UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

ECE 445 Senior Design: Final Presentation

Carpal Tunnel Wrist Glove

Electrical & Computer Engineering

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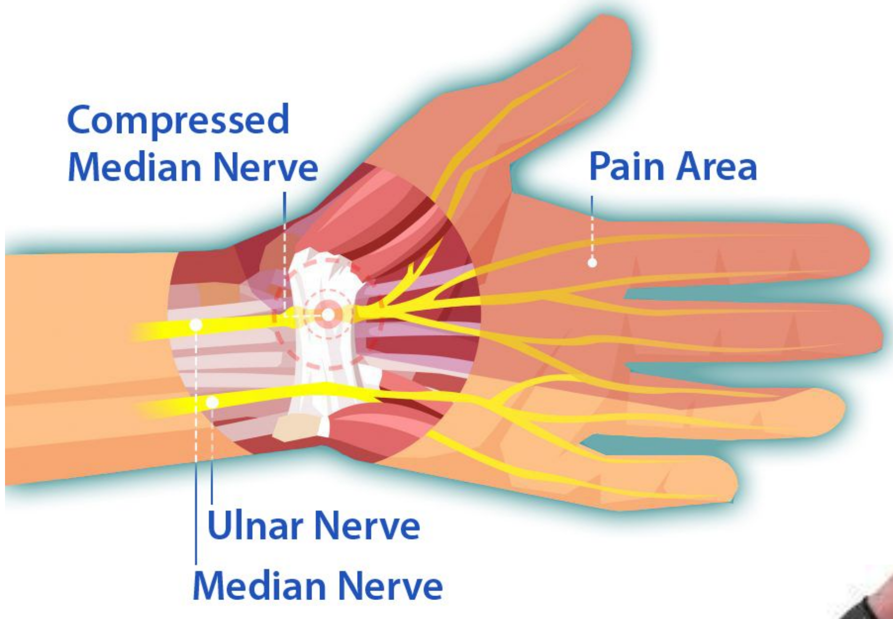
Introduction

Motivation

The Context

Artists/hobbyists that perform repetitive fine motor movements often experience fatigue and discomfort in the wrist, knuckles, and fingers. This strain may lead to repetitive strain injuries (RSIs) or carpal tunnel syndrome (CTS).



The Problem

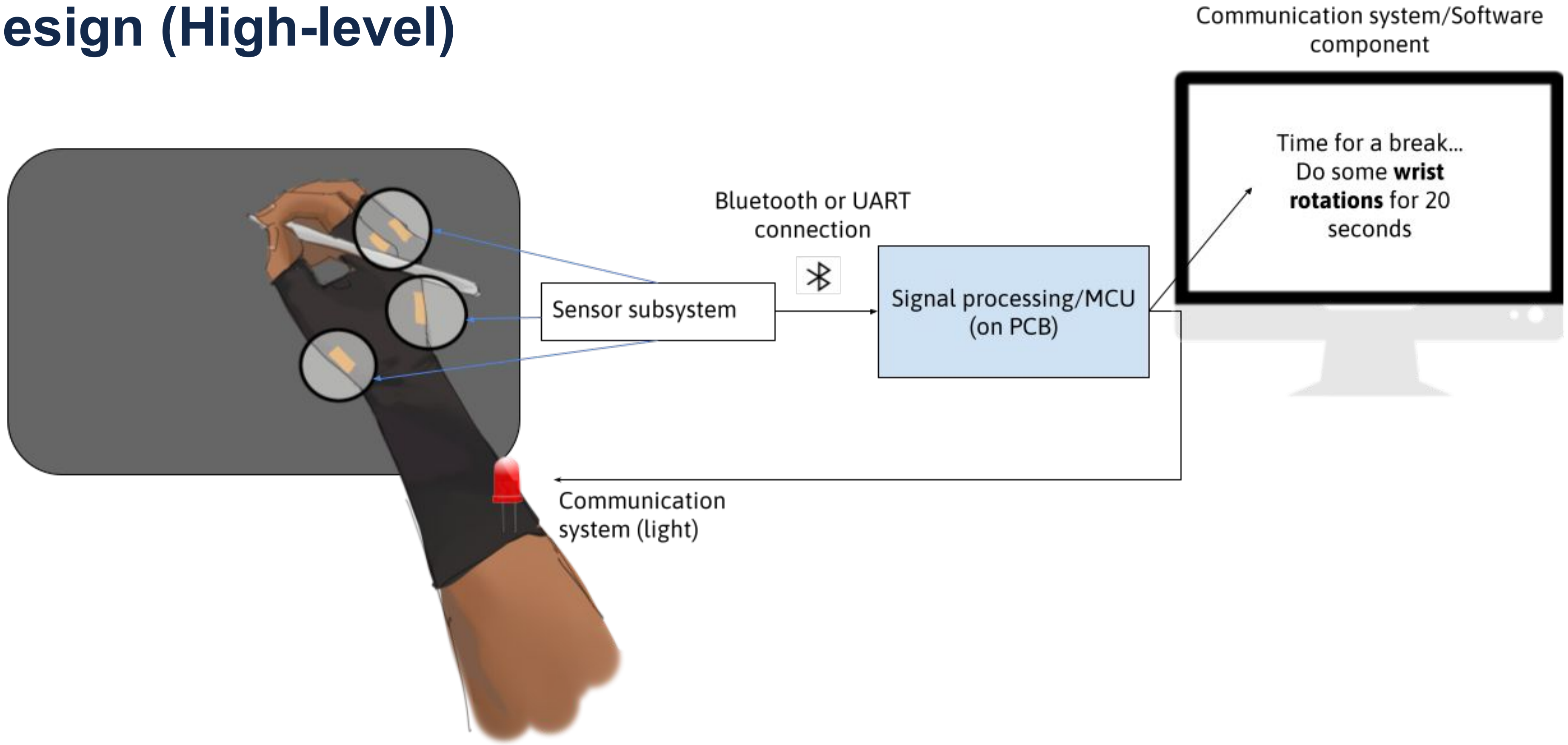
- Taking short, frequent breaks to gently stretch and bend hands and wrists can make a difference in preventing pressure and preventing RSIs
- Existing compression gloves alleviate symptoms by providing mild pressure to reduce swelling and improve circulation
- Doesn’t do much to address poor wrist and hand habits that contribute to RSIs

Objective

The goal of our project is to add a technical component to existing compression gloves that interfaces with user and promotes ergonomic practices to ensure long-term hand and wrist health.

Design

Initial Design (High-level)

