Preliminary Design Report

TEAM 24 – DIGIT

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1 ABSTRACT

Team DIGIT will design and construct a sensory glove for the purpose of tracking real-time motion of the fingers and wrist using sensors, to better assist doctors with monitoring and helping patients with hand impairments. The glove is intended to be used in sessions with patients, who will wear the glove and be instructed to perform specific movements using their hand. A 3D model will be viewable to allow for easier viewing and analysis of data. The glove will aim to improve on prior versions, by reducing the form factor of the circuity and maintaining constant connectivity to the glove. This report provides an overview of the project's breakdown and preliminary design for the glove.

2 PROBLEM STATEMENT

2.1 Need

There is a need to help monitor patients who have impaired motor function in their hands, such as those who have suffered a stroke, have spinal cord injuries, or other ailments that affect hand motor skills. It is important for medical professionals to be able to collect hand motion data to assess a patient's hand motor skills in real time. By utilizing hand motion data, medical professionals could assess the current condition of a patient or determine the impact of treatments or injuries. Medical professionals need the ability to instruct patients to perform certain hand motor functions and record their movements using means that minimally impact motion while simultaneously monitoring the data in real time.

2.2 Objective

The goal of project Sensory Glove V4 is to implement this glove as a medical device for doctors to use during therapy sessions for patients struggling with impairment in the hands. The design objectives include tracking motion in the hand such as fingers and wrist motion, recording and storing data for comparison in data analysis, displaying data, and prompting commands. Team DIGIT's technical solution for these design objectives will be to (1) create a PCB capable to support sensors (2) record and capture data with the sensors on the PCB then transfer data wirelessly to a secondary device (3) develop a user-friendly GUI in a GUI software development environment.

2.3 Background

It is estimated that one in four adults over the age of 25 will have a stroke in their lifetime [1] with 50% to 70% experiencing movement impairment [2]. These numbers only pertain to hand paresis from strokes and do not account for paresis caused from carpal tunnel surgery and other neurodegenerative disorders such as MS, ALS, and Parkinson's. Physical and occupational therapy is a very common practice to help patients try to regain movement, however depending on the severity of the injury/disorder, the increased out of pocket expenses can put patients in financial jeopardy. Depending on if the patient has insurance, each therapy session can be as low as $15 or up to around $250 if uninsured [3]. Additionally, the therapist may recommend the purchase of equipment to aid in recovery at home.

There are currently some therapy gloves in the market geared toward rehabilitation of hand movement such as the MusicGlove [4], the Neofect Smart Glove [5], and the CyberGlove [6]. These products can be used to improve hand function recovery by fostering motor learning and brain reorganization. While these products can be useful, they can be very expensive, which limits their accessibility to the public.

The previous iterations of the project were inherited by Team DIGIT however they were geared to be for basketball players to improve their game. These gloves had the main objective of shot tracking to improve their game and shooting form by comparing a shot made by an individual to a previously set benchmark shot [7]. Team SCREEN in 2021 improved upon the previous iterations developed by teams S.W.I.S.H in 2019 and S.H.O.T. in 2020 by creating a glove that was smaller and less obstructive than the previous iterations and measured data in a more concise manner. Team SCREEN used a fingerless glove, which was a stretchy knit winter glove [8]. Team SCREEN had a wireless glove that was powered with two-coin cell batteries and had a Bluetooth module to transmit data from the sensors to the application.

Team DIGIT's glove is meant for rehabilitation for impairment in the hands and will need to be improved to fit the needs and objectives from above. Our sponsor would like for the glove to eventually be used at the same time as an EEG cap to compare the data from movement and electrical brain activity. Since the glove will be used simultaneously with the EEG cap, the data needs to be recorded in real time to a secondary device to ensure that the two sets of data can be compared with each other. Our sponsor is currently using VRFREE gloves by sensoryx [9] for the current stage of her study. However, the gloves are bulky and hard to put on patients that have very rigid hands. The gloves occasionally stop sending data to the computer, creating lags in the data. The sponsor ultimately wants a game to coincide with the glove that provides instructions for movements, feedback based on progress, and goals for patients to reach.

3 REQUIREMENTS SPECIFICATION

3.1 Marketing Requirements

The marketing requirements were created after looking at the previous iterations of the glove and meeting with our sponsor to determine what she wanted in the glove.

1. **Shall** track finger, hand, and wrist motion
2. **Should** be wireless
3. **Shall** include a goal-based game
4. **Should** send data to 3D modeling software
5. **Shall** display data from sensors in real time
6. **Shall** be easy to put on and remove
7. **Shall** be cleanable
8. **Shall** not interfere with patient's movement
9. **Should** have a rechargeable battery

3.2 Objective Tree

The objective tree, shown in Figure 3.1, was created from the marketing requirements. Weights were assigned to each grouping, using the AHP pairwise comparison tables shown in the appendix.

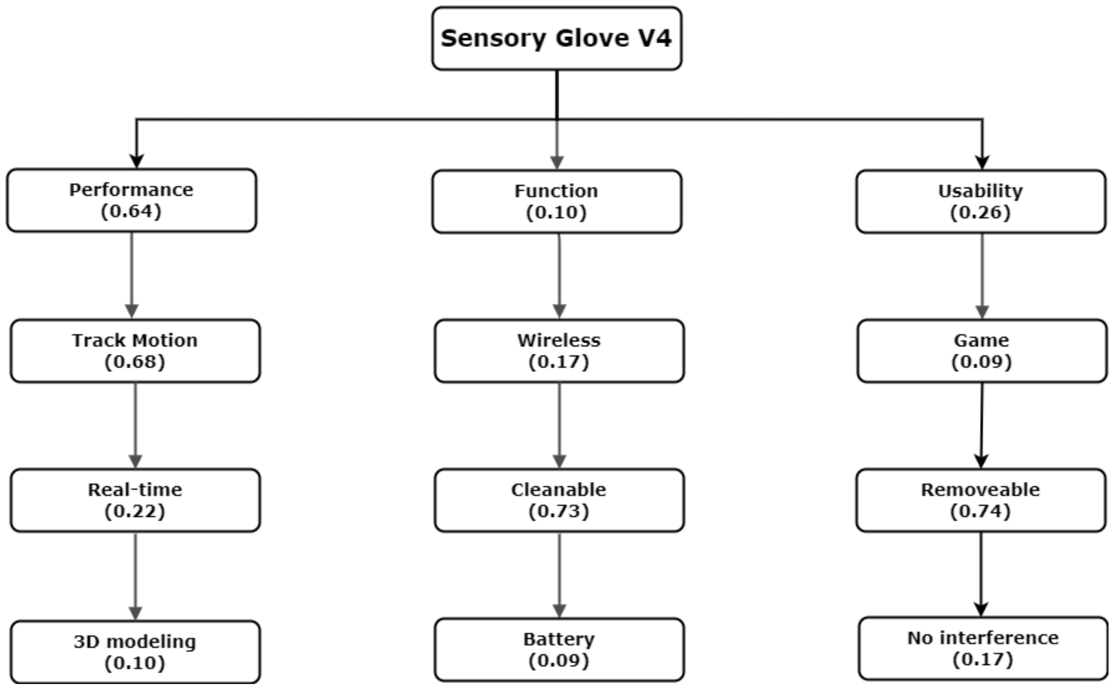


Figure 3.1 Objective Tree

3.3 Engineering Requirements

The following table defines the engineering requirements related to this project. Each engineering requirement represents an attribute of the glove and/or software which is derived from at least one of the marketing requirements 3.1. The corresponding justifications are provided to clarify the engineering requirement's importance to the overall project.

Table 3.1 Engineering Requirements

No.	MR	Engineering Requirements	Justification
1	2, 9	Battery should last 5-8 hours while powering the PCB	For the glove to be wireless, a battery with a long life is required. To ensure that the glove does not shut down during consecutive data collecting sessions that last 60 minutes, the battery life should last 5-8 hours
2	2, 5	Should monitor battery level	By monitoring the battery level, the user will be able to detect low power in the battery. This is to ensure the glove does not shut down during data collection.
3	3, 4	Shall be programmed in LabVIEW, MATLAB, or Python	The sponsor required that our code is written in either LabVIEW, MATLAB, or Python.
4	1, 5	Sensors shall be connected to the ADC pins on the PCB	Sensors hooked up to ADC pins will allow the microchip to detect changing voltage with analog to digital conversion (ADC). The ADC pins allow a range of voltage to be read compared to the digital pins that only read two values.

No.	MR	Engineering Requirements	Justification
5	8	PCB shall be smaller than the previous PCB design (1.95” x 2”)	Designing a smaller PCB will make it easier to put on or take off the glove especially if the patient is rigid from stroke or disability.
6	8	PCB shall contain the control system and connections to all sensors on a single PCB	Designing a PCB to contain all the electronics removes extra weight
7	5	Data shall be streamed in real time	Allows for immediate feedback based on results.
8	4, 5	Should be displayed in 3D motion	An easier method to view and discuss results with patients.
9	6, 7	Circuity shall be removable	Helps with cleaning and working with circuitry while glove is currently not being used.
10	1	Shall contain a minimum of 8 sensors	This allows motion tracking with all 5 fingers and wrist movements.
11	4, 5	Shall achieve a sampling rate greater than 10 Hz	The sponsor is currently unable to achieve a sampling rate higher than 10 Hz with her prototype. She has requested that we attempt to achieve higher rates to track hand motion more precisely.
12	2, 9	Glove should use Bluetooth or Wi-Fi	Both are affordable and high-speed data transmission technologies. Either option will allow us to have a high sampling rate, as indicated in ER 11.
13	2, 9	Should be powered by a rechargeable battery	Using a rechargeable battery reduces our overall waste expenditure and removes the need to buy and store disposable batteries. The battery will be removed and charged via a micro-USB charger
14	1, 3	Secondary device shall provide positive feedback when patient correctly follows commands	Allows patient to receive quick input regarding whether they are following directions correctly.
15	6, 8	The glove shall be made from material that allows flexibility with different hand sizes	Allows the glove to fit over a variety of patients' hands.
16	1, 4, 5	Data from the glove shall be sent to a secondary device	Allows the user to look at the collected data from the glove while the patient is actively using the glove. This removes interference with additional wires.

No.	MR	Engineering Requirements	Justification
17	1, 3	Secondary device shall display commands to instruct patient to perform specific tasks to test hand movement	Simple visual commands issued through the game will provide an easy method to communicate instructions to the patient during testing.
18	6, 8	The overall weight of the glove shall not be more than 4oz	A lightweight glove will allow the user to effectively use the glove and allow the user to easily remove glove from hand.
19	6, 7	The circuity shall be encased	Allows for the circuitry to be removed from the glove and reattached to the glove easier.

3.3.1 Verification of Engineering Requirements

Verification ensures the design meets the requirements and specifications. Table 3.2 describes how each engineering requirements will be verified for each prototype.

Table 3.2 Verification of Engineering Requirements

No.	ER	Verification
1	Battery should last 5-8 hours while powering the PCB	Charge battery to full and then leave the PCB powered for up to 8 hours. Confirm after 5 hours that the PCB is still powered.
2	Should monitor battery level	Confirm that the battery level can be viewed through observation by either software or hardware.
3	Shall be programmed in LabVIEW, MATLAB, or Python	Confirm that all code written is in either LabVIEW, MATLAB, or Python.
4	Sensors shall be connected to the ADC pins on the PCB	Wiring the sensors to ADC pins then read in changing voltage with the software using ADC.
5	PCB shall contain a PCB smaller than the previous PCB design (1.95” x 2”)	Measure both PCB designs and compare both designs to see if the new PCB is smaller than 1.95” x 2.”
6	PCB Shall contain the control system and connections to all sensors on a single PCB	Observing that all connections lead back to the PCB (no additional small PCB breakout boards for sensors).
7	Data shall be streamed in real time	Move sensors on the glove and see if data shows up on secondary device simultaneously.
8	Should be displayed in 3D motion	Check that hand model matches the current position and orientation of the actual hand being tested.
9	Circuity shall be removable	The circuitry will be detached and reattached to the glove. Then the glove will be turned on and tested to see if it is working.
10	Glove shall contain a minimum of 8 sensors	Test each sensor and be able to read the data.

