ECE 445

Senior Design Laboratory

Carpal Tunnel Wrist Glove

Design Document

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Contents

1. Introduction

1.1 Problem

Digital artists often experience fatigue and discomfort in the wrist, knuckles, and fingers after prolonged drawing sessions. This strain typically goes unnoticed until pain develops. Continued stress on the hand muscles can lead to more serious conditions, such as carpal tunnel syndrome (CTS), which can cause hand/wrist pain, burning/numbness in fingers, and overall weakness in the wrist and hand [1]. The repetitive motions of digital art that come with brush strokes, sketching, and rendering, can cause significant swelling around the tendons in the carpal tunnel, resulting in pressure on the median nerve [1].

Although there are existing compression gloves used to alleviate symptoms related to carpal tunnel syndrome, they primarily function by providing mild pressure to reduce swelling and improve circulation. However, they do not necessarily do much to address poor wrist and hand habits that contribute to repetitive strain injuries (RSIs). Many digital artists and professionals unknowingly adopt prolonged repetitive motions without incorporating sufficient rest periods; taking short, frequent breaks to gently stretch and bend hands and wrists can make a difference in preventing pressure and preventing RSIs [2].

1.2 Solution

While compression gloves can be a supportive tool, they should be complemented with ergonomic practices and habitual breaks to ensure long-term hand and wrist health [2]. To address this gap, the propose solution would use strain gauge sensors and inertial measurement units (IMUs) to monitor the user’s grip and joints/muscles that undergo prolonged repetitive motion. These sensors will collect real-time biomechanical data, allowing a software/communication component to analyze patterns of repetitive strain and movement. The communication component aims to provide notifications, reminding users to take breaks at optimal intervals. Based on target muscles identified by strain gauges, it would suggest targeted stretches and exercises tailored to specific regions experiencing strain. By combining real-time monitoring and proactive intervention, this solution can not only help prevent RSIs, but also encourage long-term behavioral changes.

1.3 Visual Aid

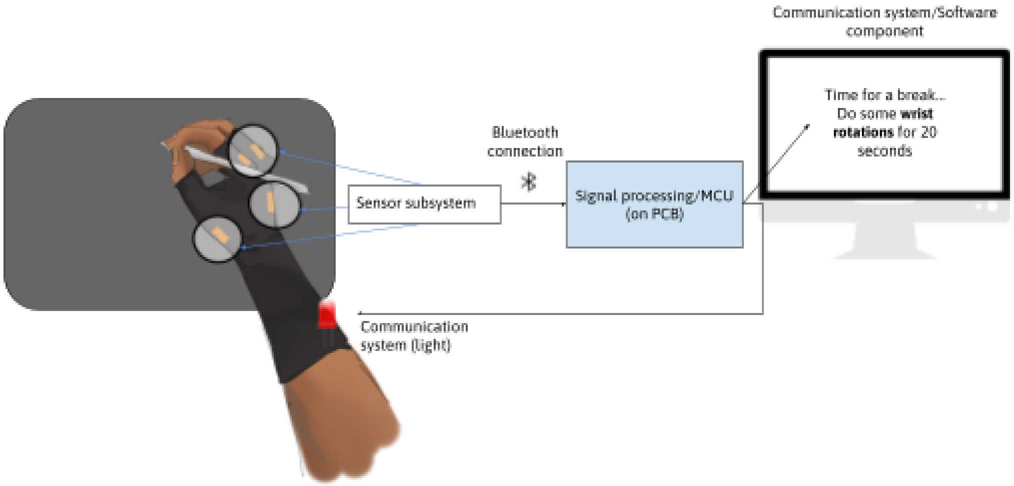


Figure 1: Tentative illustration of the glove & high-level system

1.4 High-Level Requirements

The following is a list of 3 quantitative characteristics this project should exhibit to solve the problem.

- **Accuracy:** The device must accurately measure repetitive motion, location of motion, and angle of wrist flexion and extension – then use live data filtered through scientific metrics to notify the user of prolonged muscle strain compared to threshold value with 80% accuracy. To determine this, the application will show 100% of the filtered and compared data, and user testing of the LED functionality should send a notice of unsafe muscle grip patterns at least 80% of the time it was identified on the application.