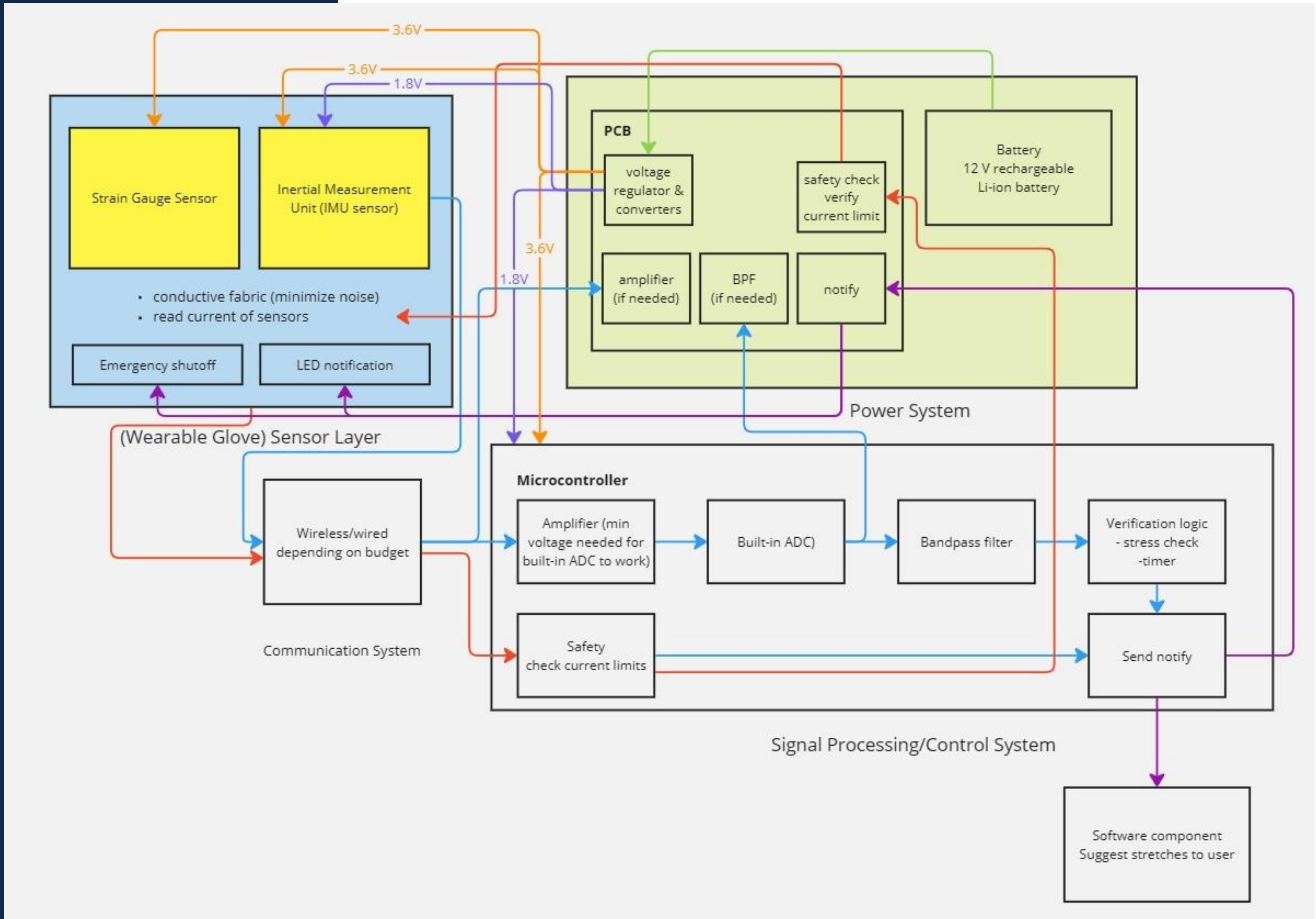


Tentative illustration of the glove & high-level system

Block Design

Subsystem overview

- Power
- Sensor layer
- Signal processing
- Communication protocol



High Level Requirements

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

- **Accuracy:**
  - Measure repetitive motion, location of motion, and angle of wrist flexion and extension and notify the user of prolonged muscle strain compared to threshold value with 80% accuracy.

- **Unique User Compatibility:**
  - For 2 different individuals with different grips, system must be able to:
    - Detect signals from the sensor layer
    - Send notifications to user

- **Output to User**
  - The user must be notified to take a break of prolonged muscle strain and repetitive motion
  - Stretches *effective* to the *specific* areas of strain must be suggested to the user

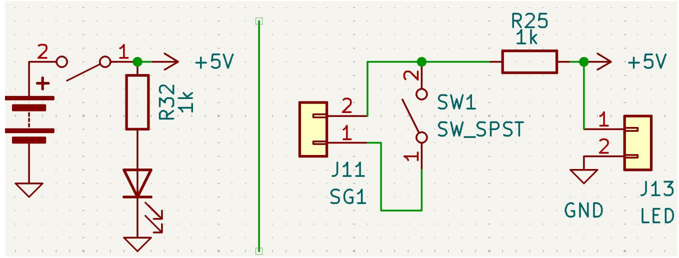
Power Subsystem

Physical design & initial sensor placement

Power subsystem

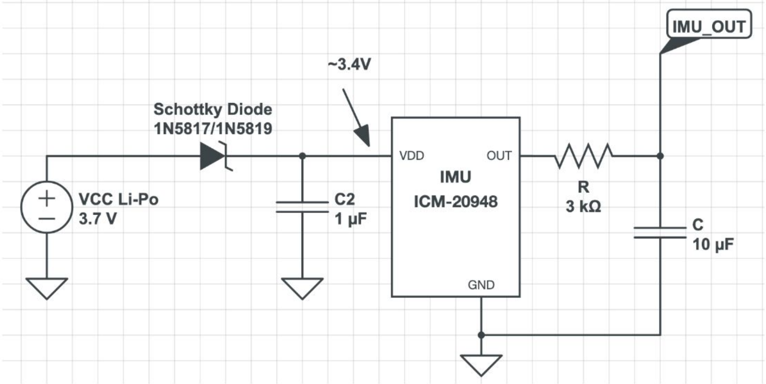
Power

- 3.7V Li battery to power the whole system
- **Requirement**: Ensure proper operating voltages and current limits for PCB components
- Power Switch:



Component	Operating voltage	Current Limit	Actual V	Actual input current
MCU (ATmega328P)	1.8V - 5.5V	40 mA	3.687 V	32 mA
Op-amp (LM358)	3V - 32V	30 mA	3.687 V	11mA (static res.) 16 uA (strain gauge)
UART cable	3.3V - 5V	*N/A*	3.687 V	34 mA
IMU (ICM-20948)	1.71V - 3.6V	3.11 mA	*N/A*	*N/A*

- Voltage Converter Circuit for IMU:

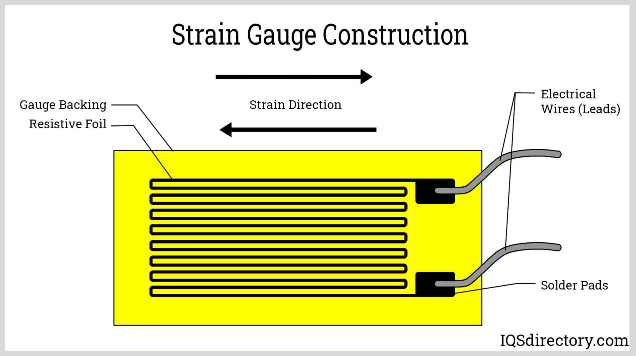


Sensor Layer Subsystem

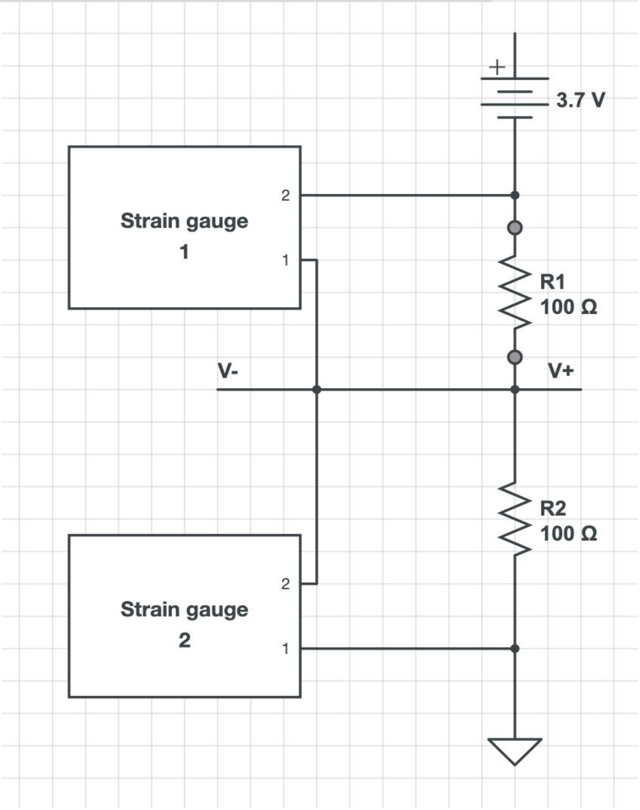
Our design aims to leverage 2 types of sensors: strain gauges and inertial measurement units (IMU).