No.	ER	Verification
11	Shall achieve a sampling rate greater than 10 Hz	Check how many datapoints the glove can receive in one second of testing.
12	Glove should use Bluetooth or Wi-Fi	Check that glove has the capabilities to transmit data over either technology.
13	Glove should be powered by a rechargeable battery	Deplete battery completely, and then charge until full again and check battery level to confirm.
14	Secondary device shall provide positive feedback when patient correctly follows commands	Run an instance of the game and test that when a command followed correctly, positive feedback is issued on screen by the game.
15	The glove shall be made from material that allows flexibility with different hand sizes	Test flexibility by putting the glove on various hand sizes and flexing the fingers and rotating the wrist.
16	Data from the glove shall be sent to a secondary device	Test the Bluetooth/or Wi-Fi connection from the primary device to the secondary device.
17	Secondary device shall display commands to instruct patient to perform specific tasks to test hand movement	Run an instance of the game and check to make sure commands are being issued continuously as the patient completes previous tasks.
18	The overall weight of the glove shall not be more than 4oz	Weigh the glove on a scale with all components attached.
19	The circuity shall be encased	Check that all circuitry except for sensors and associated connecting wires are packaged in a case

3.4 Design Impact Statements

3.4.1 Environmental

The impact of technology on our environment is a growing issue in the modern world. To mitigate our electronic waste, we have set requirements to try and help our glove be more ecofriendly. We plan to make all circuitry on the glove removable, in order to make sure the glove is cleanable. This will allow us to reuse the glove and eliminate the need to buy new gloves after each session and/or for each patient. In addition, we plan on using a rechargeable battery[1].This will eliminate the need to constantly dispose of old batteries and will reduce our waste.

3.4.2 Manufacturability

The sponsor and mentor have expressed their desire for the glove to be made a product in the market. The following are the constraints for manufacturability. (1) The design will consist of accessible components in the market so that future replications of the device are identical to the prototype. (2) The construction process of the design will be documented in detail for the sponsor and the mentor to have the capability to replicate the device.

[1] Marketing Requirement 9

3.4.3 Social

Although this sensory glove's intended use is for medical sensing by medical professionals, making this glove easy to use and easily accessible will allow a wide variety of people to take advantage of this technology. In addition to medical professionals using the glove in the office or at home for diagnosis or physical therapy, a commercial market could also be possible. For example, self-monitoring using devices such as watches is becoming very popular for health and fitness applications. If hand motion data can be demonstrated as an accurate early indicator of issues and, if appropriately priced and marketed, individuals could be motivated to collect hand motion data for themselves. While it would not necessarily be appropriate to provide a diagnosis, recommending consulting with a medical professional would be an option.

3.4.4 Standards

Standards ensure that the product works together and follows organization regulations to avoid product failure. The medical sensory glove will follow the standards from the International Electrotechnical Commission (IEC) such as standards IEC 62304 about medical device software [10] and IEC 60601-1-11 for medical electrical equipment [11]. Standards from the Institute of Electrical and Electronics Engineers (IEEE) will also be respected including the IEEE 1233 Guide for Developing System Requirements Specification [12] and IEEE 802.15.1-2005, Standard for Information technology [13]The glove will also be created keeping in mind the standards from the Association for the Electronic Interconnection Industry (IPC), specifically IPC-6011, the Generic Performance Specification for Printed Boards [14] and IPC-2221A, the IPC Standards for PCBs [15].Finally, with the intention of eventually getting FDA approval so that the glove can be sold to mass markets and used in therapy centers, the FDA standards for medical devices [16] will also be respected.

3.4.5 Economic

Healthcare equipment can be very expensive which can impact patient care. Developing a sensory glove that is inexpensive benefits both medical facilities and patients. Inexpensive equipment is accessible to greater numbers of care providers which, in turn, provides more accessibility to a greater number of patients while also reducing overall costs. Because this is medical equipment, it is important that it provide accurate and reliable data. Inexpensive sensors and materials need to be thoroughly examined to determine if they will be accurate and reliable. Another aspect to cost is repairability. If cheaper sensors are accurate but less durable, it may be possible to replace them after one or more uses.

4 DESIGN

4.1 Functional Decomposition

4.1.1 Level 0

Figure 4.1 Medical Sensory Glove Level 0

Level 0 of the functional decomposition visually describes the overall functionality of the medical sensory glove which is displayed in Figure 4.1. The functional requirements are given in Table 4.1. Fingers and wrist movements are inputs into the system that are used to determine the bend of the fingers and twist of the wrist of a patient. The outputs of the system are a 3D model, battery level, movement data, feedback, and the next task. All five outputs are used for immediate feedback to the patient and data analysis to the therapist.

Table 4.1 Medical Sensory Glove Functional Decomposition Level 0

Module	Medical Sensory Glove
Inputs	•Finger/Wrist Movement
Outputs	•3D Model •Battery Level •Movement Data •Next Task •Feedback
Functionality	Records finger and wrist motion which is then stored as a text file for data analysis. Then the data is used for a command-prompt game.

4.1.2 Level 1

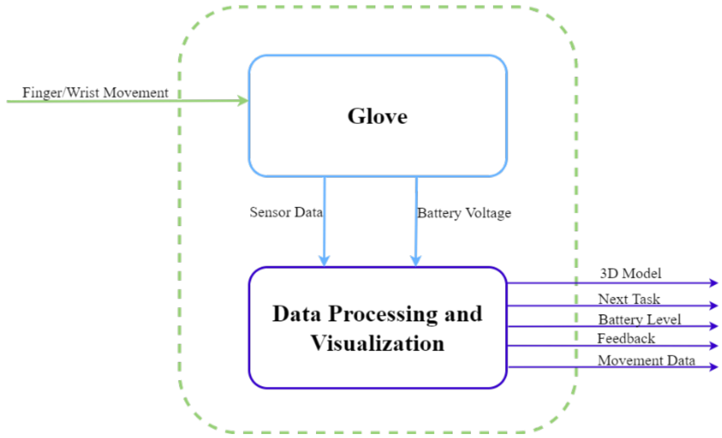


Figure 4.2 Sensory Glove Level 1

Level 1 of the functional decomposition visually describes the overall functionality of the medical sensory glove broken down into two sub systems which is display in Figure 4.2. Finger and wrist movements are inputs into the glove subsystem that are used to determine the bend of the fingers and twist of the wrist of a patient. Then, battery voltage and sensor data are outputs of the glove system and inputs into the data processing and visualization subsystem. The outputs of this subsystem are a 3D model, battery level, movement data, feedback, and the next task. All five outputs are used for immediate feedback to the patient and data analysis to the therapist. The functional requirements for Level 1 subsystems of the glove and data processing are given in Table 4.2 and Table 4.3.

Table 4.2 Glove and Accompanying Electronics Functional Decomposition Level 1

Module	Glove and accompanying electronics
Inputs	•Finger/Wrist Movement
Outputs	•Sensor Data •Battery Voltage
Functionality	Measures finger and wrist movement, collects the raw data, and then transmits the data to the secondary device.

Table 4.3 Data and Processing Visualization Functional Decomposition Level 1

Module	Data Processing and Visualization
Inputs	•Sensor Data •Battery Voltage
Outputs	•3D Model •Next Task •Battery Level •Feedback •Movement Data

Functionality	Sensor data is processed in LabVIEW and then sent to the game's code. The game first compares the data to a benchmark, and then displays the results on screen for the patient.

4.1.3 Level 2

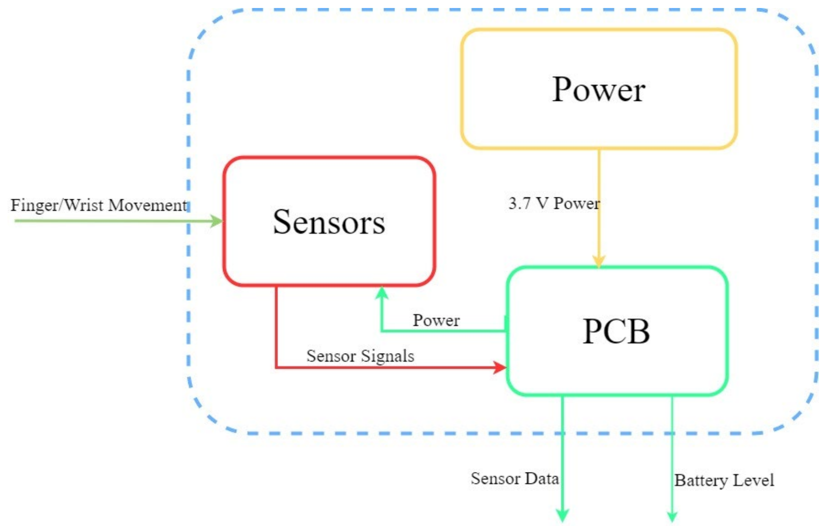


Figure 4.3 Glove Level 2

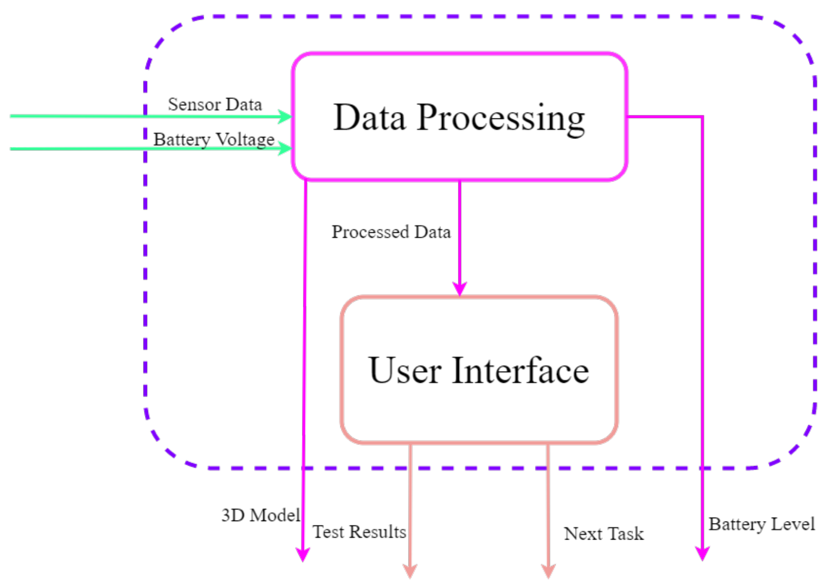


Figure 4.4 Data Processing and Visualization Level 2

Level 2 of the functional decomposition separates the glove and the secondary device into their respective subsystems, as depicted in Figure 4.3 and Figure 4.4.

The data processing and visualization block in Figure 4.4, takes in the raw data from the sensors and the battery voltage, which is sent wirelessly over Bluetooth or Wi-Fi (depending on which option is ultimately chosen). The data is first processed in the Data Processing block, in LabVIEW, and then sent to the User Interface block, where it is compared to a benchmark for the current task. The results of the current test, as well as the next task to complete, are outputted from this block, through the patient's screen. In addition, the Data Processing block also outputs the current battery level, as well as the 3D model representation of the patient's hand movement data. The functional requirements for the level 2 subsystems are given in Table 4.4 - Table 4.8.

Table 4.4 Power Functional Decomposition Level 2

Module	Power
Inputs	•N/A
Outputs	•3.7V Power
Functionality	Provides 3.7 volts of power to the PCB

Table 4.5 PCB Functional Decomposition Level 2

Module	PCB
Inputs	•3.7V power •Sensor signals
Outputs	•Battery Voltage Power •Sensor Data •Battery Level
Functionality	The PCB mechanically support and electrically connect electronic components using conductive pathways, tracks or signal traces etched from copper sheets laminated onto a non-conductive substrate

Table 4.6 Sensors Functional Decomposition Level 2

Module	Sensors
Inputs	•Finger/Wrist Movement •Power
Outputs	•Sensor Signals
Functionality	Measures finger/wrist movement and outputs voltage signal sensors to microcontroller

Table 4.7 Data Processing Functional Decomposition Level 2

Module	Data Processing
Inputs	•Sensor Data •Battery Voltage
Outputs	•Processed Data •3D Model •Battery Level
Functionality	Takes data from the sensors on the glove then processes and calibrates the data to be used later.

Table 4.8 User Interface Functional Decomposition Level 2

Module	User Interface
Inputs	•Processed Data
Outputs	•Test Results •Next Task
Functionality	Handles the comparison of test data to benchmarks, and manages the game used for command issuing

4.2 System Flow

4.2.1 Overall Testing Flow

The Medical Sensory Glove is intended to be used in therapy sessions with a patient. The secondary device, which is a computer, is required for the sessions. Figure 4.5 illustrates the setup in the doctor's office for a session. Patients will be asked to sit in front of a computer monitor, where the user interface, or game, is open for the patient to interact with during testing. The doctor administering the tests will be seated separately with their own monitor in front of them, where they can view test data in real-time. Both monitors will be connected to the secondary device, which will allow the doctor to interact with the game as well if necessary.

