Critical Design Report

TEAM 24 – DIGIT

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1 ABSTRACT

This paper presents an analysis of the critical design delineating the ongoing development of the medical sensory glove designed by Team DIGIT. Team DIGIT will design and construct a sensory glove for the purpose of tracking real-time motion of the fingers 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. The report begins with the problem statements and requirements that were developed at the beginning of the project to guide Team DIGIT in the design and build of the glove. The only change to the requirements was removing the wrist movement from marketing requirement one after talking to our sponsor, as the tracking of wrist movement was important for the previous versions of the glove for basketball shot tracking but is not necessary for the medical sensory glove. Subsequently, the subsystem design and design summary are discussed

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, spinal cord injuries, or have 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 fingers, 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.

2.3 Background

It is estimated that one in four adults over the age of twenty-five 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 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 awfully 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 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 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 Appendix A

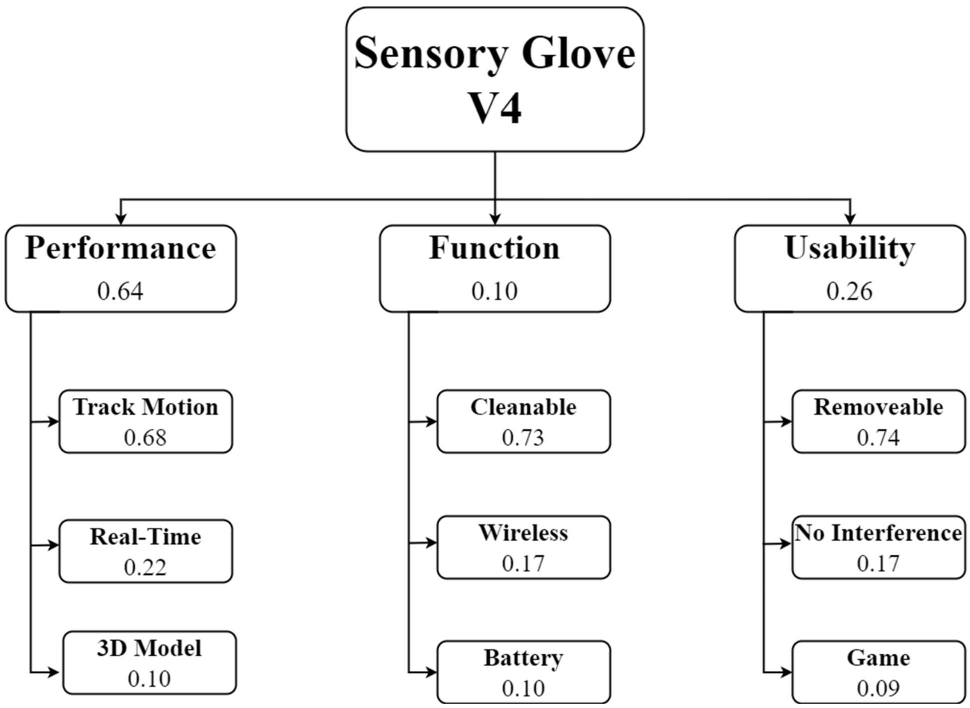

Figure 3.1 Objective Tree

3.3 Engineering Requirements

The following table defines the Engineering Requirements (ER) related to this project. Each Engineering Requirement represents an attribute of the glove and/or software that is derived from at least one of the Marketing Requirements. The corresponding justifications are provided to clarify the Engineering Requirement's importance to the overall project.

The following Engineering Requirements are color coded to show the progress of satisfying each requirement. The colors green indicates the requirement has been tested and verified to work; Yellow indicates the requirement is being tested; Red indicates the requirement has not been tested yet. The details of the testing can be found in Subsystem Testing.

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 one hour, the battery life should last 5-8 hours

No.	MR	Engineering Requirements	Justification
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	Shall be programmed in LabVIEW, Python, or MATLAB.	The sponsor required that our code is written LabVIEW, MATLAB, and 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.
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 display 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 the glove is currently not being used.
10	1	Shall contain a minimum of 8 sensors	This allows motion tracking with all 5 fingers and adduction/abduction movement. Our sponsor will be using 5 flex sensors and 3 pressure sensors.
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	The 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	The secondary device shall provide positive feedback when the patient correctly follows commands	Allows patients 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.