- **Unique User Compatibility:** Since the hand/wrist anatomy of the user is unique, the system must be able to detect signals from both strain gauges and inertial measurement units and send notifications to user & data updates to application for 2 different individuals with different grips and patterns of hand/wrist motion to ensure adjustment to unique users.

- **Output to user:** To notify user of prolonged muscle strain and repetitive motion, an LED light is used to notify the user to take a break. A wireless connected application additionally will propose hand stretches that target the specific muscles under the most stress based on medically proven techniques. Suggested stretches engage and relieve target specific muscle identified from signals from the strain gauges.

2. Design

2.1 Block Diagram & Physical Design

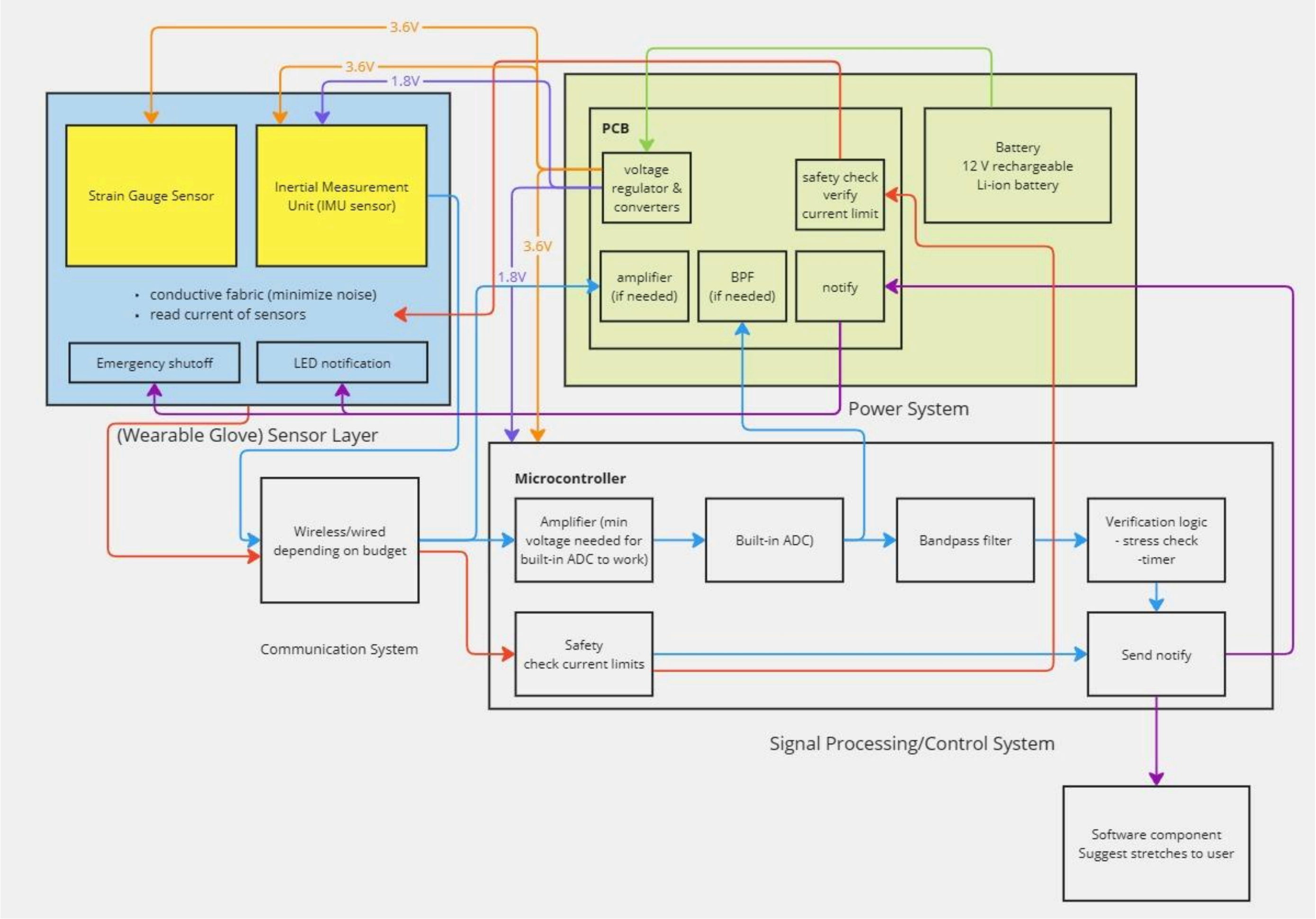


Figure 2: Block diagram

There are 3 main areas in which we will place our wheatstone bridges and 1 intended place for the IMU. We plan on putting strain gauges on the thenar muscles (base of thumb, responsible for thumb movement and gripping), finger flexors/extensors, and wrist flexors/extensors. We plan on placing the IMU on the PCB, right above the wrist near the metacarpal bones so acceleration/velocity and rotation can be sufficiently recorded. The PCB itself will be carefully encased onto the glove, as space on the glove allows.

Figure 3: Physical design & sensor placement

2.2 Subsystems Overview

2.2.1 Power Subsystem

As shown in the block diagram, the main power systems are transferring the required amount of voltage from the PCB to the battery, communication module, and MCU. The biggest component to discuss is the rechargeable battery which will connect to the glove. We will most likely use a lithium ion battery.

The PCB will be designed on KiCad and will be the 'brain' of the system. The design will route the microcontroller signals to the notification system, ensuring that power will be supplied to both portions of the design (live input & user-facing). Both subsystems will likely have varying current limits and required voltage inputs, which will be taken care of on the PCB using voltage regulation and power conversion techniques - possibly a buck converter or linear regulator.

2.2.2 Sensor Layer Subsystem

The sensor layer subsystem is powered by the power subsystem and outputs data signals to be processed by the signal processing subsystem (2.2.3). The sensor layer comprises 2 different sensors: strain gauges and inertial measurement units (IMUs).

Strain Gauges