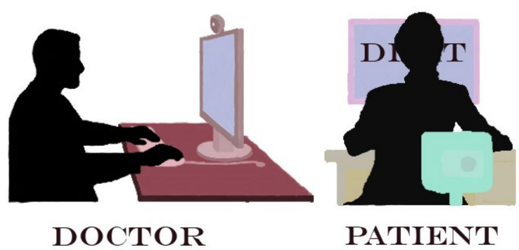


Figure 4.5 Testing Setup

Figure 4.6 shows the overall flow for patient testing. Five randomly selected tasks will be chosen per test for the patient to try and complete. They will have a predetermined amount of time to attempt each task. If they are successful, they are awarded a point by the game. At the end of the test session, the point total will be displayed on screen, to allow the patient to see how they performed overall.

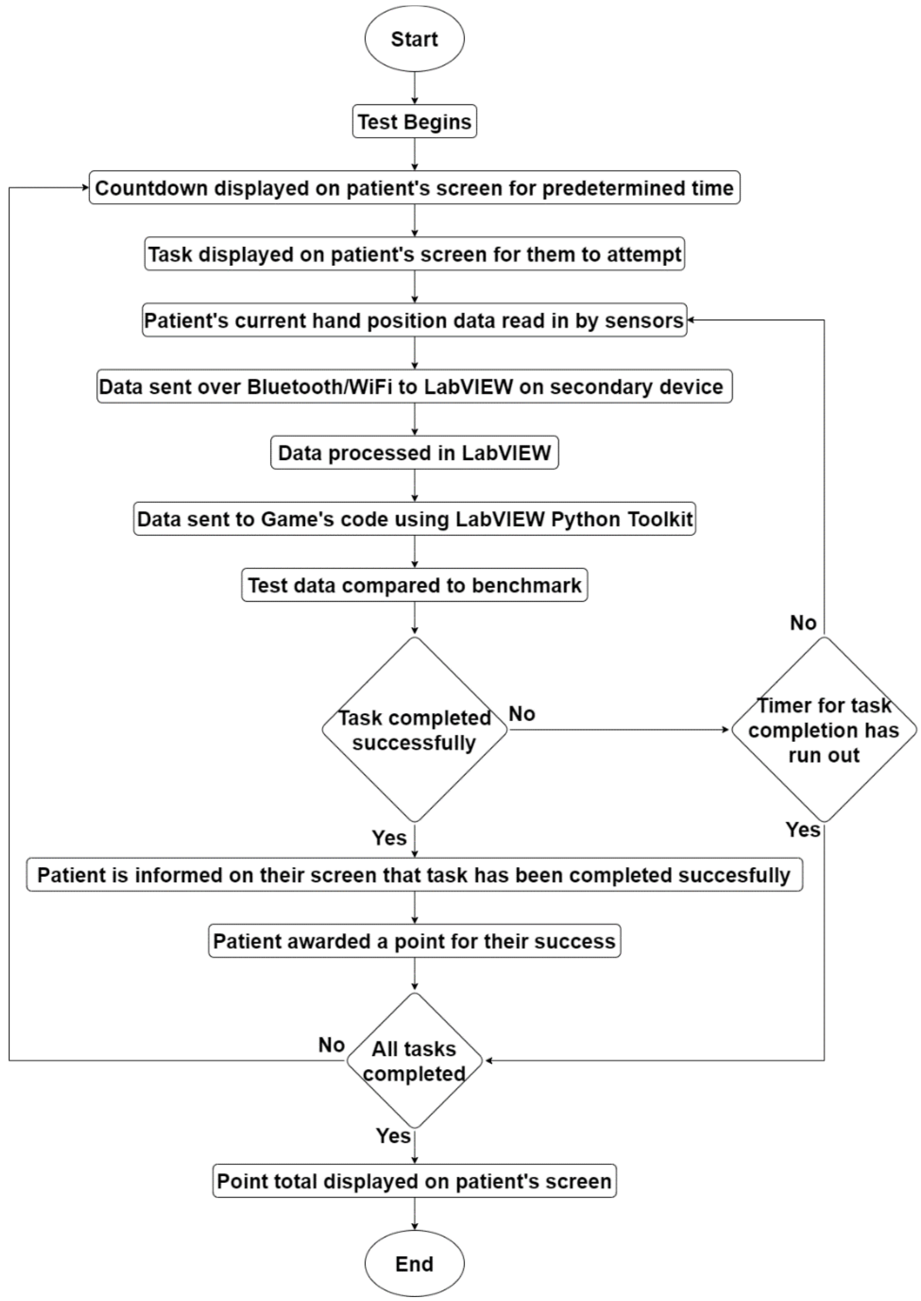


Figure 4.6 Overall Test Flow

4.2.2 Game Flow

Figure 4.6 shows the overall flow of the game's code during testing. In Pygame, when a new screen needs to be displayed, the current screen must be completely reset. To make the code cleaner and more readable, the different screens displayed during the game will be coded separately and will be referenced as function calls. A main function will handle the general flow of the game. This function will also reference the test comparison function once it has been implemented after the sub-projects have been integrated together.

The game begins with the title screen, displaying the game title and any other important information. Once the patient is ready, the game then moves onto a countdown screen, letting the patient know a task is about to be displayed. Once the countdown finishes, the task is displayed on screen for a predetermined amount of time. If the patient succeeds in performing the task, they are shown a task success screen, and are awarded a point. The game uses a point system to provide positive feedback for the patient and encourage them to keep going. If the patient fails, the game simply moves on without displaying any kind of failure screen. This is in order to align with our goal of avoiding any negative feedback to make sure the player does not feel discouraged. After all tasks have been completed, the final screen is displayed, showing the patient their point total.

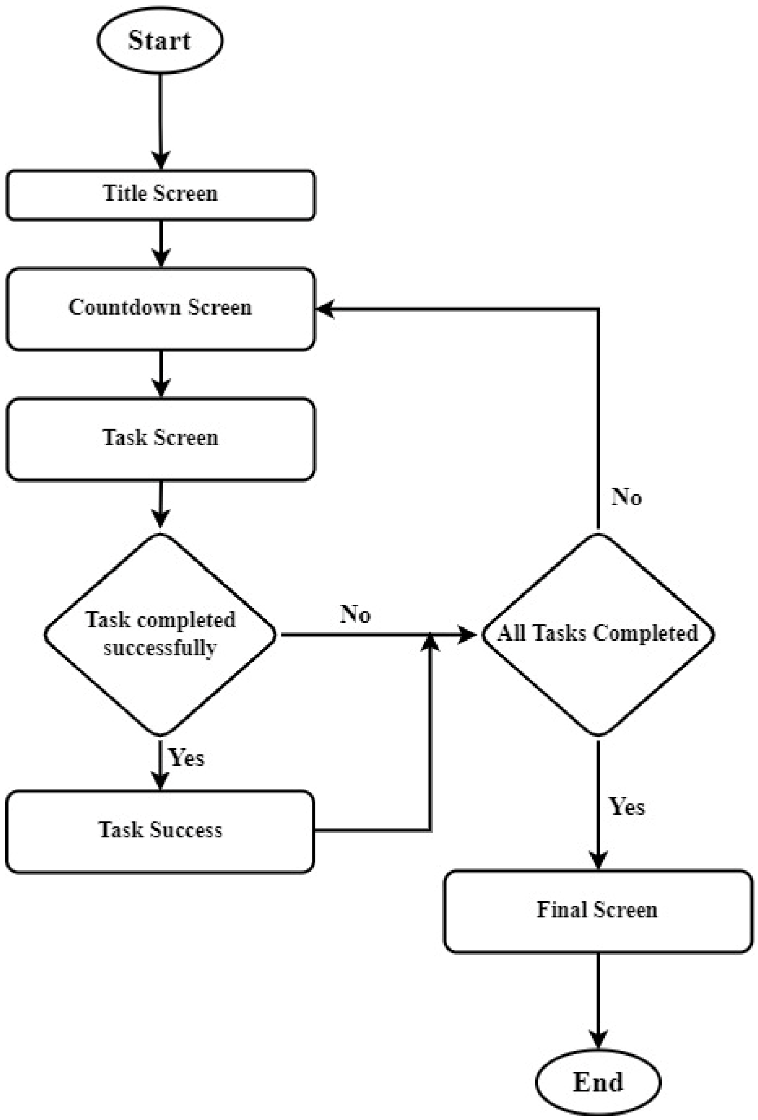


Figure 4.7 Overall flow of the game's code

4.3 Subsystem Selections

4.3.1 Sensors

Flex sensors, which were available from previous projects, have been tested and they performed well for measuring the amount of bend in fingers. Another candidate for measuring the bend in fingers was a Conductive Rubber Cord Stretch Sensor from Adafruit [17]. These Stretch sensors have been ordered and they will be tested against the flex sensors once they are received. In addition to measuring the bend of fingers, the separation between two fingers needs to be measured. Two different range-finding optical sensors have been ordered and they will be tested for measuring the varying distance between 2 fingers.

The range-finding sensors that are planned for testing and were easily purchased were an Adafruit Time of Flight Distance Sensor [18] and the Adafruit Proximity and Lux Sensor [19]. The Adafruit Time of Flight Distance Sensor uses a small laser with a matching sensor to detect how long the light takes to bounce back to the matching sensor. This sensor can measure distances down to approximately 1mm, which is a much smaller distance than other sensors with similar capabilities. The Adafruit Proximity and Lux Sensor determines range by measuring the amount of light being returned to the sensor and can measure distances down to approximately 0mm. These small distance measuring capabilities make these two sensors good candidates for measuring the separation between fingers. The conductive rubber stretch sensor increases resistance as it is stretched. This sensor can be stretched by bending a finger which would then increase the resistance. This sensor is also less intrusive to hand movement since it is thinner.

Additional sensors (stretch and optical proximity/time-of-flight sensors) were recently received, and initial testing will be performed soon. Fortunately, flex sensors were available from previous sensory glove projects and five of these sensors were tested to verify their ability to measure the movement of each finger. These five sensors were set up and connected to the Arduino micro. Then, as seen in Figure 4.8, five traces are displayed of the voltage level of each sensor. Each sensor trace has a spike that correlates to when the flex sensor is bent. It should be noted that the sensor voltage levels and offsets are at different levels. This is not unexpected, and part of the signal processing/conditioning work will include applying a calibration to the sensors to provide consistent voltage levels that correlate with how far the flex sensor is bent.

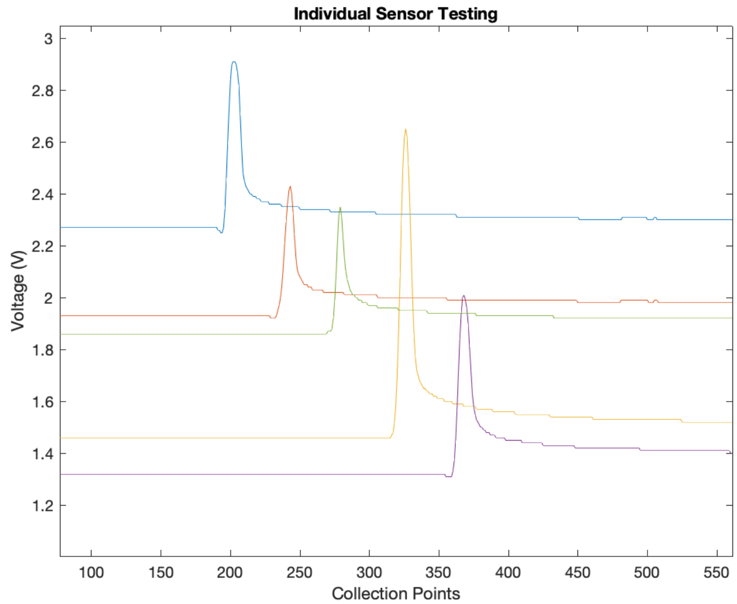


Figure 4.8 Individual Sensor Testing

4.3.1.1 Signal Processing

When collecting real-world data, signal conditioning/processing becomes an important aspect of the data collection process [20]. For example, digitization errors can occur during the A-to-D conversion of the voltage of the flex sensors to the digital integer representation. This digital integer should be converted to a decimal number representing the actual voltage being recorded and some smoothing function may be beneficial to minimize digitization noise.

There are two obvious options for smoothing the collected signals. The first option is a moving average filter which is very simple and yet does an excellent job of removing high frequency noise while maintaining the main signal characteristics [21]. The other option is a more traditional low-pass filter. Low-pass filters remove high frequency noise, but they may not be as easy to implement or as efficient as the moving average filter. MATLAB has built-in functionality to design and test both moving average and low-pass filters [22].

In order to properly display the real-time data, a scrolling MATLAB window code was written [23]. This code worked well during plotting tests but using the plot command can be inefficient for more complicated plots including multi-line plots. The plotting method that is now being used is the MATLAB animated line method. This plotting mechanism is more efficient because it only updates the new points and not the entire plot window. This animated line method is currently producing smoothly varying plots within MATLAB for 5 separate sensors [24].