Physical design & initial sensor placement

Sensor layer – Strain gauges



$$\frac{\Delta R}{R} = GF \cdot \epsilon$$



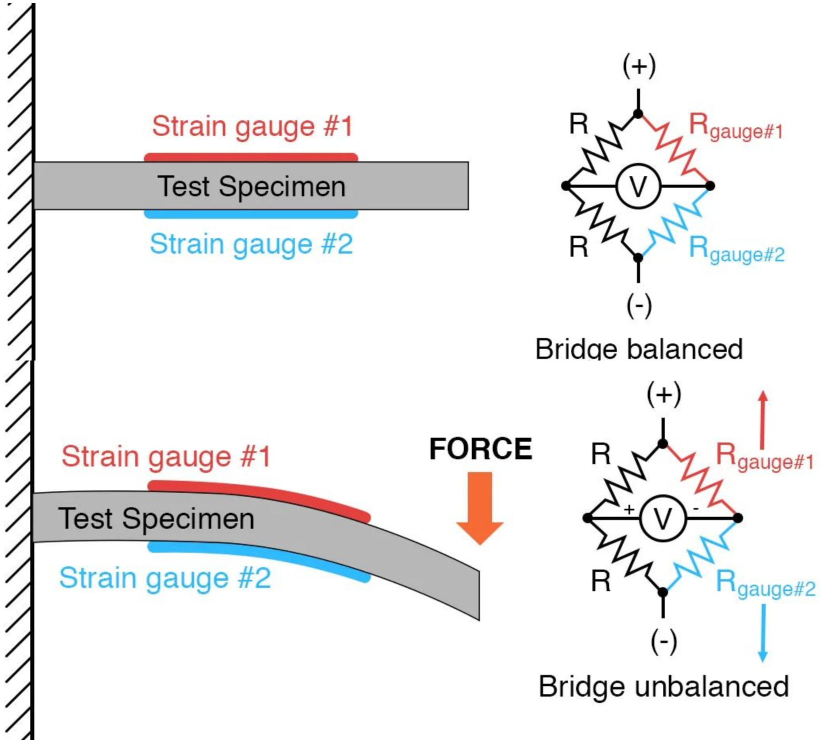
Strain Gauges

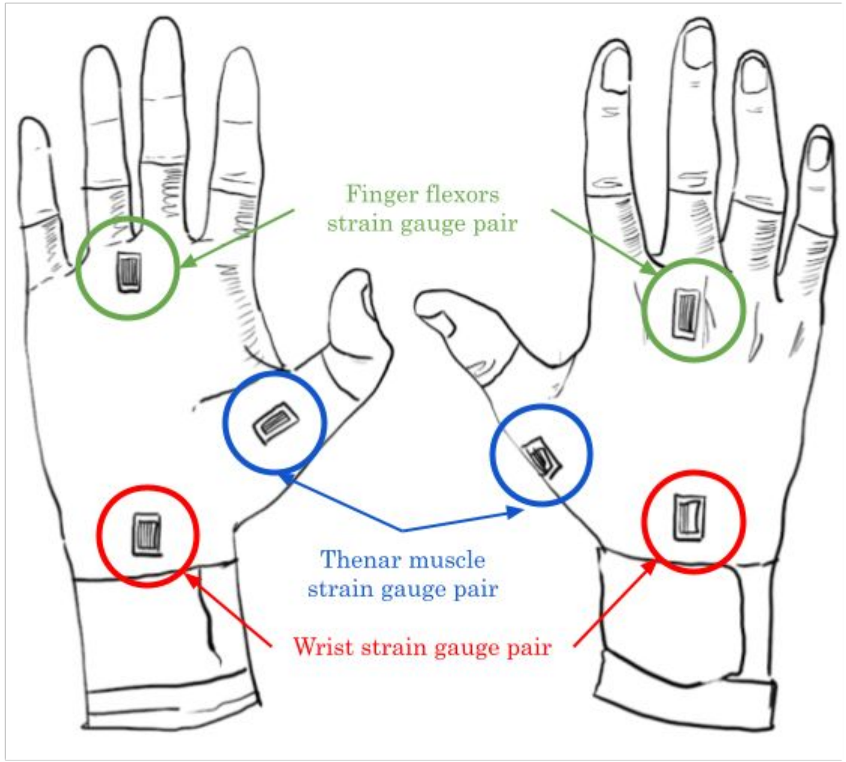
Purpose: Detect and measure strain at key areas of flexion/extension in the wrist and hand

How they work:

- Strain Gauges measure strain by changing its electrical resistance in response to change of length of the gauge itself
- Gauge factor (GF) determines magnitude of resistance change. Our GF = 2 and nominal resistance = 350 Ohms
  - Strain gauges with a GF of 2 will exhibit a change in electrical resistance of: 2(500 * 10^-6)=0.1%
- Resistance changes are used as input to the strain gauge component of the signal processing subsystem

Sensor layer – Strain gauges





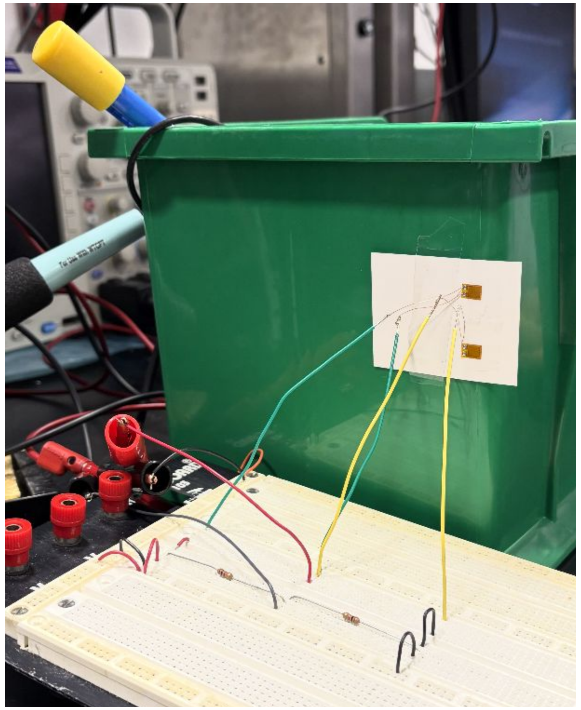
New strain gauge placements to target flexion/extension at key areas of the hand based on strain gauge experimentation

Requirements & Verification

Strain gauges must detect wrist flexion and extension angles within ±5° of actual movement when compared to a reference protractor.

1. Record strain gauge output data and convert it to angular measurements; verify computed angles are within ±5° of measured angle
2. 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
3. *Also demonstrated and verified for our breadboard demo*

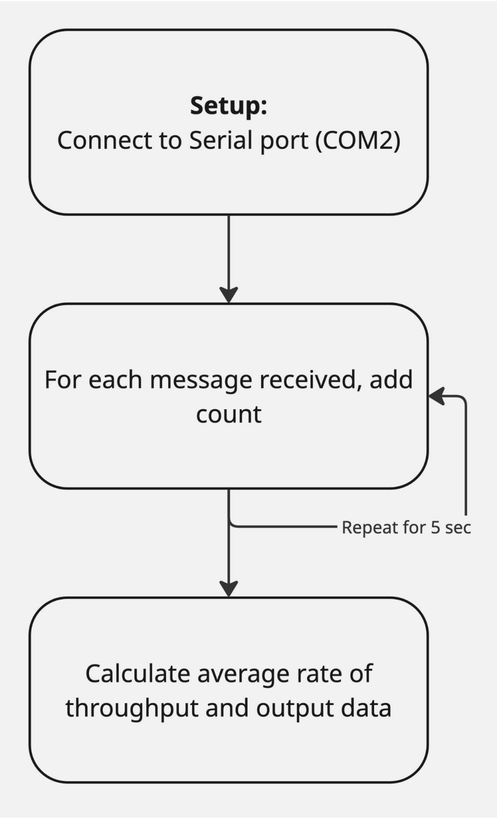
Angle [°]	Voltage Difference Across Bridge [mV]	Change [mV]
0	3.100	0.000
-30	2.947	-0.060
+30	3.010	+0.030

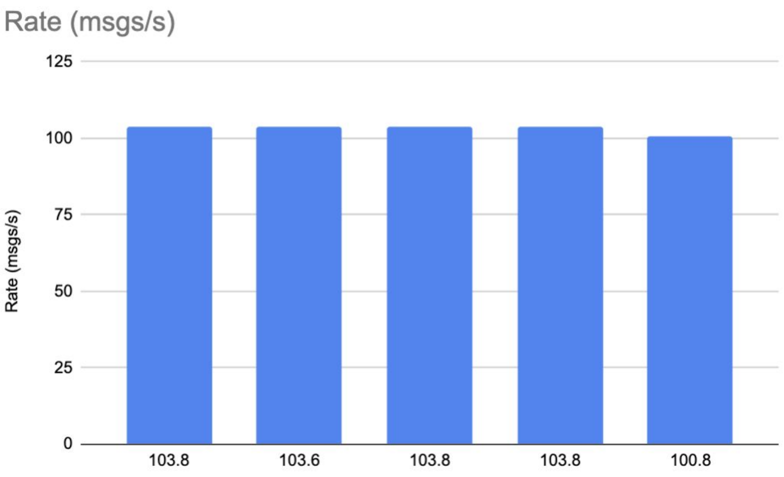


Sensor layer – IMU

Inertial Measurement Unit (IMU)

Purpose: Detect and measure repetitive motion





Requirements & Verification

MCU must sample motion data from IMU at a frequency of ≥ 100Hz to capture fine motor motion and repetitive movements

Test:

- Wrote script to count how many messages are received through serial port & calculated rate