Strain gauges can measure deformation or mechanical strain within a material by changing its electrical resistance when stretched or compressed, which works well for applications related to structural load analysis. Strain gauges used in tandem with IMUs allow for a fuller picture of mechanical movement within the hand, i.e. wrist angle and flexion detection (which correlates to potential nerve compression risks). A strain gauge rosette can measure wrist angles and analyze strains that occur during wrist flexion/extension/radial and ulnar deviation, and will be placed near key ligaments such as the wrist, digital branches of the median nerve, and thenar muscle. A suitable strain gauge that may be used is the Vishay CEA-06-062UR-350, as it can measure multi-axial strains. This approach adds a biomechanical analysis layer to the glove, which may detect harmful wrist postures even when muscles are not active.

Inertial Measurement Unit (IMU)

IMUs can track repetitive motion by measuring linear acceleration and angular velocity, which makes them useful to detect wrist and hand movements associated with repetitive strain which can then contribute to nerve compression. An option for an IMU would be a ICM-20948, which is a low-power sensor making it suitable for wearable applications such as our glove. These IMUs would be placed in specific positions of the wrist (such as the dorsal side to capture radial/ulnar deviation), just above the wrist to track forearm rotation, and the back of the hand (near the metacarpals) to monitor fine motor motion such as finger extension/flexion dynamics.

2.2.3 Signal Processing Subsystem

The signal processing subsystem takes signals from the sensor layer subsystem (2.2.2) as input, processes the signals with necessary amplification/filtering, and outputs the processed signals to some verification logic to decide whether to notify the user to take a break and, if so, to an additional software component that displays the user which muscle to stretch and suggests a specific stretch for that target muscle.

Strain Gauge Signal Processing

Strain gauges measure strain by changing its electrical resistance; to convert these tiny resistance changes into measurable voltages, a Wheatstone bridge is used to amplify changes in resistance caused by strain (we aim to use a full-bridge with four gauges to maximize sensitivity and thermal stability). The output of resistance changes into voltage is usually too small; the signal will first be amplified and filtered (will likely use low-pass filtering to remove high-frequency noise since strain gauge signals are typically maximum 5 Hz for human motion [3]) prior to analog-to-digital conversion. Then, the microcontroller will calculate wrist angle and stress based on the digital signal and trigger any feedback (i.e. user notification or display system).