In order to transfer the data to a secondary device for visualization, game play and recording the microcontroller and the secondary device must use compatible protocols [25]. Both wired and wireless transfer mechanisms as well as protocols such as serial, TCP/IP (Transmission Control Protocol/Internet Protocol), etc. have been considered. At this point, a serial protocol is being used because it is simple, efficient (low power), widely available on most platforms and can be used over both wired and wireless connections.

Initial signal processing has been tested both directly on an Arduino and within MATLAB when sampling the data at various sample rates from 10Hz to 50Hz where 30Hz seemed to provide smooth data for visualization in real-time. Processing to convert A-to-D binary values to voltage levels along with a 3-point moving average filter have been implemented directly on the Arduino to test for unacceptable processing delays when used in real-time.

In order to obtain a proper comparison between different filtering methods, a MATLAB routine was written to store approximately one minute of data for all 5 finger sensors (currently flex sensors). A 5-point moving average filter, 3-point moving average filter, a low pass filter and a double low pass filter were implemented, tested, and observed in MATLAB. These 4 filters were compared using the raw data collected by the sensors as can be observed in Figure 4.9. Since the filters were applied after the data was collected and for the sensory glove they would need to be applied in real time, they were shifted according to how they would appear in real time. From the graph, it can be seen that the low pass filtered lines were shifted further in time and the double low pass filter would take longer than the others to filter. The concern is that longer delays would impact real-time visualization of the data where the plot change happens too long after the actual movement therefore creating confusion for the medical practitioner. The moving average filters seem to have the least amount of delay; however, they were less smoothed on the plot. The goal is to smooth any unwanted noise but maintain the ability to capture small motions while minimizing the signal delay.

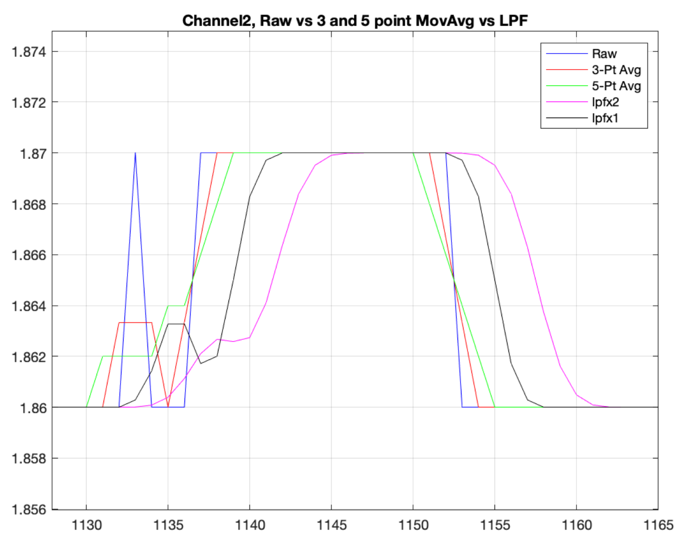


Figure 4.9 Moving Average versus Low Pass Filter Comparison

4.3.2 Power

For the power supply, it will need to be able to supply enough voltage to power the components on the PCB and all the sensors for consecutive sessions which each last around one hour. The ranking of importance of the attributes for the power supply, were done using the AHP pairwise comparison Table B.4 in the appendix. For the overall project, an environmental design impact was discussed on how we hoped to minimize our electronic waste by using rechargeable batteries. For this reason, the rechargeability of a battery is a number one priority. The nominal voltage and capacity that a battery has are almost tied in weight of importance with capacity being slightly higher due to the fact that the glove needs to last consecutive 60-minute sessions. The weight of the battery should not dramatically increase the weight of the glove once everything is connected which is why is has a lower ranking. Our sponsor did not indicate how much an individual glove shall cost to create, so the cost of the battery is the least important. In addition, since the battery needs to be rechargeable, it will cost more since rechargeable have a higher price than non-rechargeable ones and a charge is needed in order to recharge the battery which adds to the price. Ultimately using these criteria, Team DIGIT will be able to determine if it is reasonable to have a power supply and make the glove wireless. While there a plenty of rechargeable batteries available, the battery will need to be able to provide the voltage and capacity needed while adding as minimal weight as possible and not interfering with users' movements.

The Table B.5 in Appendix B compares different power supply options in approximate weight (g), approximate size, cost of individual, nominal voltage (V), nominal capacity (mAh), and if it is rechargeable. When it comes to small rechargeable batteries, the main two options are lithium-ion batteries or coin cell batteries. Both of these have maximum nominal voltages around 3.7 volts. Initially, the PCB was going to need at least seven volts of power which would have required at least two batteries in order to reach seven volts or need a voltage regulator module to increase the output power. However, it was discovered that voltage regulators drain the battery faster, especially for a small battery like a 3.7 volt, so in order to be effective, at least nine volts is recommended for a voltage regulator. The teammate working on the PCB, was able to redesign the PCB so that it will only need around 3.3 volts of power, so that only one battery is needed, and no voltage regulator is needed.

The five options from Table B.4 have a nominal voltage of around 3.6 to 3.7 volts; however, their weight and nominal capacity are widely varied. Equation 1 is used to calculate the total battery life with the total load.

$$Battery\ life\ (in\ hours) = \frac{Battery\ Capacity\ (in\ mAh)}{Load\ Current\ (in\ mA)}$$

Equation 1 Battery Life

4.3.3 Game

Before design of the game could begin, a software package to code the game in had to be chosen. The data collection and processing software we currently plan on using is LabVIEW. This software, along with the data collection, is grouped into a different sub-project. LabVIEW provides an easy way to integrate with external code, using the Python Integration Toolkit for LabVIEW [26]. Due to the ease and availability of this toolkit, as well as the various game development options available [27]. Python was chosen as the language to develop the game in. When initially given this project, it was suggested that we use Pygame for developing the game. In addition to Pygame, the packages Pyglet and PyOpenGL stood out and were chosen to be looked into. The AHP process will be used to determine which option is the best choice for this project. The details and tables involved with the process can be seen in Appendix B.3. Based on the results, Pygame was chosen to be our game development package.

4.3.3.1 Pygame

Pygame is a Python implementation of a previously created library for C [28]. Due to this, it's largest advantage over other libraries, is that it is easy to learn, due to being entirely based on previously defined functions [29]. This also has the added benefit of meaning the code will be shorter, and clearer to understand. The documentation for Pygame is extensive, and there are countless tutorials available. This ultimately makes learning the package even simpler. The biggest downside to Pygame is that it is slow [29]. This might not be a major issue for our project however, as our game is meant to be very simple, and is not too reliant on speed.

4.3.3.2 Pyglet

Pyglet's biggest advantage over other game development libraries is its speed [29]. In addition, it is known for its support of multi-monitor computers, as well as its 3D support [29] [30]. These benefits, however, would be lost on this project, as the game we are developing is meant to be simple. A big downside to using Pyglet is its low community support due to its lower popularity than other packages [29]. Considering that prior to this semester, my experience with both game development and coding in Python was close to zero, this is an important factor to consider.

4.3.3.3 PyOpenGL

PyOpenGL is a game development library, that is actually a wrapper around Pygame. It is used to connect Python to OpenGL APIs [31]. Given that it is essentially an enhanced version of Pygame, all the benefits of Pygame should be true with PyOpenGL as well. However, just like Pyglet, the added benefits of using PyOpenGL would be lost on our game, since it is intended to be simple. In addition, due to it being old, there is not a lot of documentation and tutorials available [31].

4.3.4 PCB/Microcontroller

The PCB design research started off with finding compatible controllers that LabVIEW [32] can target. The sponsor of team DIGIT, Madison Bates, used National Instrument's USB-6211 [33], which is a Multifunction I/O Device. The device weighs a total of 7.2 oz. This device is far from meeting the engineering requirement of 4 oz. However, a LabVIEW add-on was discovered which allows LabVIEW to target Arduino boards, BeagleBone [34] and Raspberry PI [35] controllers. Additionally, Arduino offers Autodesk Eagle [36] CAD files to the community so that custom PCBs can be developed. There are many different types of Arduinos to consider. A few worth noting was Arduino Micro [37], Arduino Leonardo [38], and Arduino Nano 33 BLE [39]. Another microcontroller that isn't an Arduino brand worth noting is the TinyPico [40].

The Arduino Micro and Arduino Leonardo have 12 analog input channels, 32 KB flash memory, 2.5 KB SRAM, 16 MHz clock speed, and 10-bit ADC Resolution. However, the Micro has 20 mA DC Current per I/O pin while the Leonardo has 40mA. These controllers use the ATMega32U4 processor which operates between 2.7V -5.5V.

The Arduino Nano 33 BLE has 8 ADC pins, 1MB flash memory, 256 KB SRAM, 64 MHz clock speed, 15 mA DC Current per I/O pin, and 12-bit ADC Resolution. This controller uses the nRF52840 processor that has an operating voltage of 1.7V- 5.5V. With this processor, it comes with Bluetooth communications where it can be a Bluetooth Low energy and Bluetooth client and host.

The Tiny Pico microcontroller. The TinyPico has Bluetooth BLE 4.2, 4MB SPI Flash, 4MB Extra PSRAM, and a ESP32-PICO-D4 processor that has the built-in Bluetooth and an operating voltage of 2.7V-3.6V. This processor chip comes with 18 ADC channels. Unfortunately, the TinyPico doesn't have built-in UART capabilities and isn't LabVIEW compatible.

Now, the two previous processor chips mentioned earlier (ATMega32U4 and nRF52840) aren't available in the market since there is an on-going chip shortage. This leads to a search more for available chips. The Arduino Uno [41] uses the ATMega328p processor chip. This chip has 6 ADC pins and 10-bit ADC resolution and an operating voltage of 1.8V-5.5V. Another processor chip that's like the ATMega328p is the ATMega328 which is used on the Arduino Nano [42]. The difference between the two is that the ATMega328 has 8 ADC pins and an operating voltage of 1.8V-5.5V. This chip has 10-bit ADC resolution as well.

Table B.11 shows a summary of the processor chips and compares each one. The AHP Table B.12 weighs the importance of each function

In conclusion, the ATMega32U4 processor chip was chosen for this project. The rationale for this decision is that this processor chip meets engineering requirement 10 with the processor chip having 12 ADC pins. This chosen processor meets engineering requirement 3 since the chip is LabVIEW compatible, and the processor chip has a built-in UART.

The Arduino Micro and Arduino Leonardo both use the processor chip ATMega32U4. The main difference between the two boards is the size and DC Current per I/O pin. Since the Arduino Micro is much smaller, this controller will be modified to make a custom PCB. The Arduino Micro is a 4-layer board that operates from 5V. This controller can be battery powered, but it's recommended external power source is 7V-12V due to the on-board 5V voltage regulator.

The number of components on the Arduino Micro and the size of the Micro requires the design to be a 4-layer board. A 4-layer board adds $10 cost to each set of 3 boards from OSHPark [43]. The 4-layer boards are needed for the Micro due to its size and the two different power sources. To eliminate the extra two layers, eliminating the need for two power sources and only run the circuit from one power source will reduce the number of layers needed for the board.

To pick a single power source to power the board, a few of the design requirements was considered such as engineering requirement 1 and 18. The battery must last 5-8 hours, and the overall weight of the design must be no greater than 4oz. With a 2000mAH 3.7V rechargeable lithium battery, the weight of the battery is 1.2oz. It was also considered that this design uses 5 SpectraSymbol flex sensors [44] that has a resistance range of 10k ohms for flat resistance and a bend resistance from 60k ohm to 110k ohms. To calculate the battery life of a 5-flex sensor load, the total current consumption needed to be calculated using the voltage divider formula.

In Figure B.1, R1 is the flex sensor at a flat resistance of 10k ohms. R2 is the resistor that creates the voltage divider circuit. The total current from this single load using Equation 2

$$I = \frac{V}{R} = \frac{3.3V}{20k\Omega}$$

Equation 2 Ohm's Law

As a result, I = 0.165mA = 165 μA. As seen in Figure B.1 using Multisim [45], the current per load is 0.165 mA. Since the Max Bend Resistance Multisim Simulation design will be using at least 5 flex sensors, the total current load is 5 x 0.165mA = 0.825 mA. In Figure B.2, the flex sensor is at maximum bend of 110k **Ω**. The total current load has decreased from 0.825mA to 5 x 0.0275mA = 0.1375 mA.

Now to calculate the battery life. To calculate the battery life, all current loads from each sensor and the Bluetooth module. The Bluetooth module Adafruit Bluefruit SPI Friend [44] consumes around 15mA. Therefore, the total current with 5 sensors and a Bluetooth module is 15.825mA. Equation 1 is used to calculate the total battery life of a 2000mAh lithium-ion battery with this total load.

$$Battery\ Life = \frac{Total\ rated\ mAh}{Current\ Load(mA)} = \frac{2000mAh}{15.825mA} = 126.4\ Hours$$

This is only an estimated battery life of the 5 flex sensors and the Bluetooth module. The current load will increase as more sensors are added to the design.