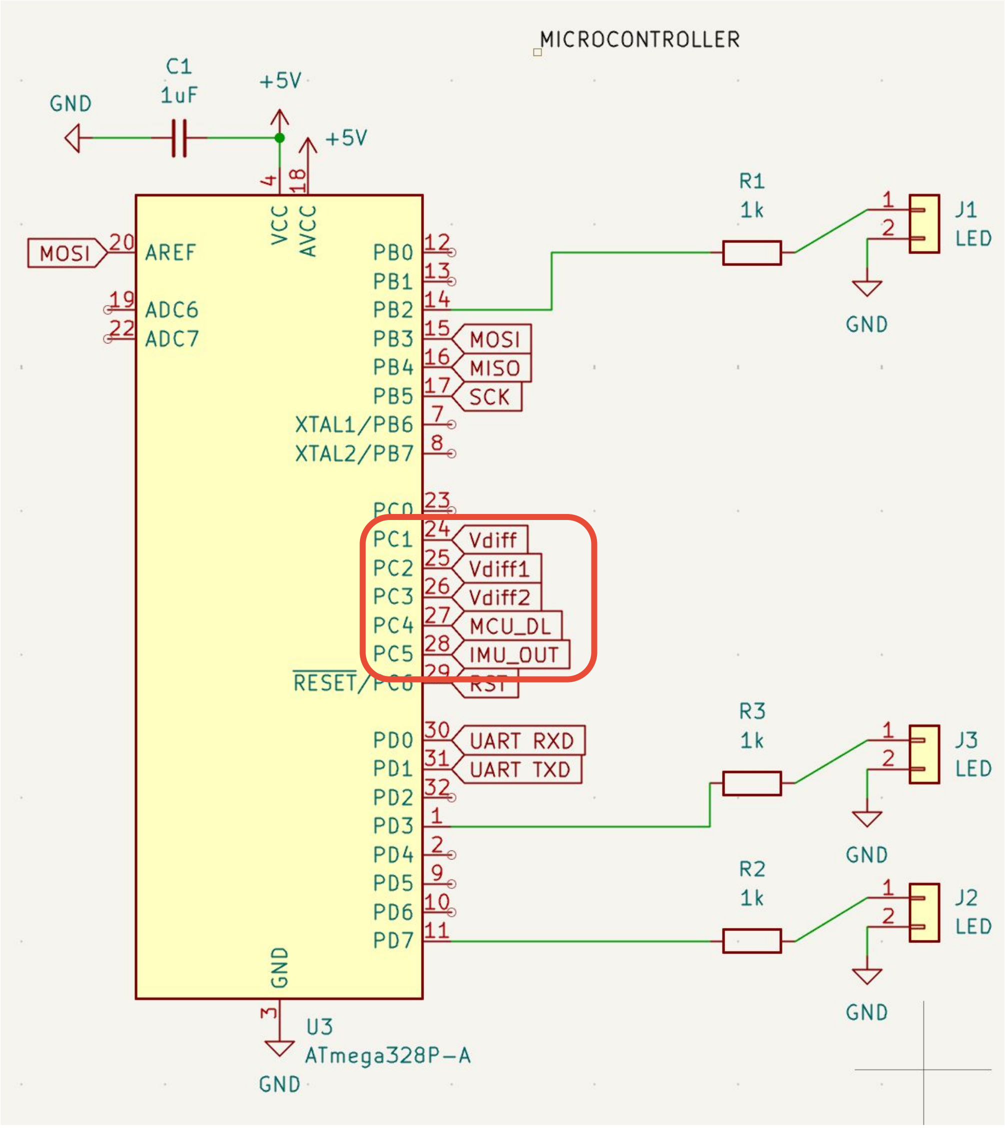
*Test on software-side instead of hardware-side to ensure that messages for processing are **received** at frequency of >= 100Hz.*

Signal Processing Subsystem

This subsystem takes signals from the sensor layer subsystem as input, processes the signals, and outputs the processed signals to the communication subsystem

Physical design & sensor placement

Signal Processing



Strain Gauge Output Amplification

A **differential op-amp** with gain was utilized to amplify a 5-7 mV signal change into a 0.2.-0.4 V reading.

$$V_{diff} = \frac{(R_F+R_1)}{(R_g+R_2)}V_2 - \frac{R_F}{R_1}V_1$$

$$V_{diff} = \frac{R_F}{R_1}(V_2 - V_1) \;\; if \;\; R_F=R_G \; and \; R_1 = R_2$$

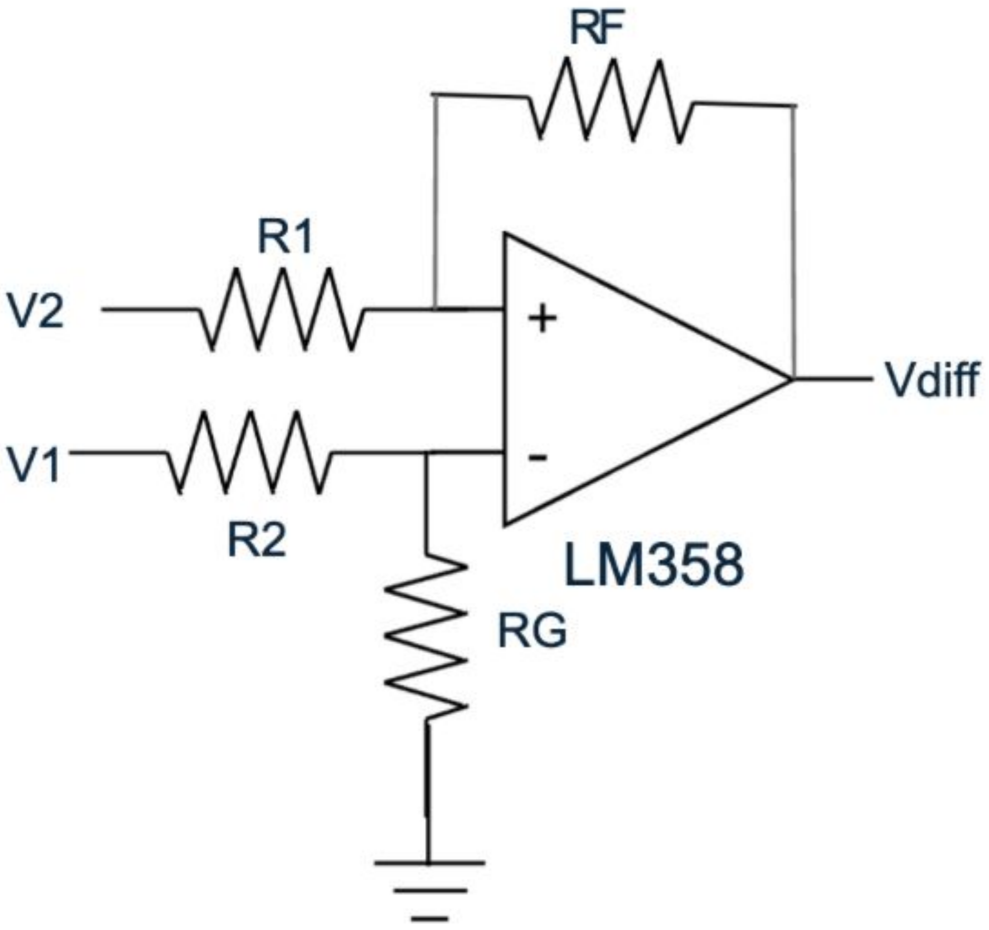
Final Values:

➔ $R_F = R_G = 100\ k\Omega$

➔ $R_1 = R_2 = 2.2\ k\Omega$

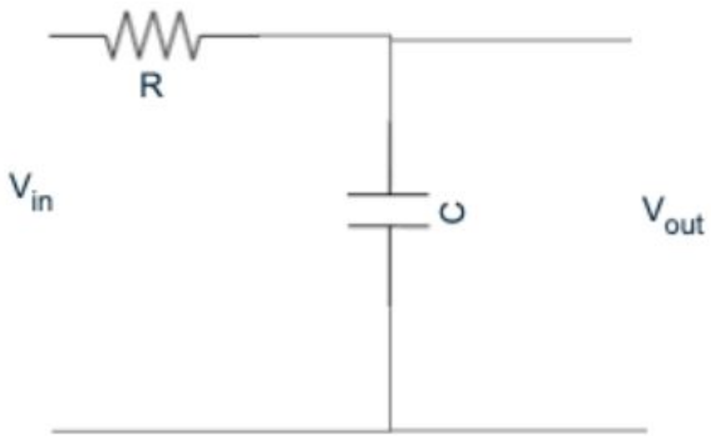
➔ Gain = 45.45

The voltage output of the op-amp is wired as a signal input to the MCU (for ADC conversion and UART communication)



IMU Low-pass Filter

The IMU required a LPF to **differentiate intentional human action from generic noise**. The frequency to differentiate this is **< 5 Hz**.