Inertial Measurement Unit Signal Processing

The raw data from the IMUs will likely involve filtering to remove noise unrelated to actual motion. Useful data related to motion frequency, range of motion, and angular velocity can be derived with FFT for orientation tracking (the IMU collects time-series data and would include periodic signals if repetitive tasks are being performed). Processed IMU data can then be correlated with strain gauge outputs to identify patterns of repetitive motion and grip.

2.2.4 Communication Protocol/Display Subsystem

This subsystem will receive signals from 2.2.3 and compare them with threshold values we set to assess whether the user is applying prolonged stress that may lead to harmful muscle activity. The output voltage readings (vout) across the strain gauge is proportional to the change in electrical resistance. We can calculate the strain by dividing the ratio of vout/vin by the gauge factor (the ratio of the relative change in electrical resistance and relative change in length). Force is then calculated by multiplying the strain, young's modulus of the material, and the cross-sectional area of the stressed material. We can then use this force value for our Maximum Voluntary Contraction (MVC) comparison with a threshold value of 20%. The stress readings from the strain gauge, along with their duration, will be compared to the 4% threshold. The wrist flexion/extension will be compared to the value 30º and radial deviation will be compared to the value of 15°.

We will have an application that communicates the result of this comparison. If any of the readings exceed the threshold, the system will suggest the user take breaks every 30 minutes [4] (through an LED light on the glove). Additionally, strain gauge readings will provide insights into which joints undergo repetitive motion and, subsequently, relevant muscles. The external app will also display various stretches to help reduce stress and tension in those muscles and joints. We will explore the possibility of exporting real-time signal data from the MCU to a PC via UART through implementing a very simple program that interprets the data and intelligently suggests a stretch out of a database.

2.3 Subsystem Requirements

2.3.1 Power Subsystem Requirements

Note: A Li-ion battery was chosen over Li-Po for safety purposes.

Bolded requirements denote requirements that, if removed, would cause the subsystem to fail:

Requirements	Verification
● **Must be able to supply 2.4 V / 600 µA to strain gauge (Vishay CEA-06-062UR-350)**	● Use a multimeter or oscilloscope to measure the output voltage at the strain gauge terminals. Verification must pass criteria of 2.4 V ± 0.05 V. ● Use a precision ammeter in series with the strain gauge to measure the current. Verification must pass criteria of 600 µA ± 10% (540 µA to 660 µA).
● **Must be able to supply 1.7 V / 220 µA to IMU (ICM-20948)**	● Use a multimeter or oscilloscope to measure the output voltage supplied to the IMU. Verification must pass criteria of 1.7 V ± 0.05 V. ● Use a precision ammeter in series with the IMU to measure the current.Verification must pass criteria of 220 µA ± 10% (198 µA to 242 µA).
● **Must be able to supply 1.8 V / 45 nA to MCU (TI-MSP430FR5994)**	● Use a multimeter or oscilloscope to measure the output voltage supplied to the MCU. Verification must pass criteria of 1.8 V ± 0.05 V.

	● Use a precision ammeter in series with the MCU to measure the current.Verification must pass criteria of 45 nA ± 10% (40.5 nA to 49.5 nA).
● Must be able to supply 1.8 V / 7 µA to Bluetooth Module (TI-CC2564C)	● Use a multimeter or oscilloscope to measure the output voltage supplied to the Bluetooth Module. Verification must pass criteria of 1.8 V ± 0.05 V. ● Use a precision ammeter in series with the Bluetooth Module to measure the current.Verification must pass criteria of 7 µA ± 10% (6.3 µA to 7.7 µA).