Figure B.3 and Figure B.4 show the overall wireless PCB design schematic generated from Autodesk Eagle.

In the case that the wireless PCB doesn’t operate, an alternative PCB design has been considered. This design will almost be a duplicate of the Arduino Micro except with modifications. The Arduino Micro is a 4-layer board with two power sources, so to make it into a 2-layer board by getting rid of the 3.3V power supply and only run the board on a 5V supply from the USB port. By getting rid of the 3.3V power source, the board will become a 2-layer PCB. This design is cheaper and capable of supporting a larger load without worrying about the power consumption. Figure B.5 and Figure B.6 show the Eagle generated schematic, and Figure B.7 shows the board layout generated in Eagle. The board is a size of 1.80” x 2.00” which meets engineering requirement 5.

4.3.5 Glove Design

The material of the glove needs to be flexible enough to wear different hand sizes can wear it and it is easy to put on and take off especially for patients with rigid hands. The ranking of importance of the attributes for the material of the glove, were done using the AHP pairwise comparison Table B.13 shown in the appendix. The main priority is that the glove and its material do not cause any impairment or interference with movements. The next two priorities are the flexibility and smoothness of the glove. The glove should not irritate patients’ skin while performing tasks and should fit to their hand size. While the cleanability of the glove is not super important especially if it goes to mass market and people buy it just for themselves, but it is important for therapist and doctors’ offices. The cost is the lowest priority compared to the other properties.

Shore hardness is used to measure and indicate the flexibility or stiffness of a material [46], with materials being on three different scales depending on the material as seen in Figure 4.10. Shore

00 Hardness Scale is for rubbers and gels that are very soft like a marshmallow or gummy candy. Shore A Hardness Scale is for flexible mold rubbers that can be anywhere from very soft and flexible to hard and almost no flexibility, similar to a pencil eraser, rubber bands and a bottle nipple. The final scale is the Shore D Hardness Scale which is the hardness of hard rubbers, plastics, and semi-rigid plastics like PVC pipes and golf balls. Two of the most common filaments for 3D printing are ABS and PLA [47], both of which tend to be on the Shore D scale, which would be too hard for a glove and not flexible enough to do simple hand movements. TPE filament, thermoplastic elastomers filament, is a wider classification for soft materials and the popular flexible filament for 3D printing. TPE can be broken down into six different classes including TPU, TPC, and TPA [48].

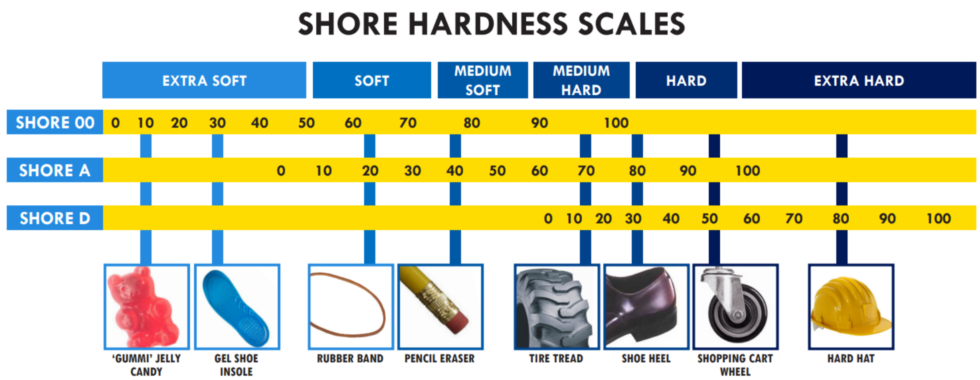


Figure 4.10 Shore Hardness Scales

Before creating the final design of the glove, the material of the glove needs to be chose. One design will be used for each material to ensure that the criteria is meet with there are no external factors being taken into consideration such as each design being varied sizes or completely different. Since the material will eventually be used to create a glove, an apple watch band design has been created in Autodesk Fusion 360 [49] as shown in Figure 4.11 following the steps outlined from Learn Adafruit [50] to see how each material wraps and feels around the wrist while doing simple tasks that will be provided during the session in the game.

Figure 4.11 Apple Watch Band Design Created in Fusion 360

To meet engineering requirement 19, the glove will need to contain a case for the PCB. This case will be 3D printed using the same filament as the glove itself. The PCB will be on a base that can be connected to straps so that the base is similar to the Apple Watch face. Figure 4.12 and Figure 4.13 illustrate the Birdseye view and top view of the base with the PCB placed in it to demonstrate how the case will work and look.

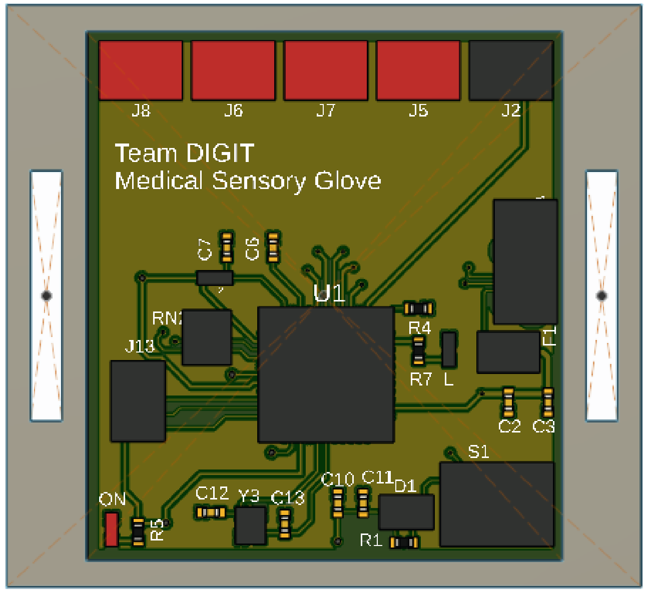


Figure 4.12 Birdseye view of base

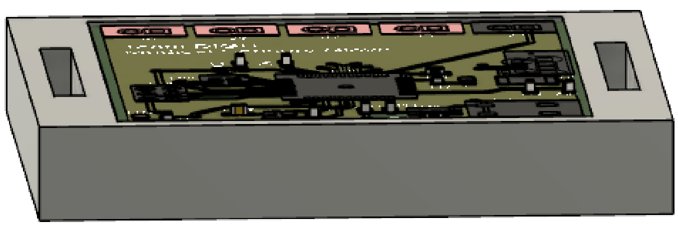


Figure 4.13 Side view of base

5 PROJECT PLAN

5.1 Work Breakdown

Table 5.1 is the workflow breakdown for the project. It provides the activities that need to be done along with a description and deliverables. Each activity has

Table 5.1 Workflow Breakdown

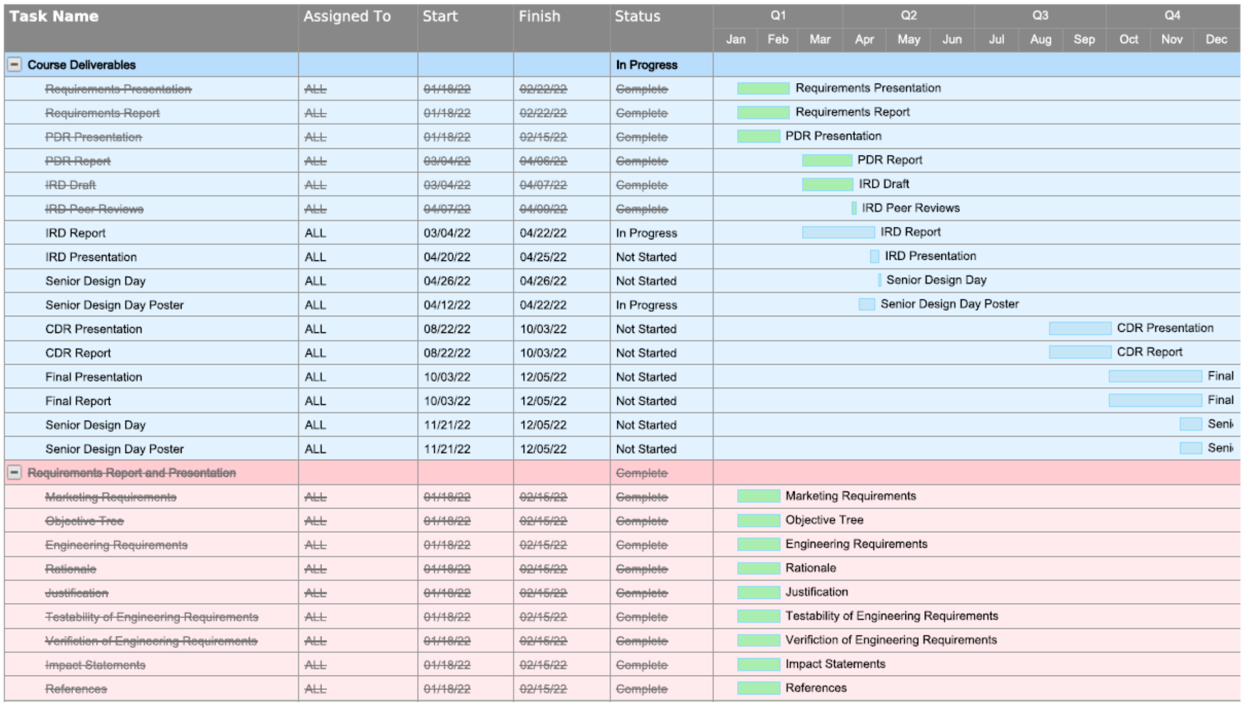
ID	Activity	Description	Deliverables	Time	People	Resources	Predecessors
1	Research						
1.1	Design of Glove	Select a material for glove	- Identify types and costs	7	-Lili	-Internet	N/A

			- Choose a material				
ID	Activity	Description	Deliverables	Time	People	Resources	Predecessors
1.2	Power Supply	Select a power supply	- Identify types and costs - Choose a power supply	7	-Lili	-Internet	N/A
1.3	PCB	Design the PCB	- Identify types and costs - Choose a microcontroller - Choose a PCB	7	-Jewell	-Internet	N/A
1.4	Sensors	Select sensors	- Identify types and costs - Choose two types of sensors	7	-Gwynne	-Internet	N/A
1.5	User Interface	Select a software package	- Identify different packages and benefits of each - Choose a software package	7	-Bobby	-Internet	N/A
2	Interface Circuity						
2.1	Purchase parts	Order and receive parts	-Place order for components -Receive parts	21	All	-Internet	1.1-1.4
2.2	Design a PCB	Use a PCB design software to create a PCB that incorporates all components for this project	-Create schematic -Create board layout	60	Jewell	-Autodesk Eagle	1.3
2.3	Purchase and	Purchase the PCB and	-Order and receive PCB	90	Jewell	-Oshpark	1.3

	integrate PCB	integrate it to the glove	-Assemble PCB			-Glove	
ID	Activity	Description	Deliverables	Time	People	Resources	Predecessors
2.4	Choose a processor chip	Select a processor chip that will satisfy the engineering requirements	--Select a processor chip	14	Jewell	-Internet	1.3
3	Secondary Device						
3.1	Create an applicatio n	Design and code an on-screen game for the patient to interact with during testing	-Design overall flow of the game -Code overall flow -Implement each individual screen within the game	90	Bobby	-PyGame -Internet	N/A
3.2	Integrate game applicatio n with data processin g applicatio n	Create a connection between the game's code and the data processing application to transfer processed data	-Establish connection between game code and data processing software -Implement the transfer of data between applications	7	-Bobby -Gwynne	-Python Integration Toolkit [26]	N/A

