

ECE 445

Senior Design Laboratory

Carpal Tunnel Wrist Glove Project Proposal

Team 78:

Deepika Batra, Li Padilla, Rawnie Singh

TA: John Li

Professor: Arne Fliflet

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 proposed 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

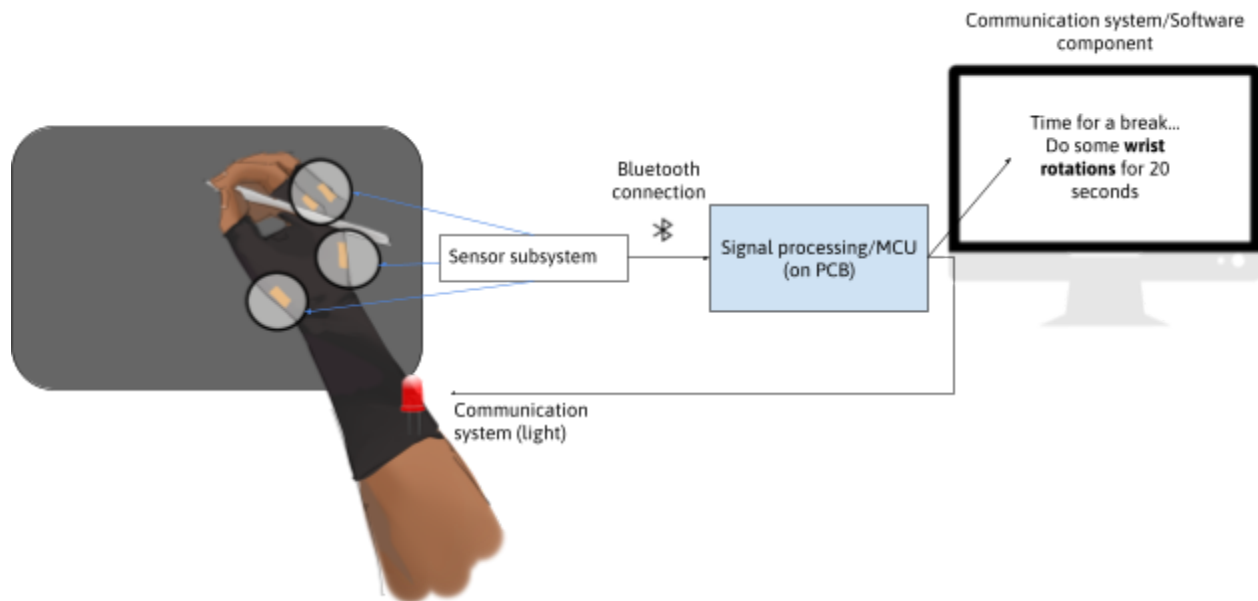


Figure 1

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

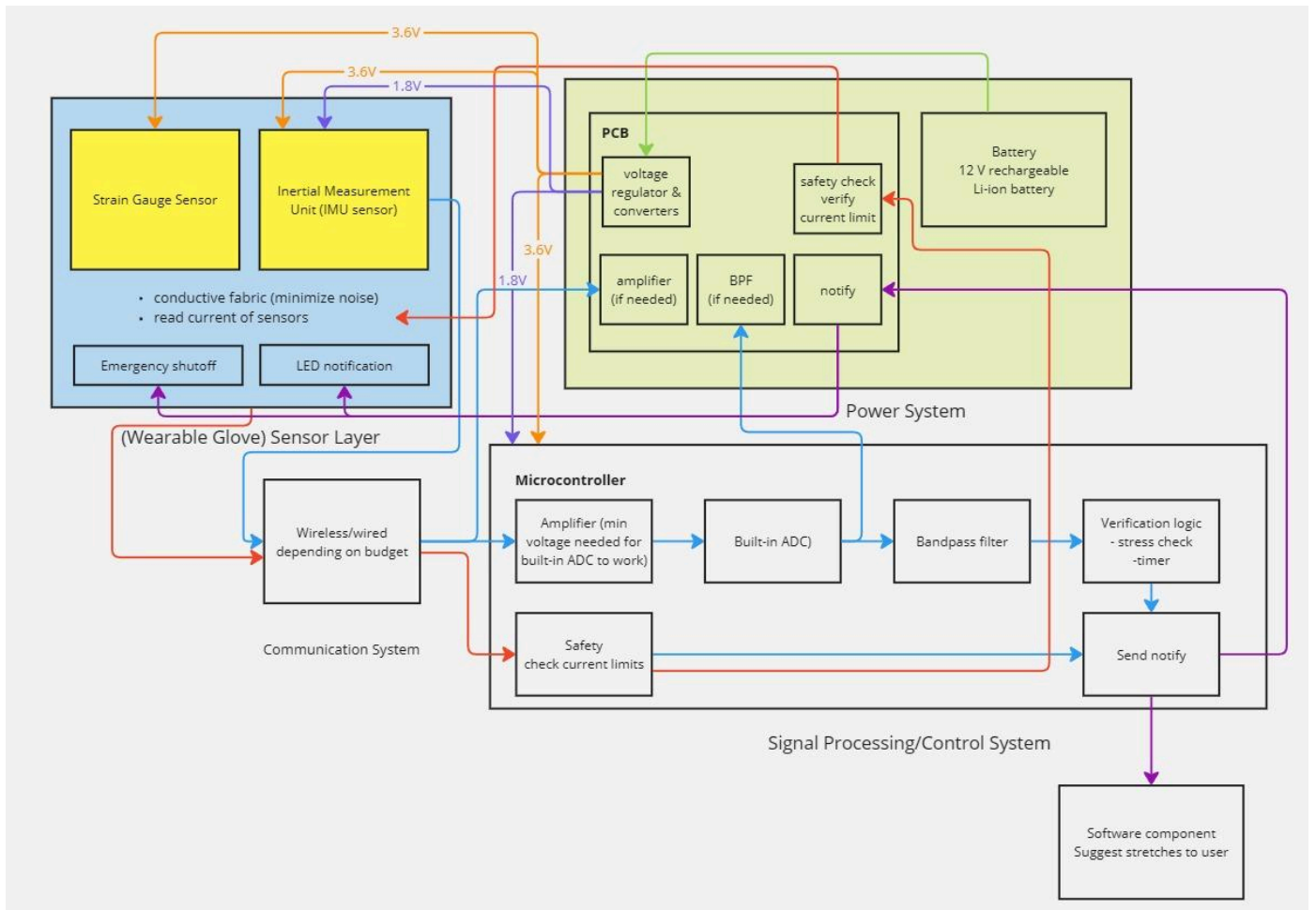


Figure 2

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 board design is explained in 2.2.5** but 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 dorsal wrist area. 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 (v_{out}) across the strain gauge is proportional to the change in electrical resistance. We can calculate the strain by dividing the ratio of v_{out}/v_{in} 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 30° 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

- ❖ **If these requirements were removed, the subsystem would fail:**
 - Must be able to supply 2.4 V / 600 μ A to strain gauge (Vishay CEA-06-062UR-350)
 - Must be able to supply 1.7 V / 220 μ A to IMU (ICM-20948)
 - Must be able to supply 1.8 V / 45 nA to MCU (TI-MSP430FR5994)
 - Must be able to supply 1.8 V / 7 μ A to Bluetooth Module (TI-CC2564C)
- ❖ Li-ion battery was chosen over Li-Po for safety purposes

2.3.2 Sensor Layer Subsystem Requirements

- ❖ **If the following requirements were removed, the subsystem would fail:**
 - **IMU must sample motion data at a frequency of $\geq 100\text{Hz}$ 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 $\geq 100\text{Hz}$ (A sampling rate around 100 Hz is sufficient for capturing daily life human activities [5])
- ❖ **If the following requirements were removed, the IMU may still detect repetitive motion and prompt the user for breaks, but the communication subsystem would fail to present to the user an accurate stretch to relieve target muscles of strain**
 - **Strain gauges must detect wrist flexion and extension angles within $\pm 5^\circ$ of actual movement when compared to a reference protractor.**
 - 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 $\pm 5^\circ$ of measured angle
- ❖ **Sensors must have a combined response time of $\leq 50\text{ms}$ 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

- ❖ **If the following requirements were removed, the subsystem would fail:**
 - **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

- ❖ **If the following requirements were removed, the subsystem would fail:**

- **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 30° 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 v_{out} / v_{in} by the gauge factor
 - v_{out} = 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 (350 Ω)

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.

http://elektron.pol.lublin.pl/elekp/ap_notes

3. 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.

4. References

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