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

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

$$R = 3\ k\Omega$$

$$C = 10\ \mu F$$

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

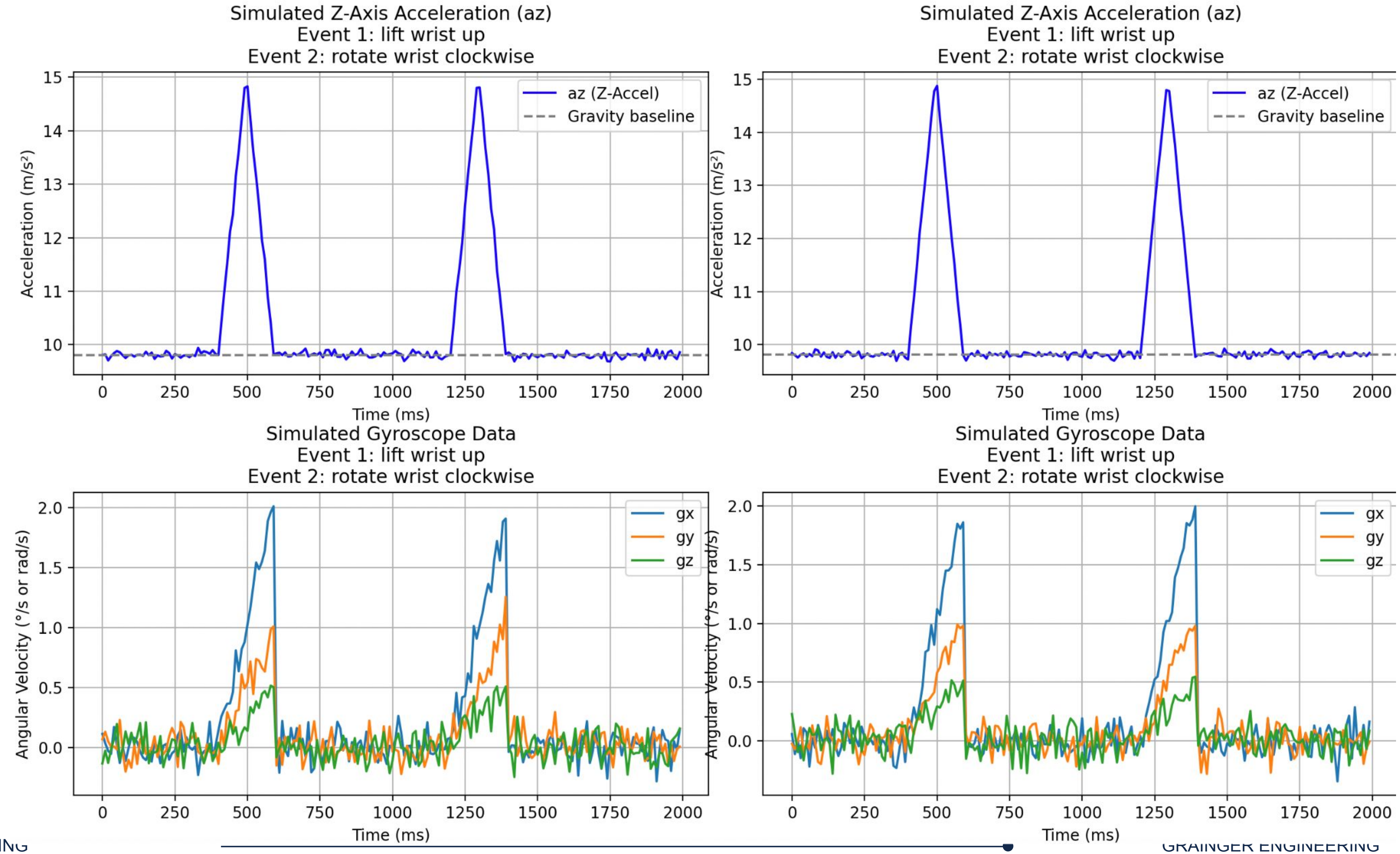
IMU Analysis

Generated 2 unique sets of mock IMU signals by:

1. Sampling @ 100 Hz for 2 seconds (200 data points)
2. Generate random # multiplied by minute noise factor (0.02-0.05) & add 9.81 accounting for gravity
3. Generate spike at moments 0.4s and 1.2s simulating actions (lift & rotate wrist)
4. Created datasets demonstrating compatibility with 2 unique users

Signal Processing - IMU

IMU Analysis



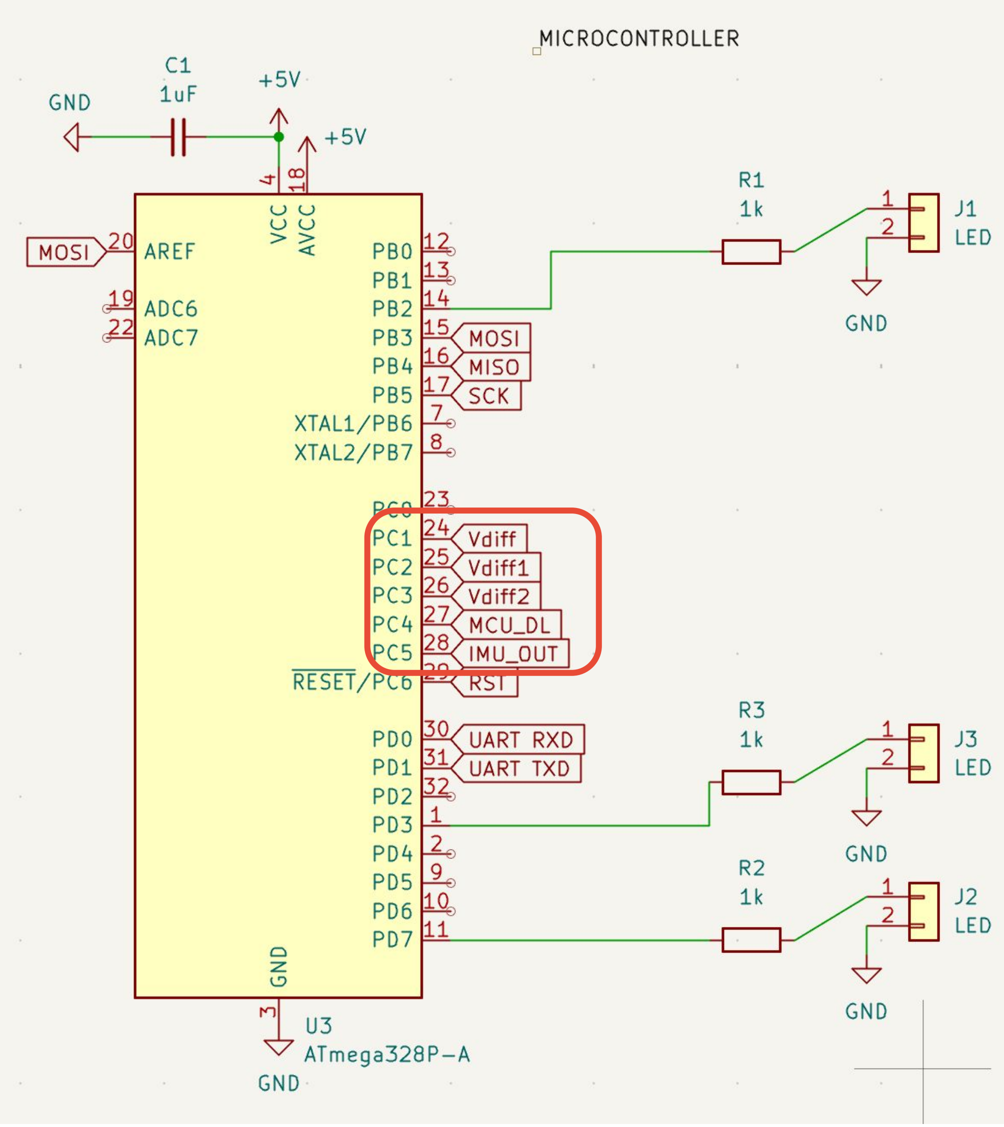
Requirements & Verification

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 *vdiff from strain gauges*

Use MCU to filter human motion from noise & determine notification status

- Further amplify and filter with an LPF designed for a maximum of 5 Hz
- Trigger user notification through display system/application based on stress levels

