectively. Lastly, we observed that it is best to have the low pass filter as the final stage as it would be able to suppress the high frequency noise that could have been generated by the previous stages of the design.

Another design choice that we made for our filtering subsystem was to use an active filter instead of a passive filter as there is no loading effect on the active filter which can affect the frequency of the signal and signal course circuit like the differential amplifier in our circuit.

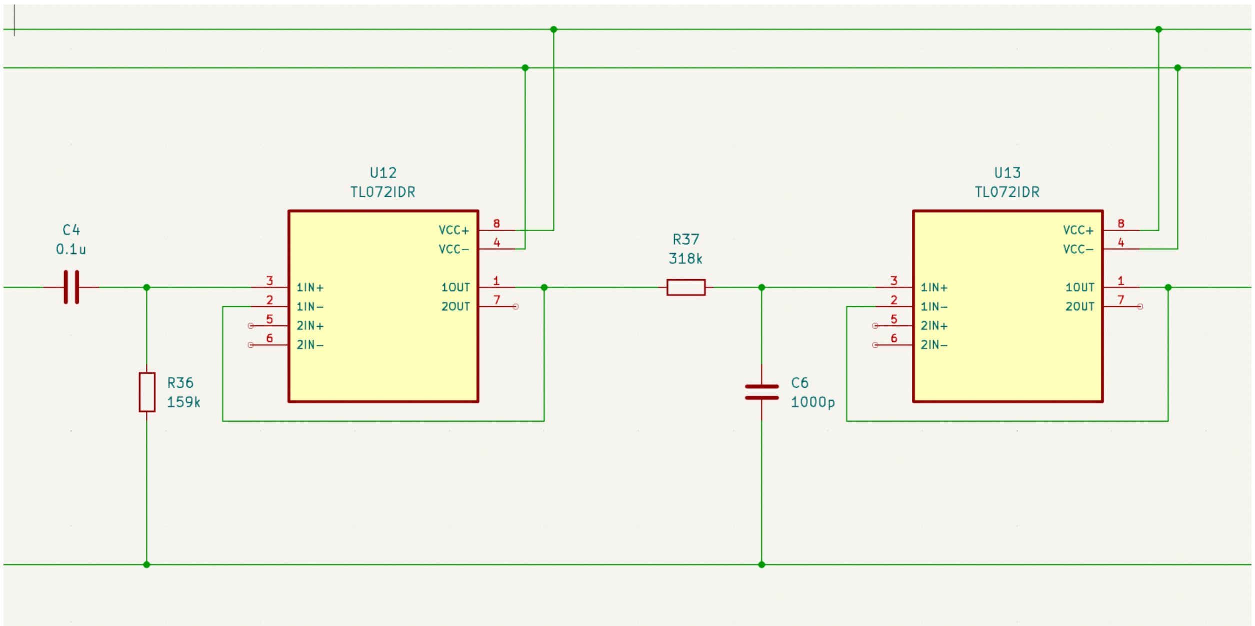

Figure 11: Filtering Subsystem Schematic

2.5.3 Requirement and Verification

Details of the requirements and verification steps can be found in Appendix A Table 9.

Frequency Signal Value	Input Peak-Peak	Output Peak-Peak	Analysis
5 Hz	800 mV	116.926 mV	As 5 Hz is lower than the lower bound frequency cutoff set by the high pass filter, this signal will be attenuated which can be observed as the output peak to peak is significantly lower than the input peak to peak
200 Hz	800 mV	751.667 mV	As 200 Hz is within the range of 10 Hz - 500 Hz, the output peak to peak is close to the input peak to peak which shows that the most relevant information for our design lies within this range
1000 Hz	800 mV	384.186 mV	As 1000 Hz is higher than the upper bound frequency cutoff set by the low pass filter, this

			signal will be attenuated which can be observed as the output peak to peak is significantly lower than the input peak to peak

Table 2: Filtering Subsystem Results

2.6 Power Subsystem

2.6.1 Description

The power subsystem for our design interacts with all the subsystems as it ensures a constant voltage supply of 9 V to the rest of the fitness device.