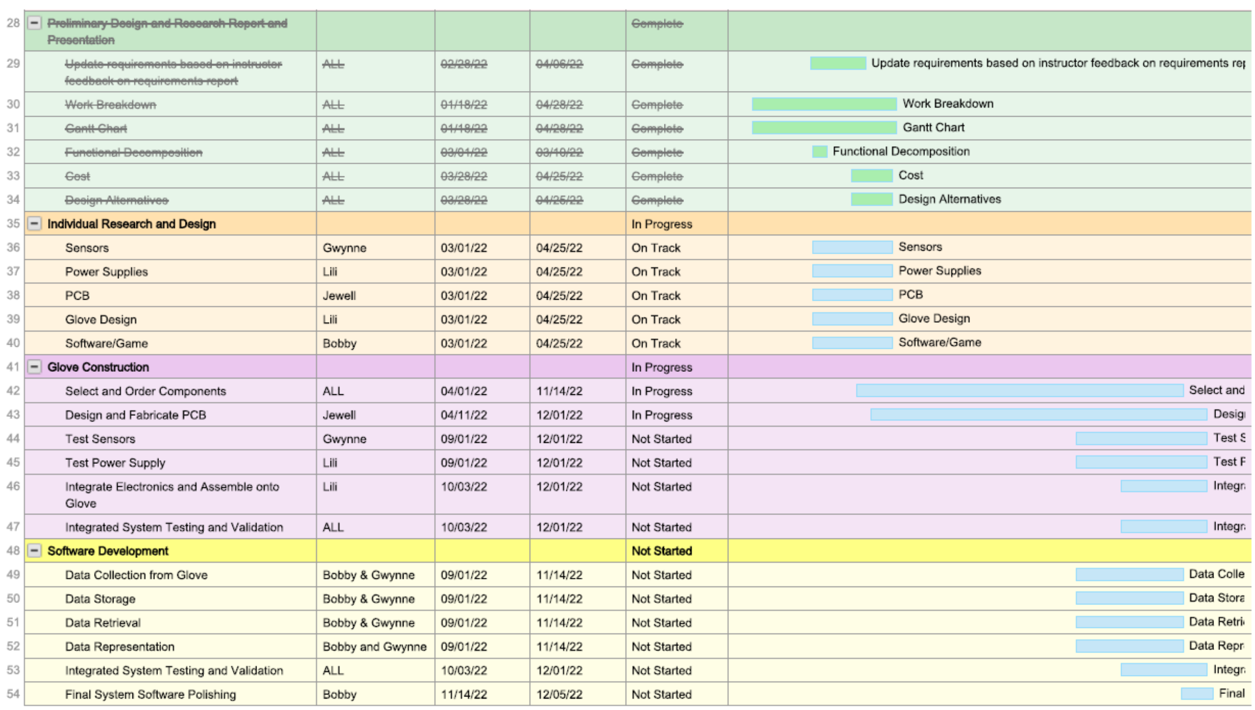
5.2 Gantt Chart

Figure 5.1 and Figure 5.2 are the Gantt chart for the entire project and were created using Smartsheet [51]. Tasks that are crossed out, have been completed. The Gantt chart starts out with the course deliverables/the main assignments for each semester. From there, the assignments have been broken down into their respective parts.



#	Task Name	Assigned To	Start	Finish	Status
1	**Course Deliverables**				**In Progress**
2	~~Requirements Presentation~~	~~ALL~~	~~01/18/22~~	~~02/22/22~~	~~Complete~~
3	~~Requirements Report~~	~~ALL~~	~~01/18/22~~	~~02/22/22~~	~~Complete~~
4	~~PDR Presentation~~	~~ALL~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~
5	~~PDR Report~~	~~ALL~~	~~03/04/22~~	~~04/06/22~~	~~Complete~~
6	~~IRD Draft~~	~~ALL~~	~~03/04/22~~	~~04/07/22~~	~~Complete~~
7	~~IRD Peer Reviews~~	~~ALL~~	~~04/07/22~~	~~04/09/22~~	~~Complete~~
8	IRD Report	ALL	03/04/22	04/22/22	In Progress
9	IRD Presentation	ALL	04/20/22	04/25/22	Not Started
0	Senior Design Day	ALL	04/26/22	04/26/22	Not Started
1	Senior Design Day Poster	ALL	04/12/22	04/22/22	In Progress
2	CDR Presentation	ALL	08/22/22	10/03/22	Not Started
3	CDR Report	ALL	08/22/22	10/03/22	Not Started
4	Final Presentation	ALL	10/03/22	12/05/22	Not Started
5	Final Report	ALL	10/03/22	12/05/22	Not Started
6	Senior Design Day	ALL	11/21/22	12/05/22	Not Started
7	Senior Design Day Poster	ALL	11/21/22	12/05/22	Not Started
8	~~Requirements Report and Presentation~~				~~Complete~~
9	~~Marketing Requirements~~	~~ALL~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~
0	~~Objective Tree~~	~~ALL~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~
1	~~Engineering Requirements~~	~~ALL~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~
2	~~Rationale~~	~~ALL~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~
3	~~Justification~~	~~ALL~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~
4	~~Testability of Engineering Requirements~~	~~ALL~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~
5	~~Verification of Engineering Requirements~~	~~ALL~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~
6	~~Impact Statements~~	~~ALL~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~
7	~~References~~	~~ALL~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~

Figure 5.1 Gantt Chart Part 1



#	Task Name	Assigned To	Start	Finish	Status
28	~~Preliminary Design and Research Report and Presentation~~				~~Complete~~
29	~~Update requirements based on instructor feedback on requirements report~~	~~ALL~~	~~02/28/22~~	~~04/06/22~~	~~Complete~~
30	~~Work Breakdown~~	~~ALL~~	~~01/18/22~~	~~04/28/22~~	~~Complete~~
31	~~Gantt Chart~~	~~ALL~~	~~01/18/22~~	~~04/28/22~~	~~Complete~~
32	~~Functional Decomposition~~	~~ALL~~	~~03/01/22~~	~~03/10/22~~	~~Complete~~
33	~~Cost~~	~~ALL~~	~~03/28/22~~	~~04/25/22~~	~~Complete~~
34	~~Design Alternatives~~	~~ALL~~	~~03/28/22~~	~~04/25/22~~	~~Complete~~
35	**Individual Research and Design**				In Progress
36	Sensors	Gwynne	03/01/22	04/25/22	On Track
37	Power Supplies	Lili	03/01/22	04/25/22	On Track
38	PCB	Jewell	03/01/22	04/25/22	On Track
39	Glove Design	Lili	03/01/22	04/25/22	On Track
40	Software/Game	Bobby	03/01/22	04/25/22	On Track
41	**Glove Construction**				In Progress
42	Select and Order Components	ALL	04/01/22	11/14/22	In Progress
43	Design and Fabricate PCB	Jewell	04/11/22	12/01/22	In Progress
44	Test Sensors	Gwynne	09/01/22	12/01/22	Not Started
45	Test Power Supply	Lili	09/01/22	12/01/22	Not Started
46	Integrate Electronics and Assemble onto Glove	Lili	10/03/22	12/01/22	Not Started
47	Integrated System Testing and Validation	ALL	10/03/22	12/01/22	Not Started
48	**Software Development**				**Not Started**
49	Data Collection from Glove	Bobby & Gwynne	09/01/22	11/14/22	Not Started
50	Data Storage	Bobby & Gwynne	09/01/22	11/14/22	Not Started
51	Data Retrieval	Bobby & Gwynne	09/01/22	11/14/22	Not Started
52	Data Representation	Bobby and Gwynne	09/01/22	11/14/22	Not Started
53	Integrated System Testing and Validation	ALL	10/03/22	12/01/22	Not Started
54	Final System Software Polishing	Bobby	11/14/22	12/05/22	Not Started

Figure 5.2 Gantt Chart Part 2

5.3 Cost Analysis

Table 5.2 outlines the total cost to produce one glove. All costs are currently estimated based on the individual research. The cost is also slightly higher than it will be as the material of the glove, is the estimate for one spool of filament, not the price for the amount of filament that will be used.

Table 5.2 Total Cost

Item	Individual Cost	Qty	Vendor	Total Cost
PCB	$ 27.32	1	Oshpark	$ 27.32
Battery	$ 12.50	2	Adafruit	$ 25.00
Battery Charger	$ 5.95	1	Adafruit	$ 5.95
Material of Glove	$ 39.99	1	Amazon	$ 39.99
Sensors	$ 12.89	8	Adafruit	$ 103.15
Total				$ 201.41

5.4 Team Member Responsibilities

Table 5.3 Team Member Responsibilities

Team Member	Primary Responsibilities	Secondary Responsibilities	Explanation of Task
Bobby Bose	User Interface	Data Processing	Designing and coding the user interface to be used with patient tests.
Jewell Catlett	PCB	Wireless Connection and Power	Designing a custom PCB to read sensor data and transfer sensor data via Bluetooth to secondary device.
Lili Petrowsky	Design of glove	Wireless Connection and Power	
Gwynne Symons Buxton	Sensors	Data Processing	Identification of sensors and appropriate data rates and signal conditioning for real-time analysis.

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APPENDIX A: Objective Tree AHP Tables

This section explains how our group obtained the weights for each branch of the objective tree (Figure 3.1). Using the analytical hierarchy process (AHP) from Appendix B in the back of the book [52], we took our marketing requirements (3.1) and categorized them into three objectives and ranked each one according to its relative importance. The geometric mean for each row is computed and totaled using the formula $GM = \sqrt[n]{\alpha_1 \alpha_2 \ldots \alpha_n}$. The weight for each row is then computed by dividing the individual geometric mean by the sum of the means. For the weighted score, the weight from each row was multiplied by the category weight.

Table A.1 Sensory Glove Category AHP

	Functionality	Performance	Usability	GM	Weight
Functionality	1	1/5	1/3	0.40	0.10
Performance	5	1	3	2.47	0.64
Usability	3	1/3	1	1	0.26
Sum	9	1.33	4	3.88	1.00

Performance of the glove is most important because the overall goal of the glove is the track and record hand movements. Without performance, the project would be an ordinary glove that does not track hand movement. The second most important category is usability. Usability comes after performance because being able to use the glove with ease, no interference, and with a goal-based game is what makes the glove a product. The last category, functionality, comes after the other two because battery, wireless, and cleanable are not completely necessary for the system to operate.

Table A.2 Functionality AHP

Functionality	Wireless	Cleanable	Battery	GM	Weight	Weighted Score
Wireless	1	1/7	3	0.75	0.17	0.01
Cleanable	7	1	5	3.27	0.73	0.07
Battery	1/3	1/5	1	0.40	0.09	0.00
Sum	8.33	1.2	9	4.43	1.00	0.10

The cleanability of the glove is essential to ensure that our product can remain hygienic. This is especially important in a doctor/therapy setting, where the glove is planned to be primarily used. Therefore, cleanable is weighted with at least five times the importance of wireless and battery. Both designing the glove to be entirely wireless and using a rechargeable battery are goals we aim to accomplish to minimize our environmental impact. We prioritize wireless over battery due to wireless also contributing to the glove's requirement to not impair hand motion during testing. Furthermore, if the glove is not wireless, then a battery is not needed as the glove would be powered from the computer. Therefore, we weigh wireless as three times as important as battery.

Table A.3 Performance AHP

Performance	Track Motion	3D Modeling	Real-time	GM	Weight	Weighted Score
Track Motion	1	3	7	2.76	0.67	0.43
3D Modeling	1/3	1	1/5	0.40	0.09	0.06

Real-time	1/7	5	1	0.89	0.22	0.14
Sum	1.48	9	1	4.06	1.00	0.64

The main objective of the glove is that it tracks the motion of the hand and wrist movements. Without this, the glove is nothing more than something the patient is wearing since it would not be providing data and feedback. For this reason, tracking motion is weighted three and six times higher than real time and 3D modeling respectively. The sponsor will be using the glove simultaneously with an EEG cap, so data needs to be streamed to a secondary device in real time with little to no lag. Hence, real time is weighted about twice as much as 3D modeling. Interest was expressed by the sponsor for the movements to be streamed onto a secondary device as a 3D model so that patients and therapists can see what is happening. However, this is not necessary for the glove to work as intended so it has a weight less than 10 percent.

Table A.4 Usability AHP

Usability	Game	Easy	No Interference	GM	Weight	Weighted Score
Game	1	1/5	1/3	0.40	0.09	0.02
Easy	5	1	7	3.27	0.73	0.19
No Interference	3	1/7	1	0.75	0.17	0.04
Sum	9	1.14	8	4.43	1.00	0.26

When meeting with our sponsor, she emphasized that a lot of patients that use the glove, have rigid hands and such little movement that the glove needs to be easy to put on. Therefore, the category of easy/removeable is weighted about four times higher than the no interference and ten times higher than the inclusion of a game. If the circuity cannot be removed and the glove is not flexible, it can be very hard to put on and take off. In addition, the glove and its components should not get in the way of patient's movements and therapy session otherwise the data may have some error and it can make the session harder than it needs to be on the patient. Eventually it is desired that the glove will be driven by a game that is on the secondary device that is goal based and provides feedback to patients based on their progress. This is something that does not have to happen, but it would be nice if we are able to achieve this, hence why it has the lowest weight out of the three categories.

APPENDIX B: Design Alternative

B.1 Sensors

In Table B.1 below, the weighted criteria on determining the best sensors to use for each type of measurement can be seen. Functionality of the sensors was weighted as the most important since data cannot be collected from the glove without a properly working sensor. The size was weighted as the next most important part of sensor criteria since the weight and size of the glove could impact a patient's hand movement and therefore interfere with the integrity of the data. Power consumption was weighted as the third most important criteria. While power consumption is important, since the glove does not have to be wireless it was less important than the other factors. Cost was weighted the lowest since it is medical equipment and the cost is not as critical as working, reliable sensors.