No.	MR	Engineering Requirements	Justification
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.
17	1, 3	The secondary device shall display commands to instruct the 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 the glove from the 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 Requirement 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 the secondary device simultaneously.
8	Should be displayed in 3D motion	Check that the 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 data points the glove can receive in one second of testing.
12	Glove should use Bluetooth or Wi-Fi	Check that glove has the capability to transmit data over either technology.
13	Glove should be powered by a rechargeable battery	Deplete the battery completely, and then charge until full again and check the battery level to confirm.
14	Secondary device shall provide positive feedback when the patient correctly follows commands	Run an instance of the game and test that when a command is 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 the 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. Electronic waste is a term used to describe electrical devices that are at or near the end of their lifetime. It is possible to dispose of this waste in specific ways to allow it to be recycled and reused in the future. However, most people do not do this. Since this product is intended to be marketed to the general public, it cannot be expected that everyone will comply with electronic disposal procedures. Therefore, 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. 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. The parts picked for the prototype will allow the sponsor and mentor to choose different sizes and type of connectors. For example, the on-board connectors are a 2mm pitch male connector. Any other 2mm pitch male connector may be replaced with the original connector; (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. The detailed documentation will include ECAD files, bill of materials (BOM), block diagrams to determine which sensor connects to which pin for the software development, and instructions for assembly of the device.

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. Furthermore, while our glove game application is intended to help with data collection, it could spawn a new application for general gaming.

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 directly impacts accessibility, and this lack of accessibility can negatively impact patient care. Developing a sensory glove that is inexpensive benefits both medical facilities and patients. Inexpensive equipment is accessible to a greater number of care providers which, in turn, provides more accessibility to a greater number of patients while also reducing overall costs. Because the glove is intended to be used as medical equipment, it is important that it provides accurate and reliable data. Inexpensive sensors and materials need to be thoroughly examined to determine if they will be accurate, repeatable, and reliable. Other aspects of cost are reusability and repairability. If cheaper sensors are accurate but less durable, it may be possible for sensors to need replacing after one or a few uses. Providing a mechanism for component removal and replacement would also allow the glove to be disassembled for cleaning and reuse.

4 DESIGN

4.1 Design Summary

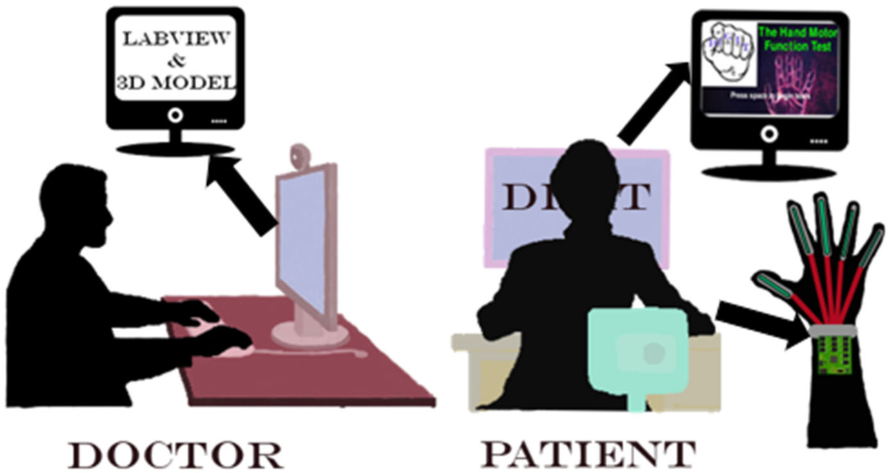

Figure 4.1 Testing Setup

The Medical Sensory Glove is intended to be used in therapy sessions with a patient. It will be interfaced with an external EEG cap that is used to monitor brain activity correlated with hand movement data. The cap is not being created by this team and will be connected later. The secondary device, which is a computer, is required for the sessions. Figure 4.1 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. Typically, each session lasts 2 hours, but can vary per patient.

Before testing, patients will put on the glove, which is also connected to the secondary device. How long this takes depends on the patient and their hand impairment, but it can be up to 30 minutes. Randomly selected tasks will be chosen for the patient to try and complete and will be displayed on the patient's screen. They will have 10 seconds to attempt each task. Data from the sensors on the glove will be continuously streamed in real-time during this period. If the patients are successful in completing a task, they are awarded points 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.