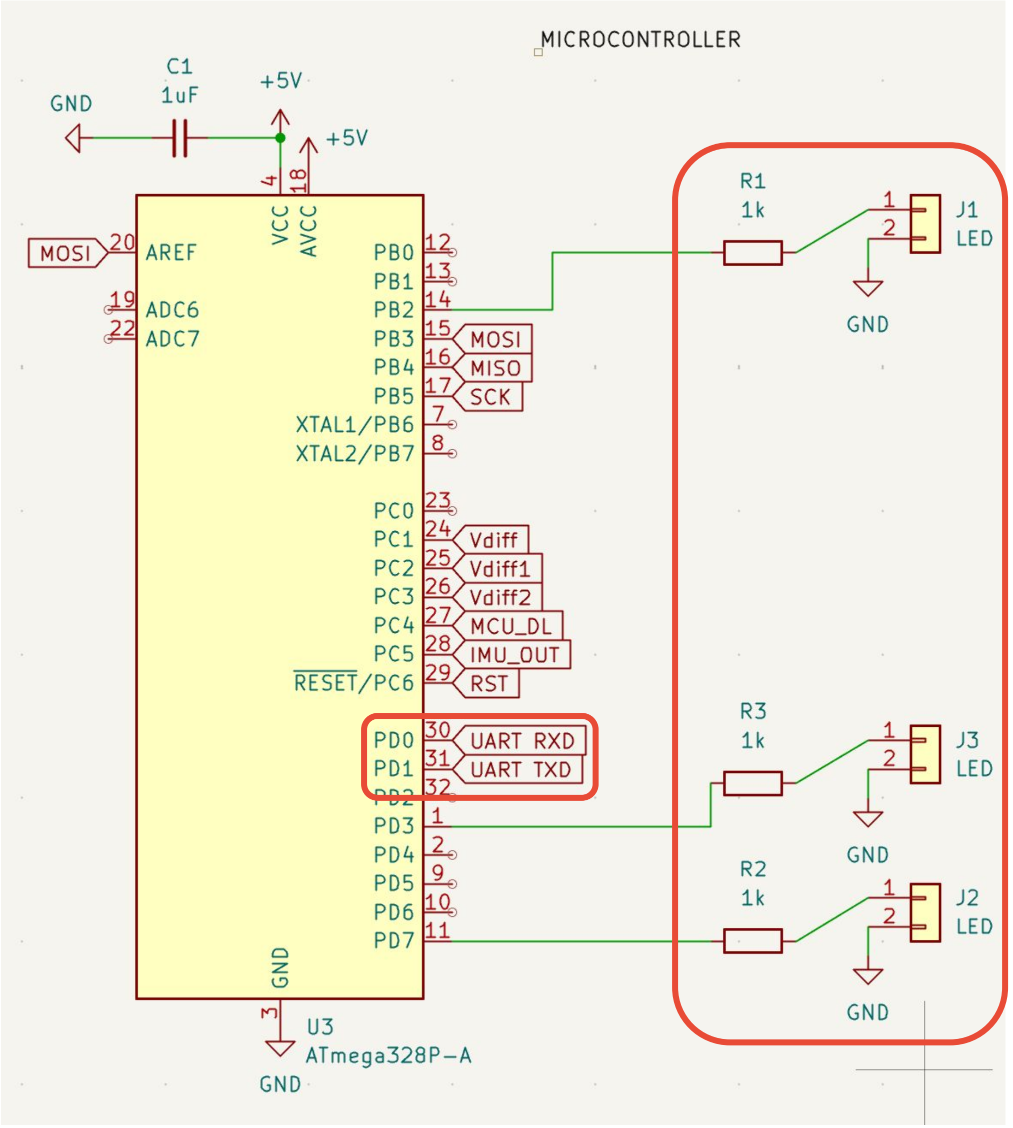


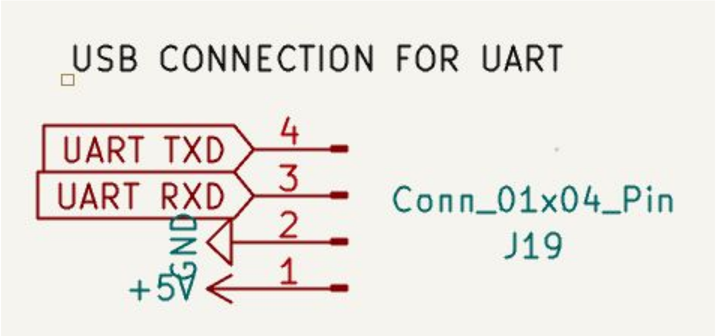
Communication Subsystem

This subsystem will receive processed signals as input and determine whether or not to warn the user of strain and prompt them to take a break & suggest stretches.

Physical design & sensor placement

Communication Protocol





Communication Protocol

UART

- MCU tx/rx pins are wired to UART cable
- Python software on PC interprets signals received from UART
- **A pop-up is shown to the user to take a break if:**
  - Strain gauge voltages surpass a voltage threshold past a predetermined time duration
    - Stretch suggestions are determined based on which strain gauge voltages exceed voltage threshold
  - Accelerometer data sees a recurring frequency <= 5Hz past a predetermined time duration

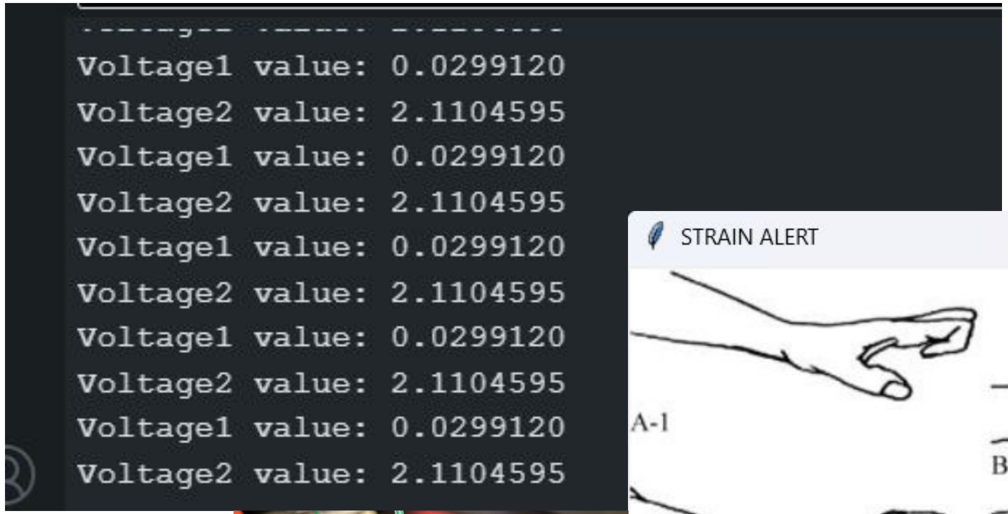
Communication Protocol

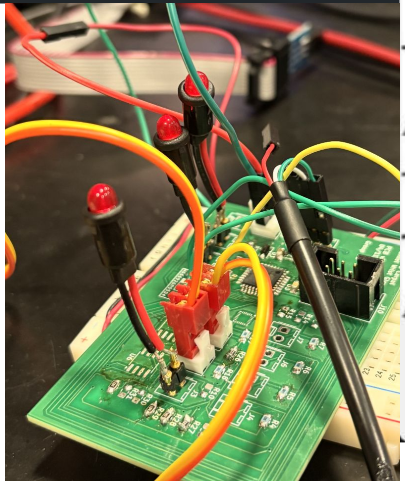
Requirements & Verification

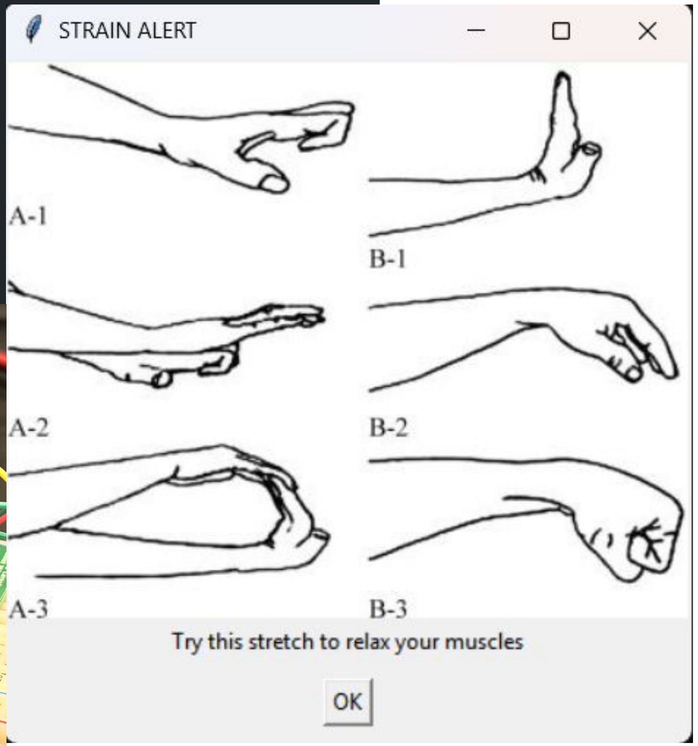
Communicate readings with user through application; this requirement is absolutely necessary for the communication subsystem to notify the user to take a break