2.6.2 Design Decisions

Our design required two 9 V batteries in order to generate a positive 9 V and a negative 9 V. The purpose of having a +9 V and a -9V battery is that each time a muscle contracts or expands, either a negative or positive voltage potential is created between the two electrodes on the arm muscle. The differential amplifier used in our initial amplification subsystem can take both the negative as well as the positive voltage. Thus, both the positive 9 V and the negative 9 V batteries are required so that these two separate parts of the circuit can function. In addition to this, we used a 5 V linear regulator in order to power the microcontroller and a switch to be able to control the voltage running through the circuit.

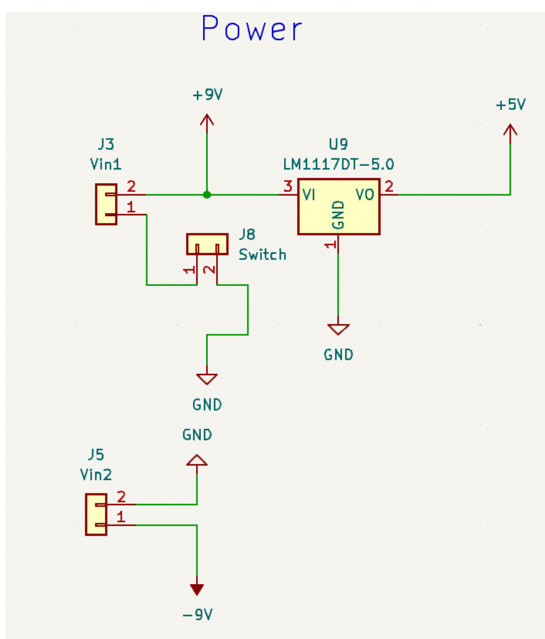

Figure 12: Power Subsystem Schematic

2.6.3 Requirement and Verification

Details of the requirements and verification steps can be found in Appendix A Table 10.

Time (minutes)	Voltage supplied to the subsystems
60	9.454 V
40	9.605 V
20	9.588 V
0	9.588 V

Table 3: Power Subsystem Results

From the table above we can observe that when we run all the components with the two 9 V batteries for 60 minutes and check the voltages with a multimeter periodically, every 20 minutes, we are able to see that there is consistent supply of the 9V battery through all the subsystems. We chose to run the battery for 60 minutes by taking into consideration that a typical workout routine of an individual lasts an hour.

3 Cost Analysis

3.1 Parts and Materials

For our project, we required a single PCB board and had a few additional components included to make the entire arm sleeve design. A list of parts and materials used can be found in Appendix B Table 11. The parts and materials cost sums up to be $66.61.

3.2 Labor Costs and Schedule

After performing online research, we concluded that a reasonable salary for Computer Engineers is $59/hour. Total labor costs and hours worked per week were determined by the schedule defined as a group which can be found in Appendix C Table 12. Table 4 below shows the total labor cost for the entire group.

Name	# of Weeks	Hours per Week	Hourly Earnings	Uncertainty Factor	Cost
Anushka Pachaury	10	8	$59	2.5	$11,800
Sreyas Dhulipala	10	8	$59	2.5	$11,800
Sangyun Lee	10	8	$59	2.5	$11,800

Table 4: Labor Cost

Total Labor Cost: $35,400

3.3 Total Cost

Cost Categories	Cost
Labor	$35,400
Parts	$66.61

Table 5: Total Cost

Total Cost: $35,466.61

4 Conclusion

4.1 Accomplishments

We were able to successfully test and verify that the majority of our subsystems are working. While our sensing subsystem was not properly tested, we were able to replicate its output so the other subsystems could be tested. Using a signal generator, we confirmed that our power, amplification, and filtering subsystems performed their appropriate functions as needed by our design specifications. Furthermore, we confirmed that our software was working as intended. This meant the software was able to take in input signals and then provide a voltage output to the LEDs with varying illumination levels. While we were not able to successfully develop the entire arm sleeve, we can confirm the majority of our subsystems work and have a good understanding of what changes need to be made to finish the project.