As part of the initial design of the project, we were asked to create a 3D model of the hand using the sensor data, as indicated by Engineering Requirement 8. At this point in the project, we have decided to not focus on this anymore, due to the time it would take to learn how to develop it, and the other, more essential requirements that still need to be completed. Despite this, the Engineering Requirement has been kept in order to indicate for future users or development teams, that this is something the sponsor was interested in.

4.2 Functional Decomposition

4.2.1 Level 0

Figure 4.2 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 4.2. The functional requirements are given in Table 4.1. Finger movements are inputs into the system that are used to determine the bend of the fingers 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 Movement
Outputs	• 3D Model • Battery Level • Movement Data • Next Task • Feedback
Functionality	Records finger motion which is then stored as a text file for data analysis. Then the data is used for a command-prompt game.

4.2.2 Level 1

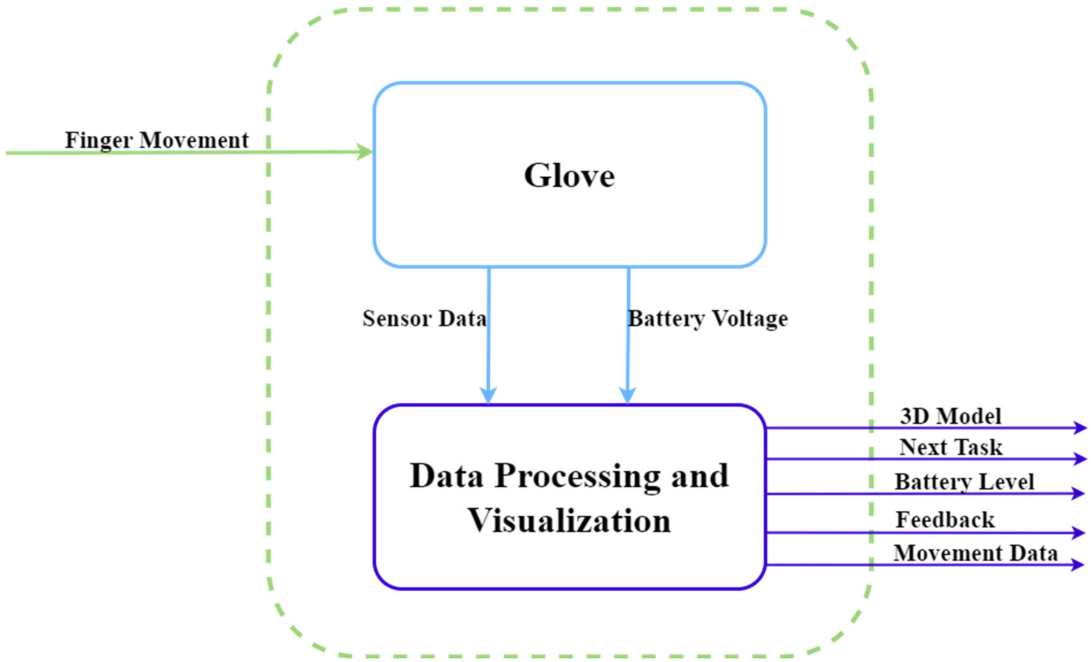

Figure 4.3 Sensory Glove Level 1

Level 1 of the functional decomposition visually describes the overall functionality of the medical sensory glove broken down into two sub systems which are display in Figure 4.3. Finger movements are inputs into the glove subsystem that are used to determine the bend of the fingers. 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 Movement
Outputs	• Sensor Data • Battery Voltage
Functionality	Measures finger movement, collects the raw data, and then transmits the data to the secondary device.

Table 4.3 Data Processing and Visualization Functional Decomposition Level 1

Module	Data Processing and Visualization
Inputs	• Sensor Data • Battery Voltage

Module	Data Processing and Visualization
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.