2.3.2 Sensor Layer Subsystem Requirements

Bolded requirements denote requirements that, if removed, would cause the subsystem to fail:

Requirements	Verification
● **IMU must sample motion data at a frequency of ≥ 100Hz to capture fine motor motion and repetitive movements**	● Have test subject enable continuous repetitive motion with the IMU ● Use logic analyzer to verify the IMU outputs data at ≥100Hz (A sampling rate around 100 Hz is sufficient for capturing daily life human activities [5])
● Strain gauges must detect wrist flexion and extension angles within ±5° of actual movement when compared to a reference protractor. ● If this requirement was removed, the IMU may still detect repetitive motion and prompt the user for breaks, but the communication	● Have test subject wear glove and perform wrist flexion and extension at set angles (e.g., 15°, 30°, 45°); use a protractor to measure angle ● Record strain gauge output data and convert it to angular measurements; verify computed angles are within ±5° of measured angle

subsystem would fail to present to the user an accurate stretch to relieve target muscles of strain	
● Sensors must have a combined response time of ≤ 50ms for real-time motion tracking & strain/motion analysis	● Apply a sudden, quick strain such as a tap and record the time from input to output signal ● Ensure that the system registers the signal within 50ms

2.3.3 Signal Processing Subsystem Requirements

Bolded requirements denote requirements that, if removed, would cause the subsystem to fail:

Requirements	**Verification**
● **Utilize wheatstone bridge to bring resistance changes of strain gauges to at least a 1 V signal**	● Design & fabricate wheatstone bridge on PCB to receive signal through bluetooth from the glove & complete initial amplification ● TI MCU requires 1 V signal to reliably filter data.
● **Use MCU to filter human motion from noise & determine notification status**	● Route amplified signal to TI MCU ● Further amplify and filter with an LPF designed for a maximum of 5 Hz [3] ● Route filtered signal to built-in analog-to-digital converter & use digital signals to categorize wrist angles to determine stress levels as referenced in 2.2.4 ● Trigger user notification through display system/application based on stress levels
● Process IMU data to identify patterns of repetitive motion and grip	● Utilize angular velocity, motion frequency, and force calculations as referenced in 2.2.4 through FFT to track grip

	● Use pattern recognition to identify repetitive harmful motion

2.3.4 Communication Protocol/Display Subsystem Requirements

Bolded requirements denote requirements that, if removed, would cause the subsystem to fail:

Requirements	Verification
● **Compare stress level with medically approved threshold values to assess user patterns that may lead to harmful muscle activity**	● Use force value for Maximum Voluntary Contraction (MVC) comparison with a threshold value of 20% to set a ‘normal force’ (unique per user) [9] ● Compare stress readings & durations from the strain gauge to the 4% threshold [6] ● Compare wrist flexion/extension to the 30º wrist angle & radial deviation to the 15° value [7].
● **Communicate readings with user through application; this requirement is absolutely necessary for the communication subsystem to notify the user to take a break**	● Design a user friendly application that allows the user to view grip and stress patterns ● Suggest user to take breaks every 20-30 minutes through an LED light on the glove if readings exceed threshold ● Provide insight into which joints and muscles undergo repetitive motion ● Explore the possibility of intelligently suggesting wrist stretch out of a database utilizing real-time data via UART
● The subsystem must calculate force on user’s grip	● Calculate strain by dividing the ratio vout / vin by the gauge factor ● vout = proportional to the change in electrical resistance

	● gauge factor = ratio of relative change in electrical resistance & length ● Calculate force by multiplying strain, young’s modulus of material, and cross-sectional area of stressed material

2.4 Tolerance Analysis

One potential risk associated with the project is sensor accuracy. The inertial measurement unit failing to signal accurate data could lead to false detections or missed repetitive events, resulting in an overall reduction of the effectiveness of the system. For the wearable device, several factors can introduce error. The equation for the gauge factor (GF) of a strain gauge, which is the ratio between relative change in electrical resistance to relative change in length of material, can be seen below.

$$GF = \frac{\Delta R/R}{\varepsilon}$$

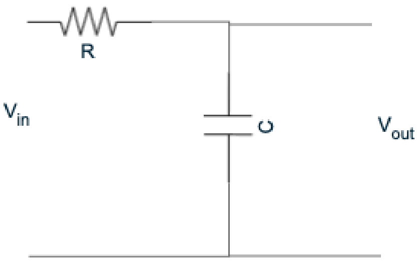
ΔR = change in resistance
R = nominal resistance (350Ω)
ε = applied strain = $\frac{\Delta L}{L}$

The gauge factor must be 2 for wearable IoT applications, so it will essentially be considered a constant through the design process. ΔR, ΔL, L, and R are also constants - so we can rely on an unchanging GF of 2. The GF then factors into the output voltage of the wheatstone bridge - which is what a change in resistance signifies - through the following equation: [10]

$$V_O = \left[\frac{R_3}{R_3+R_4} - \frac{R_2}{R_1+R_2}\right] V_S$$

This equation will then be used to select resistor values to guarantee a GF of 2.