- 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 stress
- Explore the possibility of intelligently suggesting wrist stretch out of a database utilizing real-time data via UART

Outputs

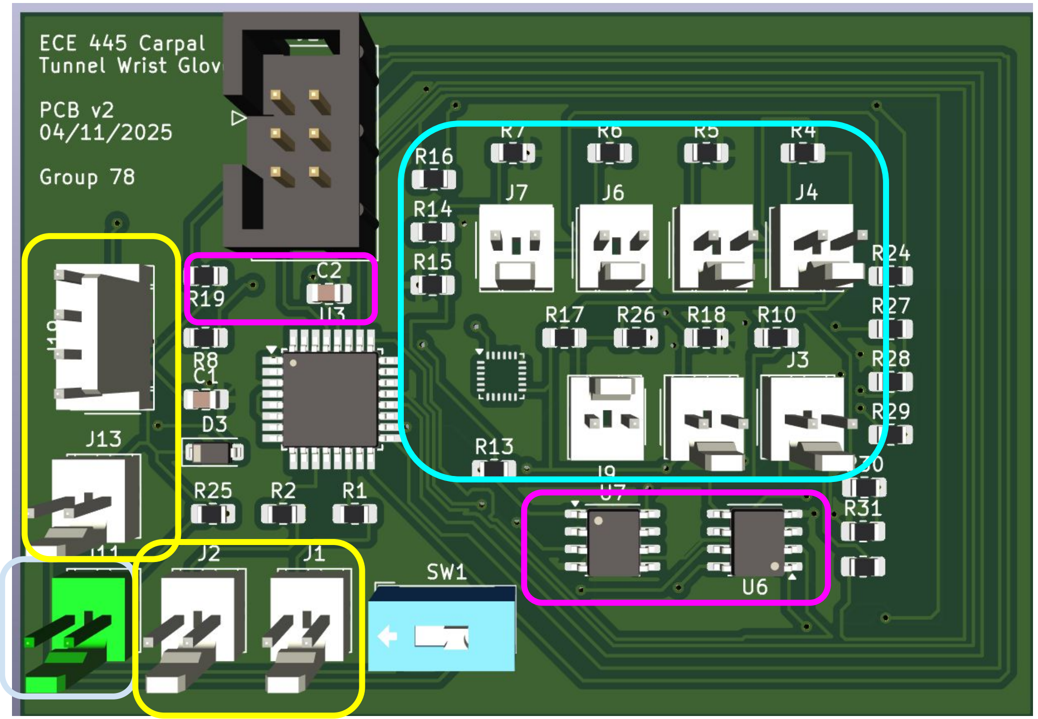






Final Results

Complete Design

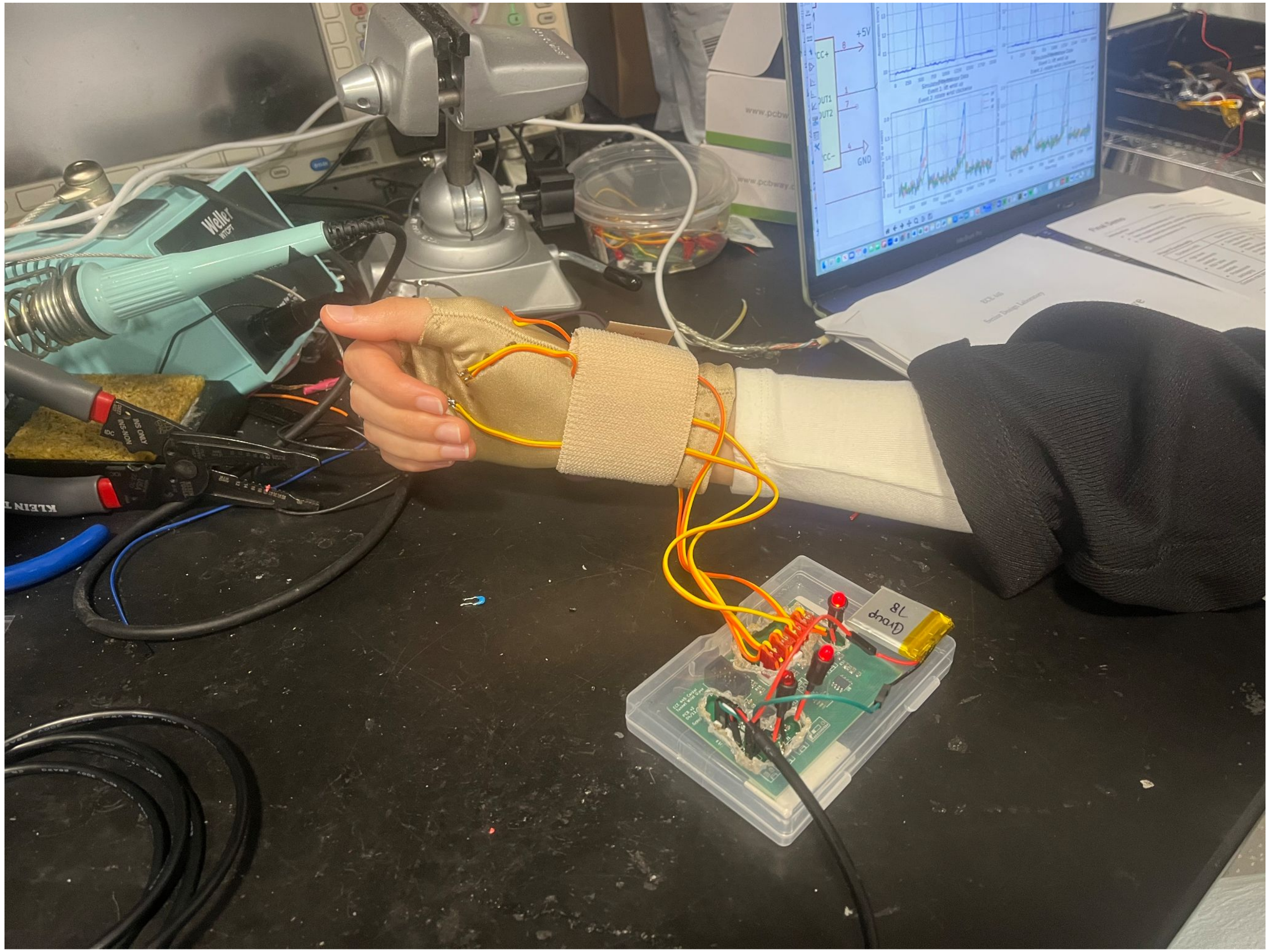


Subsystems

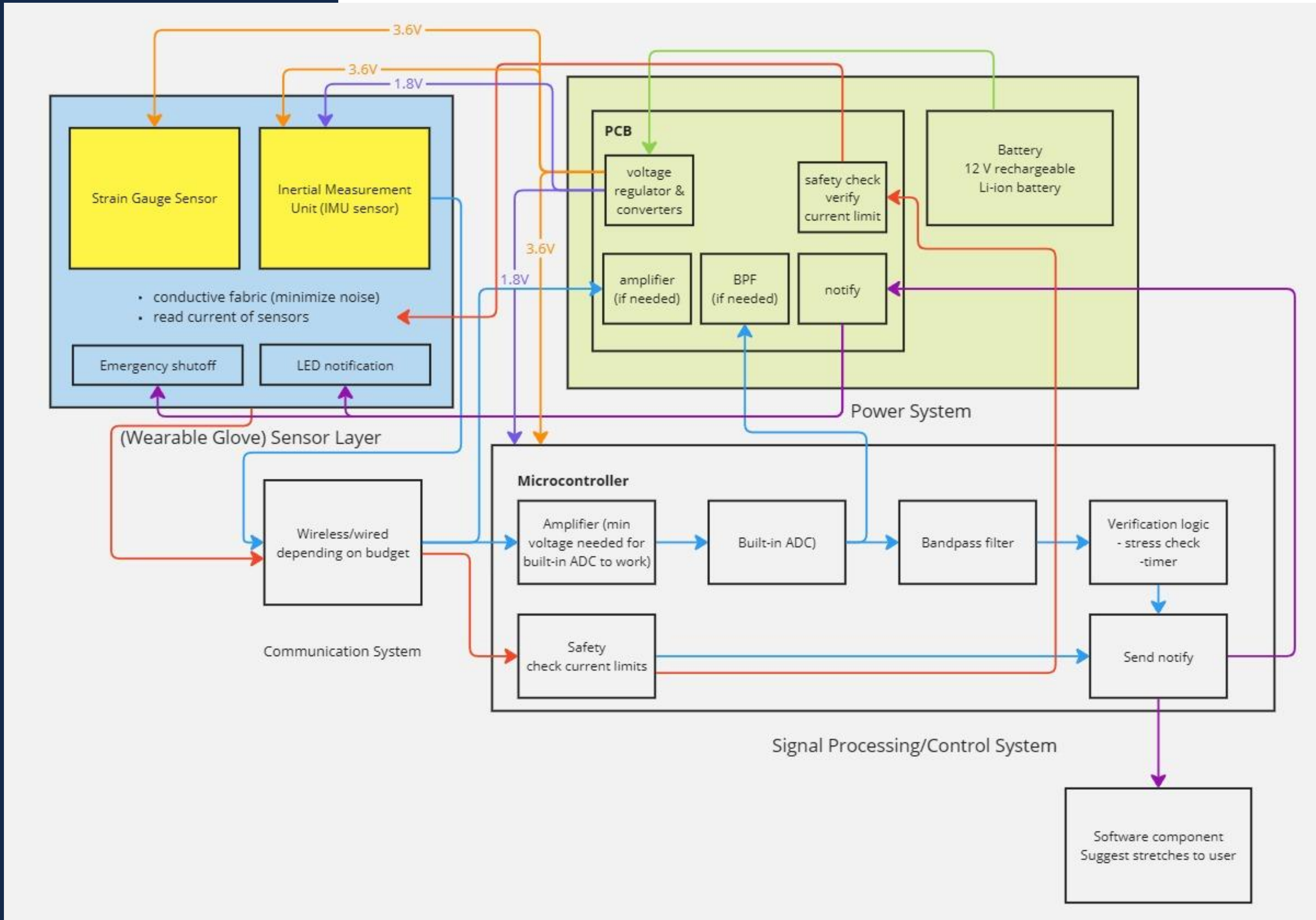
- **Gray:** Power
- **Cyan:** Sensors (strain gauges/IMU)
- **Pink:** Signal processing (op-amps/LPF)
- **Yellow:** Notification (LEDs/UART)

Final Results

Functional Design

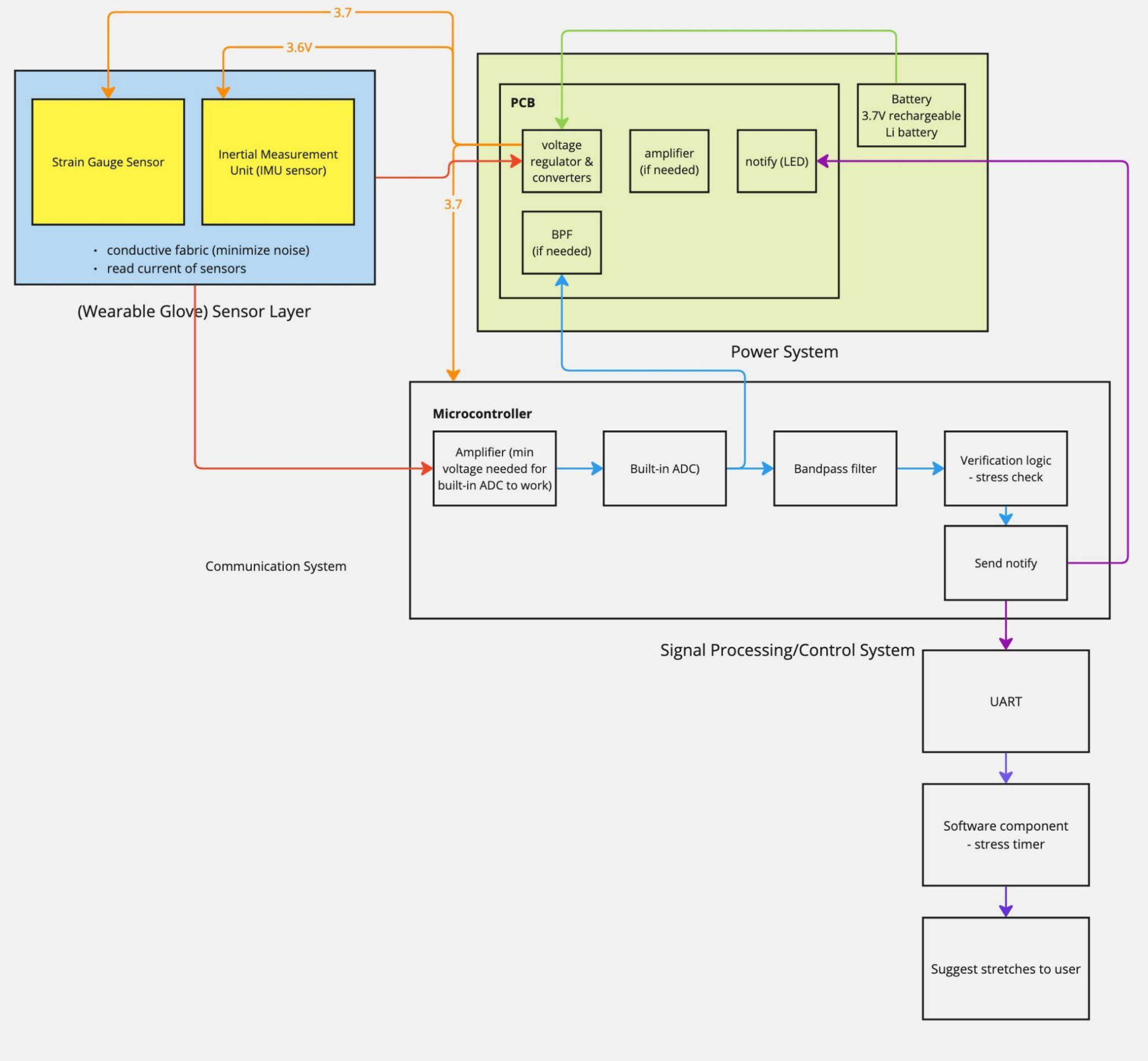


Initial Design



Implemented Design

- 3.7V VCC instead of 12V
- UART instead of Bluetooth
- Diode addition to ISP V_{CC}



Conclusion

Successes

- Functional powered PCB without external modules
- Experimentation led to adjustments to initial designs to account for current limits
- Worked around design fallbacks to ensure other high-level requirements were met
- **Ethics**
  - Ensured that the design is safe for human use (current limit, prevent raw wires exposed to user)
  - Enclosed in case to avoid direct contact with user
  - We don’t claim to scientifically prevent syndromes, we aim to promote better hand/wrist habits

Challenges

- Functionalities working on breadboard/abstracted from circuit but not working as expected on PCB
- Not able to successfully prove the *Accuracy* high-level requirement
  - Strain gauges
    - Needed higher power voltage for op-amp (for higher precision)
    - Addition of terminal wires → more resistance
  - IMU needed voltage regulator

Conclusion

Design Changes

- More portable design
  - Bluetooth module (wireless)
  - Smaller, mountable & enclosed device
- Higher input voltage for higher gain
- Sensor
  - Better strain gauge mounting method (strain gauge → intermediate substrate → glove)
  - Filter to output of op-amp to detect clean voltage changes
  - IMU integration
- Power switch & emergency shutoff

Takeaways

- Better planning regarding PCB design (hard to test IMU on a breadboard)
- Better weekly team abstraction
- Allocate time for more diverse experiments on sensors (variable environments, fabrics, placements)

Thank you!
Any questions?

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