4.2 Uncertainties and Design Alternatives

During the development of our project there were two areas which failed to function causing us to change how we implemented these portions of the project. The first failure occurred in the sensing subsystem. The electrodes we were using burnt out very fast due to a short lifespan. This occurred because the electrode material was cheap and started to wear off as they were being used. For our project, we require electrodes with a larger lifespan so they are able to stay functional on the arm sleeve. We would need to switch to higher quality electrodes with better material to make sure the sensing subsystem is functional. To overcome this issue, we instead used a signal generator to replicate the input of our electrodes by generating signals in the frequency and amplitude range of surface electrodes when detecting muscle contractions.

The next area which failed was the microcontroller on the PCB. We were unable to program the microcontroller as we kept receiving an issue about requiring an external clock. Our goal was to use the internal clock of the microcontroller, but we were unable to figure out the appropriate configurations to use the internal clock. Based on resources available online, the way to switch from external to internal is to edit the fuse values. Unfortunately, we were not successful in making this change. To overcome this challenge, we used an arduino development board instead. We fed our filtered and amplified signals into the arduino board which then replicated what our microcontroller would have done.

While testing our initial PCB, we realized that the board was heating up quickly. Our initial design was unsafe and could also cause the PCB to burn out if connected to the batteries for too long. To account for this, we included protective capacitors connected to the ends of the two batteries to dissipate heat when the circuit is connected to the batteries. This design change ensured protection of the circuit and the user using the arm sleeve.

4.3 Future Work

In the future, we would like to include other muscles in the arm such as the forearms. Furthermore, we would like to extend the product's capabilities to detect leg muscles during workouts, similar to how the arm sleeve is currently designed. Finally, as previously mentioned we want to transition to better quality electrodes to ensure our sensing subsystem is functional for a longer period of time.

4.4 Ethical Considerations

The IEEE Code of Ethics details how there should be a responsible and respective working environment during professional activities. As a group we made sure to follow this guideline by respecting each other's opinions and treating everyone equally. Additionally, we were mindful of each other's schedules and made sure to create a good working environment so we all felt welcome. Our project required us to solder which meant we needed to use the senior design lab a couple of times. During these scenarios, we kept each other accountable and worked together when soldering. Overall, we as a group met all aspects of the IEEE Code of Ethics.

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Appendix A Requirement and Verification Tables

Requirement	**Verification**
• The differential amplifier should have a gain of 10 and the non-inverting amplifier should have a gain of 5. • Using the signal generator, generate two signals where the first signal has an amplitude of 50 mV and the second signal have an amplitude of 10 mV then the differential amplifier should be able to compute voltage difference between two signals which would be 40 mV, amplify it by a gain of 10, and output the signal with an amplitude of 400 mV. • Following this example, after the differential amplifier generates a signal with an amplitude of 400 mV, the non-inverting amplifier should amplify with a gain of 5 resulting in an output signal with an amplitude of 2V	• In order to test this subsystem, set up two signals using the signal generator, first one with an amplitude of 50 mV and the second one with an amplitude of 10 mV. • Connect these two signals to the input pins of the differential amplifier • Using an oscilloscope confirm that the input signal has been amplified by a gain of 10 by observing the amplitude of the output signal • Next, connect the output signal of the differential amplifier to the input pin of the non-inverting amplifier • Using an oscilloscope confirm that the input signal has been amplified by a gain of 5 by observing the amplitude of the output signal