Table B.1 Sensor Selection AHP

Sensors	Functionality	Cost	Size	Power	GM	Weight
Functionality	1.000	7.000	3.000	5.000	3.201	0.564

Cost	0.143	1.000	0.200	0.333	0.312	0.055
Size	0.333	5.000	1.000	3.000	1.495	0.263
Power	0.200	3.000	0.333	1.000	0.669	0.118

In Table B.2 below, the weighted criteria on determining the best methods of processing the data on the glove can be seen. Accuracy and Real time processing were equally weighted since these factors are both critical to the main purpose of this sensory glove, which is to accurately read in and plot data in real time while the patient's hand is moving. Visualization was weighted as the second most important criteria since the hand motion data needs to be assessed and easily visualized to determine certain movements. Memory was weighted as the least important criteria because memory requirements for the microcontroller will be minimal.

Table B.2 Processing Technique Selection AHP

Processing	Accuracy	Real Time	Visualization	Memory	GM	Weight
Accuracy	1.000	1.000	5.000	7.000	2.432	0.424
Real Time	1.000	1.000	5.000	7.000	2.432	0.424
Visualization	0.200	0.200	1.000	3.000	0.589	0.103
Memory	0.143	0.143	0.333	1.000	0.287	0.050

In Table B.3 below, the weighted criteria on determining the best methods of collecting the data from the sensors on the glove can be seen. Compatibility and real time transfer were weighted equally as the most important since they both are involved in sending data to the secondary device. Power was weighted as the least important since the glove does not need to be wireless.

Table B.3 Collection Technique Selection AHP

Collection	Compatibility	Real Time	Power	GM	Weight
Compatibility	1.000	1.000	5.000	1.710	0.455
Real Time	1.000	1.000	5.000	1.710	0.455
Power	0.200	0.200	1.000	0.342	0.091

B.2 Power

Table B.4 Power Supply Criteria AHP

Rank		Weight	Rechargeable	Cost	Voltage	Capacity	GM	Weight
4	**Weight**	1.00	0.33	7.00	0.33	0.25	0.721	0.113
1	**Rechargeable**	3.00	1.00	6.00	2.00	3.00	2.551	0.388
5	**Cost**	0.14	0.17	1.00	0.14	0.14	0.217	0.033
3	**Voltage**	3.00	0.50	7.00	1.00	1.00	1.600	0.228
2	**Capacity**	4.00	0.33	7.00	1.00	1.00	1.563	0.237

The primary feature of the power supply is that it needs to be rechargeable, to minimize electronic waste. The power supply should provide at least 3.3 volts of power and last consecutive 60-minute sessions. The cost is not a major deciding factor when it comes to having the glove be wireless and selecting a power supply due to the fact that rechargeable batteries cost more to buy initially [53] and require a charger specifically for that battery. Table B.5 compares five different batteries in approximate weight (g), approximate size, cost of individual, nominal voltage (V), nominal capacity (mAh), and if it is rechargeable.

Table B.5 Battery Comparison

Name	Rechargeable	Brand	Cost	Approx. Weight (g)	Approx. Size	Nominal Voltage (V)	Nominal Capacity (mAh)
Lithium-Ion Battery [54]	Yes	Adafruit	$12.50	34	4”x1.4”x0.3”	3.7	2000
Lithium-Ion Battery [55]	Yes	Adafruit	$7.95	10.5	1.15”x1.4”x0.19”	3.7	500
EEMB LIR2450 Rechargeable Battery [56]	Yes	EEMB Store	$18.99	5.3	Diameter: 24.5 mm Height: 5.0mm	3.7	120
Rechargeable LIR2032 LIR 2032 3.6V Button Cell FBA [57]	Yes	Gernal	$7.19	20.13	0.79”x0.79”0.13”	3.6	Not Provided
Lithium Ion 2032 Battery Charger for Coin Cell Rechargeable Batteries LIR2032 [58]	Yes	CT Energy	$23.99	2.8	Diameter: 20.0 mm Height: 3.2 mm	3.6	40

B.3 Game

This section explains how the AHP process was used to determine the best Python game development package to use for this project. The criteria used to measure the options against each other were package simplicity, speed, and community support available. As seen in Table B.6, community support was determined to be the most important factor. This is because widely available community support results in the overall design and coding process being easier. The simplicity of the package is also an important factor. With good support however, simplicity can be less important, which is why it is ranked below it. Speed was determined to be the least important criteria. This is because although speed is important, the game we plan to design will be simple in concept and should realistically not result in any latency issues.

Table B.6 Package Criteria AHP

	Simplicity	Speed	Support	GM	Weight
Simplicity	1	3	1/3	1	0.26
Speed	1/3	1	1/5	0.41	0.1
Support	3	5	1	2.47	0.63

The package options are compared below in Table B.7, in regard to simplicity. Pygame is by far the simplest, due to being built on a previously created C library. This makes using Pygame easy to work with, since it is entirely based on just function calls. Pyglet is not as simple as Pygame, since it requires a deeper level of knowledge about what is happening behind the scenes. However, it is still easier to understand than PyOpenGL, which requires a prior knowledge of OpenGL software.

Table B.77 Simplicity AHP

Simplicity	Pygame	Pyglet	PyOpenGL	GM	Weight
Pygame	1	5	7	3.27	0.73
Pyglet	1/5	1	3	0.84	0.19
PyOpenGL	1/7	1/3	1	0.36	0.08

Table B.8 shows the comparison between the package options when looking at speed. Pyglet is known for its speed and is the fastest option available. This is followed by PyOpenGL, which itself is an enhanced version of Pygame. Pygame is the slowest option available, which is understandable due to its age.

Table B.88 Speed AHP

Speed	Pygame	Pyglet	PyOpenGL	GM	Weight
Pygame	1	1/7	1/3	0.36	0.09
Pyglet	7	1	3	2.76	0.67
PyOpenGL	3	1/3	1	1.00	0.24

Table B.9 shows the comparison between package options with regard to available community support. Pygame is scored the highest, due to having an extensive collection of documentation and tutorials. Both Pyglet and PyOpenGL do not have a large community following and are in general, much less popular than Pygame. This has resulted in them not having as much documentation easily available. PyOpenGL does benefit from being built on Pygame however, which results in it scoring higher than Pyglet.

Table B.99 Support AHP

Support	Pygame	Pyglet	PyOpenGL	GM	Weight
Pygame	1	7	3	2.76	0.65
Pyglet	1/7	1	1/5	0.31	0.07
PyOpenGL	1/3	5	1	1.19	0.28

Table B.10 shows the final package decision based on the AHP tables. Based on each option’s scores, Pygame is determined to be the best package option to use to develop the game with. Its simplicity and wide availability of community support are the main contributors in this decision. In addition, although Pygame suffers from being the slowest option available, the game we plan to develop should not require very fast software, due to its low complexity. Overall, these factors all contribute to Pygame being the best option.

Table B.1010 Final Package AHP

	Pygame	Pyglet	PyOpenGL	Weights
Simplicity	0.73	0.19	0.08	0.26

Speed	0.09	0.67	0.24	0.10
Support	0.65	0.07	0.28	0.63
Score	0.61	0.16	0.22	

B.4 PCB/Microcontroller

Table B.11 shows a summary and comparing each processor chip that was considered for this project. Some of the features worth noting are the ADC pins, operating voltage, LabVIEW compatibility, and built-in UART. The number of ADC pins are important because engineering requirement 10. The operating voltage of each processor needs to be considered because a battery voltage needs to be determined. Looking for processor chips with built-in UARTs eliminate the need to purchase a separate UART chip. Therefore, selecting a processor chip with built-in UART will save space. Selecting a processor chip that's LabVIEW compatible will satisfy engineering requirement 3.

Table B.1111 Processor Chip Comparison

Processor	Operating Voltage	ADC Pins	LabVIEW Compatibility	Built-In UART
ATMega32U4	2.7V - 5.5V	12	Yes	Yes
nRF52840	1.7V - 5.5V	8	Yes	Yes
ESP32-PICO-D4	2.7V - 3.6V	18	No	No
ATMega328p	1.8V - 5.5V	6	Yes	Yes
ATMega328	1.8V - 5.5V	8	Yes	Yes

Table B.12 shows the AHP the processor chip decision based on the AHP table and based on the processor chip comparison found in Table B.11. In Table B.12, the deciding factors of the processor chip are operating voltage, ADC pins, LabVIEW compatibility, and built-in UART. Each deciding factor was weighed in order of importance with the most weight being the most important deciding factor.

Table B.1212 Processor Chip AHP

	Operating Voltage	ADC pins	LabVIEW Compatibility	Built-In UART	GM	Weight
Operating voltage	1	1/3	1/7	1/5	0.21	0.03
ADC Pins	3	1	1/3	1/5	0.58	0.08
LabVIEW Compatibility	7	3	1	5	4.72	0.65
Built-in UART	5	5	1/5	1	1.71	0.24

Figure B.1 shows the current measurement of a single flex sensor at a flat bend using Multisim. The current measurement is used to calculate the battey life in **equation 1.**

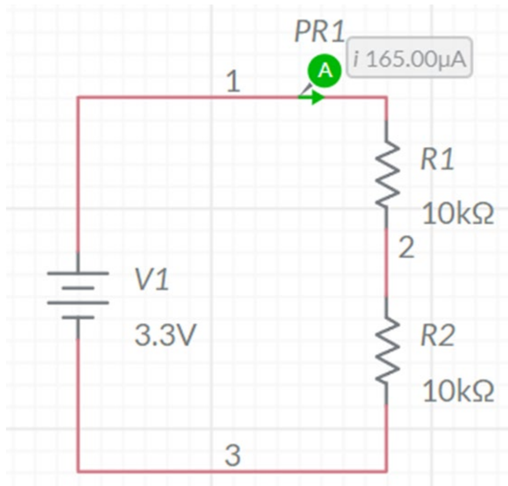

Figure B.1 Flat Resistance Multisim Simulation

Figure B.2 shows the current measurement of a single flex sensor at a max bend using Multisim. The current measurement is used to calculate the battey life in **equation 1.**

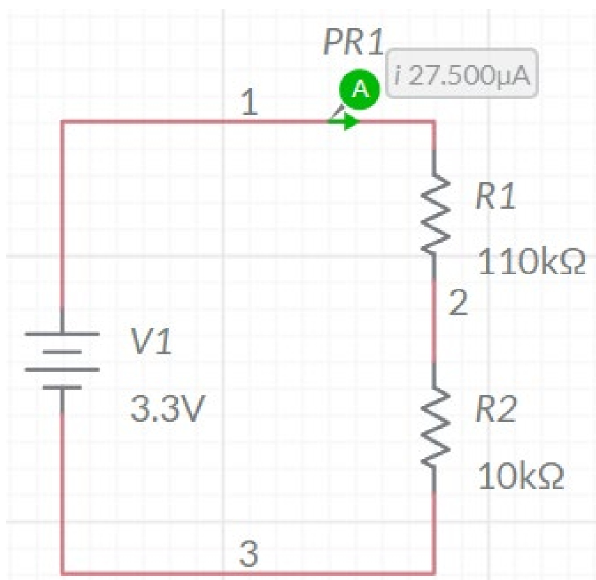

Figure B.2 Max Bend Resistance Multisim Simulation

Figure B.3 shows part 1 of the Autodesk Eagle generated schematic for the wireless PCB. The schematic shows the chosen processor chip ATMega32U4. The schematic also contains the USB port, reset button, ESD protection circuit, etc.

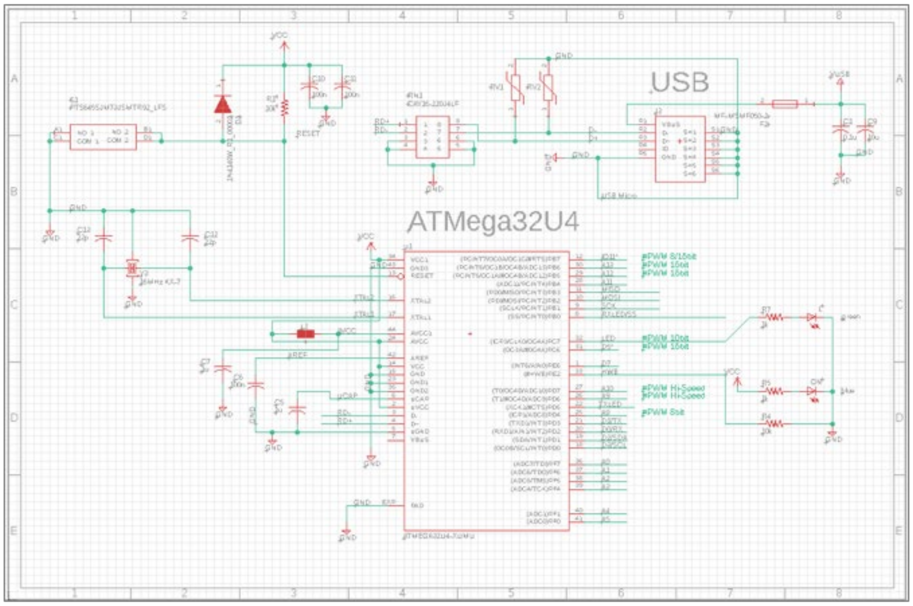

Figure B.3 Wireless PCB Schematic Part 1

Figure B.4 shows part 2 of the Autodesk Eagle generated schematic for the wireless PCB. This schematic shows the connectors for the five flex sensors, the Bluetooth connector, the power selector switch, 2x3 header pins, battery connector, and the 3.3V regulator.