Additionally, below is the design of the Low Pass Filter to signify relevant movement, which is any frequency less than 5 Hz.



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

$$5 = \frac{1}{2\pi RC}$$

$$R = 3\ k\Omega$$

$$C = 10\ \mu F$$

$$f_{actual} = \frac{1}{2\pi(3k)(10\mu)} = 5.3\ Hz$$

3. Cost and Schedule

3.1 Cost Analysis

Part	**Buy or Design?**	**Operating Voltage** voltage needed to power part on	**Current Limit** max current that the part can handle	**Location in Project Systems** (PCB would be attached to the glove so has size constraints)	**Notes**
Strain Gauge (Vishay CEA-06-062UR-350)	Buy	–	–	glove	–
IMU (ICM-20948)	Buy	1.8V (1.71V - 3.6V)	Typical is 3.11 mA but couldn't find current limit	glove	–
Heat Resistant PCB 'cover'	Buy	–	–	overall system	For safety purposes
MCU (TI-MSP430FR5994)	Buy	–	–	PCB	–
Bluetooth Module (TI-CC2564C)	Buy	3.6V	~112 mA	PCB	–
Wheatstone bridge (350 Ω)	Design - reference tolerance analysis	Start with 3.6V. Connect to the lab power supply and keep turning up until we get a readable signal equivalent to mV from the strain gauge. Set that value to be operating voltage.	I = V/R Estimate a few mA	PCB	Will need unique wheatstone bridge per muscle 350 Ohm fixed resistors; have to test excitation voltage Design layered PCB to address size constraints
Amplifier	Design	Need to test output and use values to design, but are expecting an input in mV and outputting V	Dependent on chosen RC values	PCB	Need to test a few output voltages of actual system before knowing desired gain

BPF	Design	Dependent on chosen RC values	Dependent on chosen RC values	PCB	Need to test a few output voltages of actual system before knowing desired frequencies
Voltage Regulator (2)	Design	–	–	PCB	Cap ≤ 1 μF
Switch Turn battery connection on and off	Buy	–	–	PCB	–
Battery	Buy	–	–	overall system	Need to optimize design to limit 'bulkiness' as system will be placed on glove
LED	Buy	–	–	PCB	–

Cost per part:

Description	**Manufacturer**	**Quantity**	**Part #**	**Cost/Unit**	**Datasheet**
IMUs	TDK InvenSense	1	ICM-20948	$7.11	ds
Strain Gauges	Daoki	6	BF350-3AA	$0.879	ds
MCU	Texas Instruments	1	TI-MSP430FR5994	$20.39	ds
Bluetooth Module	Texas Instruments	1	TI-CC2564C	$3.94	ds
Battery 3.7/4.2V Lithium-Ion	SparkFun Electronics	1	PRT-26059	$12.95	ds
LED (Red, 1.95V)	Kingbright	1	APTD3216SURCK	$0.32	ds
Switches (4V, 300mA, SPDT,	Mitsumi Electric	1	R-667053	$0.42	

slide switch)	Company Ltd				
Resistors		30			
3 kΩ (surface mount)	Vishay Dale		TNPW0402	$0.25	ds
Still need to determine additional resistors based on the design finalized for sensor layer					
Capacitors		20			
10 uF	Murata Electronics		GRM21BR61C106KE15K	$0.15000	ds
Still need to determine additional capacitors based on the design finalized for sensor layer					

Labor cost: $25/hr * 2.5 * 180 hrs = $ 11,250

Cost of parts = $7.11 + $5.274 + $20.39 + $3.94 + $0.32 + $0.42 + $3 + $7.5 + $12.95= $60.904