Table 6: Amplifying System Requirement and Verification

Requirement	**Verification**
• When measuring the electrical signals generated by muscle contractions, the surface electrodes should detect signals with amplitude ranging from 0-50 mV • Less muscle contraction should generate a signal with an amplitude close to 0 whereas, heavy muscle contraction should generate a signal with an amplitude close to 50 mV	• First, place three surface electrodes on the arm where one of the electrodes would be placed on the top and bottom of the bicep muscle and the third electrode is place near the elbow as the reference electrode • Then perform a bicep curl in order to contract the bicep

detected by the top and bottom electrodes on the arm muscle. However, the reference electrode placed near the elbow should always produce an amplitude near 0	• Measure the output of the electrical signals from each electrode using an oscilloscope
• Surface electrodes should constantly generate signals between 0-50 mV	• Measure output from all surface electrodes using oscilloscope and confirm signal generated in real time

Table 7: Sensing Subsystem Requirements and Verification

Requirement	**Verification**
• LED's should display different levels of brightness based on provided signal amplitude. For example, in the exercise of a close grip chin up, both the bicep and tricep muscles are activated. The bicep signal shows an amplitude of 1 V whereas the tricep signal shows an amplitude of 2.5V. The LED illumination for the bicep would be 16% of the illumination of the tricep.	• First, generate two signals of different amplitudes using signal generator • Connect these signals to the arduino board and connect the output of the arduino board to the resistors of each of the two LEDs • Observe difference in illumination where the larger amplitude signal should have brighter illumination than the smaller amplitude signal

Table 8: LED Display Subsystem Requirements and Verification

Requirement	**Verification**
• The frequency range of EMG sensor signals ranges from 10 Hz - 500 Hz, so, the bandpass filter is able to retain information for frequencies ranging from 10 Hz - 500 Hz attenuating the other unwanted frequencies.	• Using a signal generator, set up a signal with a frequency of 5 Hz which is put into the BandPass filter subsystem. 5 Hz is lower than the bound set by the HighPass filter and thus, should be attenuated.

	● Ensure that the amplitude of the output signal is significantly reduced compared to the amplitude of the input signal using an oscilloscope ● After 5 Hz, we increase the frequency in 10 Hz increments and we should ensure that as long as the range is within 10 Hz - 500 Hz, the amplitude of the output signal should have the amplitude of the input signal. ● Once 500Hz is reached, any signals there and after should be attenuated which is observed through the oscilloscope.

Table 9: Filtering Subsystem Requirements and Verification

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 while the other subsystems are functioning.

Table 10: Power Subsystem Requirements and Verification

Appendix B List of Parts

Parts	Manufacturer	Part #	Quantity	Cost per Unit
Surface EMG Electrode(10 pack)	SparkFun Electronics	SEN-12969	1	$8.95
Reference Cable(3 pack)	SparkFun Electronics	CAB-12970	2	$5.69
2 of 9.0V Battery	Amazon	6LR61	1	$5.50
Voltage Regulator	Texas Instruments	LM337KCSE3	1	$1.00
Arm Sleeve	EGOFLEX		1	$6.79
LED Display	LOAMLIN	PL0056	1	$9.66
Microcontroller	Microchip Technology	ATMEGA32U4-AU	1	$5.29
Non-inverting Amplifier	Microchip Technology	MCP616-I/P	6	$1.12
Switch	DaierTek	KCD1-101	1	$7.99
100 kOhms Resistor	Stackpole Electronics Inc	RMCF0603JT100K	4	$0.1
1M Ohms Resistors	YAGEO	RC0402FR-131ML	2	$0.1
370 kOhms Resistor	KOA Speer Electronics, Inc.	RN73H1JTTD3703F100	2	$0.2
Capacitor 0.1 uF	KEMET	C1206C103G1GEC7210	2	$0.316
Capacitor 1000 pF	Murata Electronics	GRM31C5C3A102FWA3L	2	$0.85
160 kOhms	YAGEO	RC0402FR-07160KL	2	$0.0949

Differential Amplifier	Texas Instruments	INA106U/2K5	2	$10.27
1.0 uF Tant Capacitor	KEMET	T350A105K035AT	2	$3.26

Table 11: List of Parts

Appendix C 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.

Table 12: Schedule For Division of Work