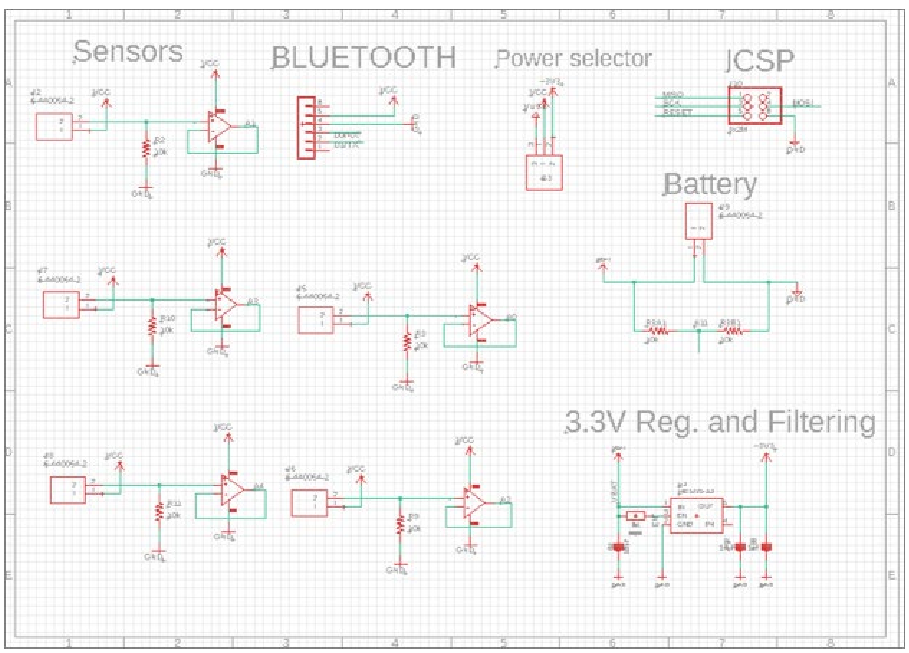

Figure B.4 Wireless PCB Schematic Part 2

Figure B.5 show part 1 of the Autodesk Eagle generated schematic for the Wired PCB. The schematic shows the chosen processor chip ATMega32U4 with the reset button and other necessary components.

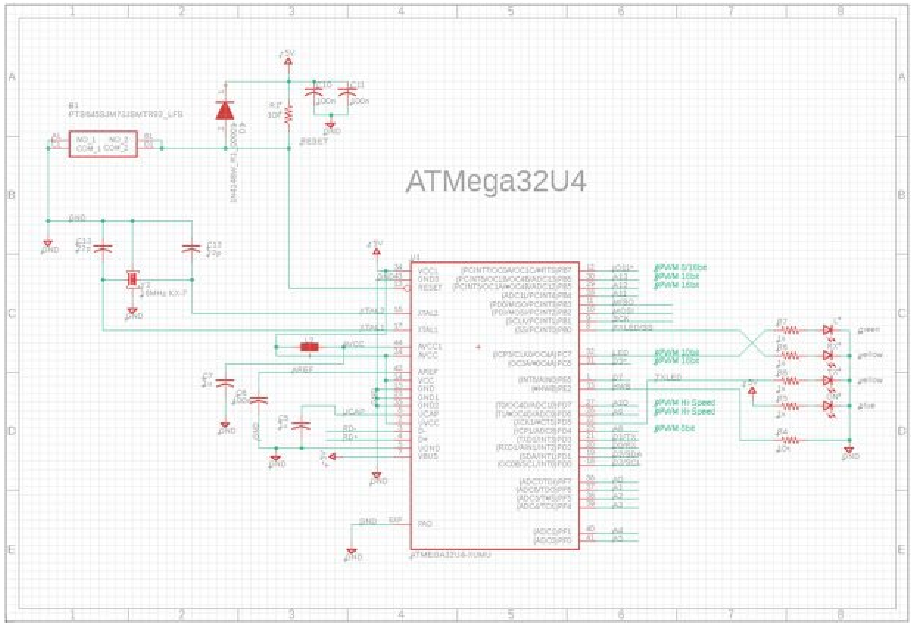

Figure B.5 Wired PCB Schematic Part 1

Figure B.6 shows part 2 of the generated schematic from Autodesk Eagle. This schematic shows the ICSP 2x3 header pins, USB port with decoupling capacitors, and the 5 flex sensor connectors.

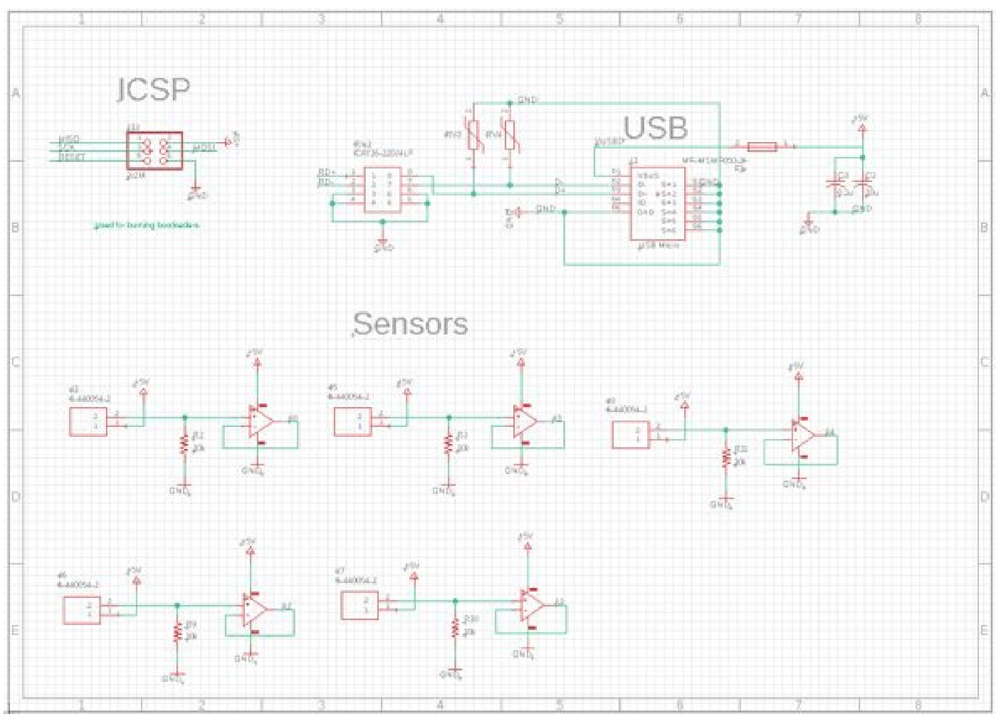

Figure B.6 Wired PCB Schematic Part 2

Figure B.7 shows the component placement and traces for the alternative PCB design. This board contains 5 sensor connectors, a USB port that supplies 5V, operational amplifiers to increase precision of the sensors, etc.

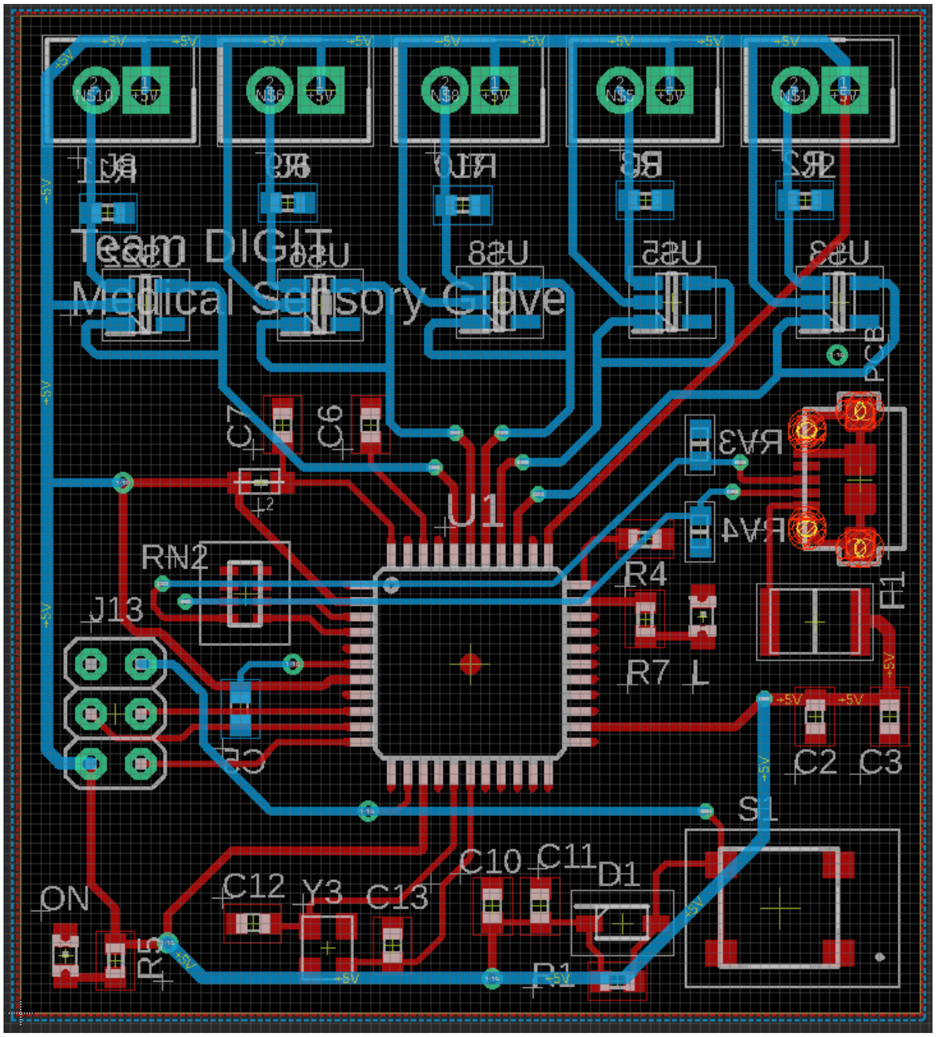

Figure B.7 Wired PCB Board Layout

B.5 Glove Design

Table B.1313 Material of Glove AHP

Rank		Flexibility	Smoothness	Cost	Cleanable	No Impairment	GM	Weight
2	**Flexibility**	1.00	2.00	8.00	4.00	1.00	2.297	0.308
3	**Smoothness**	0.50	1.00	7.00	3.00	0.33	1.285	0.172
5	**Cost**	0.12	0.14	1.00	0.25	0.11	0.517	0.072
4	**Cleanable**	0.25	0.33	4.00	1.00	0.11	0.517	0.072
1	**No Impairment**	1.00	3.00	9.00	9.00	1.00	3.00	0.417

The material of the glove is critical to the project because it needs to be flexible enough that it can it on all hand sizes and easy to put on hands that are rigid from stroke, ALS, Parkinson's, and other disorders and disabilities that cause hand impairment. The material should not cause irritation to the while the user is wearing it and performing the tasks on prompted during the game. If the glove is used in a therapist's office or in a setting where multiple people use the same glove, it needs to be easy to clean the glove. The main attribute of the glove and the material of the glove is that it should not interfere with the patients' movements or hinder them in any way. The material of the glove should not be too heavy or bulky. Table B.14 compares four different flexible filaments in cost, diameter, and shore hardness.

Table B.1414 Material of Glove Comparison

Name	Brand	Cost	Diameter	Shore Hardness
TPU [59]	SainSmart	15.99	1.75 mm	95A
Flexible PLA+ [60]	ATARAXIA Art	39.99	1.75 mm	89A
TPC [61]	Digi-Key	39.99	1.75 mm	95A
TPE [62]	Digi-Key	29.99	3.00 mm	Not Provided