Cost of glove = $25

Sum of Costs = $ 11,335.904 ~ $11,336

3.2 Schedule

	Team Goals	Deadline
Week of 3/3	➔ Complete Design Document (All of us) ➔ Test strain gauges to determine expected voltage signal (Li/Deepika) ➔ Mount strain gauges to fabric for prototype glove (Li) ➔ Use actual readings to finalize mathematical design of systems, filter design, and PCB design (Rawnie)	Thursday 3/6: Design Document Due
Week of 3/10	➔ Breadboard Demo Milestone: read signal from strain gauge & signify physical meaning (All of us) ➔ Complete PCB Design including filters and regulators (Rawnie)	Monday 3/10: Breadboard Demo Thursday 3/14: Second Round PCB Order

	➔ Begin notification system programming (Li) ➔ Begin building IMU bandpass filter (Deepika)	
Week of 3/17 (spring break)	➔ If any goals originally slated to be complete prior to 3/10, then spring break is the time period to catch up on previous deliverables	
Week of 3/24	➔ Solder and test PCB, redesign if needed (Rawnie) ➔ Modify physical design of glove and collect wrist tension data (Deepika) ➔ Continue notification system programming and digital signal processing (Li)	
Week of 3/31	➔ Complete functional prototype with breadboard (All of us) ➔ Test various use cases and document results (Li) ➔ Test power system subsystem requirements (Rawnie) ➔ Test sensor layer subsystem requirements (Deepika) ➔ Redesign PCB if needed (All of us)	Monday 3/31: Third Round PCB Order Wednesday 4/2: Individual Progress Report
Week of 4/7	➔ Assemble functional prototype with soldered PCB (Rawnie) ➔ Test signal processing subsystem requirements (Li) ➔ Test communication protocol (Deepika) ➔ Test and improve notification system	Monday 4/7: Fourth Round PCB Order
Week of 4/14	➔ Debug and modification time as needed based (Deepika) ➔ Implement emergency shutoff system based on current rating if time allows (Rawnie) ➔ Begin bluetooth if time allows (Li)	Friday 4/18: Team Contract Assessment
Week of 4/21	➔ Debug and modification time as needed based on mock demo feedback (Li/Deepika) ➔ Implement emergency shutoff system based on current rating if time allows (Rawnie)	Tuesday 4/22: Mock Demo
Week of 4/28	➔ Record video (All of us) ➔ Prepare for final presentation (All of us)	Tuesday 4/29: Final Demo Friday 5/2: Extra Credit Video

Week of 5/5	➔ Complete final paper (All of us) ➔ Submit lab notebook (All of us)	Tuesday 5/6: Final Presentation Wednesday 5/7: Final Paper Thursday 5/8: Lab Notebook **Wednesday 5/7: Lab checkout, Award ceremony

4. Ethics & Safety

Our project recognizes the risks associated with prolonged stress on the wrist and hand. We aim to enhance wrist and hand health by developing a glove with sensors that actively monitor the stress level in these areas. This glove will then provide feedback on how to alleviate this tension if detected. However, for this project to be successful, users will need to wear a glove containing sensors that will be taking these readings, and this may introduce some safety concerns.

In reference to the IEEE's Code of Ethics Section I.1 "to hold paramount the safety, health, and welfare of the public" [7], the user may be subjected to safety concerns when using the glove. These concerns include:

1. Electrical Safety - Users may be at risk due to inadequate insulation or faulty wiring. Our solution is to mitigate this is to ensure wires are properly insulated as well as proper grounding.
2. Physical Safety - Certain materials may feature sharp edges, posing a risk of injury. Our solution to avoid this is to create smooth-edged casings for all mechanical components of the glove.
3. Skin Safety - Some materials may cause irritation to the skin. Our solution would be utilizing hypoallergenic materials to minimize the risk of skin irritation.

The user may also be at risk to receive inaccurate data due to errors with sensor readings or data analysis which is in reference to the IEEE's Code of Ethics Section I.5 "to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data", and Section I.6 "to maintain and improve our technical competence" [7]. To try and mitigate this concern, we will be conducting thorough testing and incorporating error handling.

By implementing these measures, we aim to ensure the safety and well-being of all users while adhering to IEEE's Code of Ethics.

5. References

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