4.2.3 Level 2

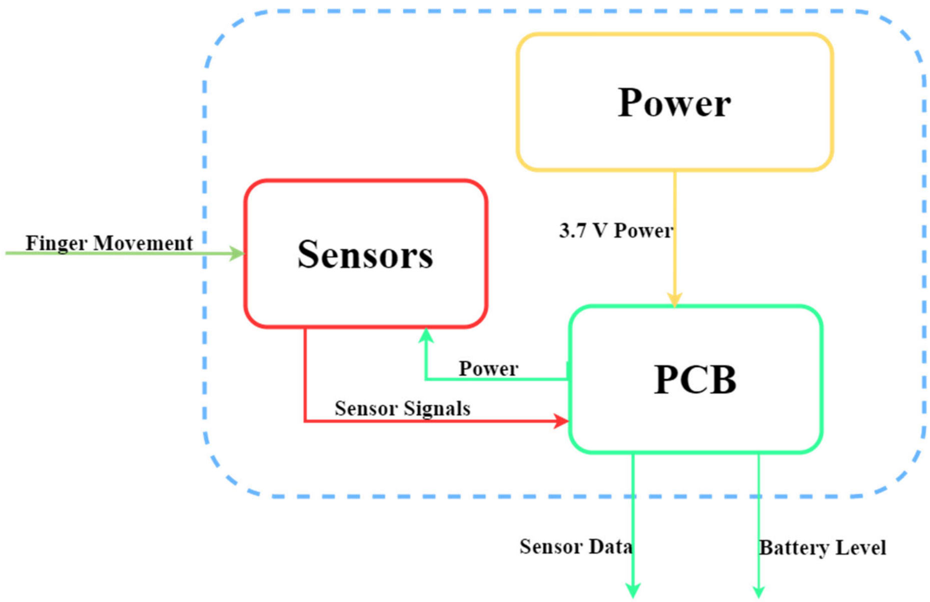

Figure 4.4 Glove Level 2

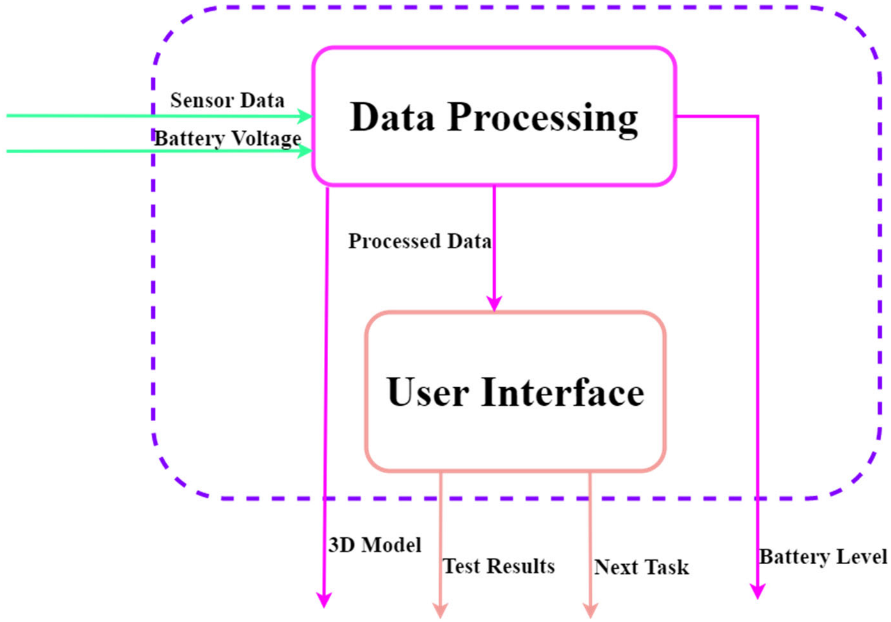

Figure 4.5 Data Processing and Visualization Level 2

Level 2 of the functional decomposition separates the glove and the secondary device into their respective subsystems, as depicted in Figure 4.4 and Figure 4.5. 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

Module	PCB
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 Movement • Power
Outputs	• Sensor Signals
Functionality	Measures finger 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

4.3 Software Flow

Figure 4.6 shows the overall flow for patient testing. When the session starts, the game begins on the title screen, displaying the game title and other important information. Afterwards, the game moves to a help screen, displaying information about how the testing works, and how to earn points. Once the patient is ready, the first test suite and first task are loaded, and the game moves on to 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. During this time, the sensors on the glove are continuously sending data from the PCB to LabVIEW, where it is processed and then sent to the game's code. Within the code, the sensor data is compared against a preset benchmark for the task. If the patient is successful in performing the task, they are shown a task success screen, and are awarded points. Points are earned both through the successful completion of a task, as well as how fast the patient completed the task.

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 game moves on to the next test suite. If there are no more test suites, then the final screen is displayed, showing the patient their point total.

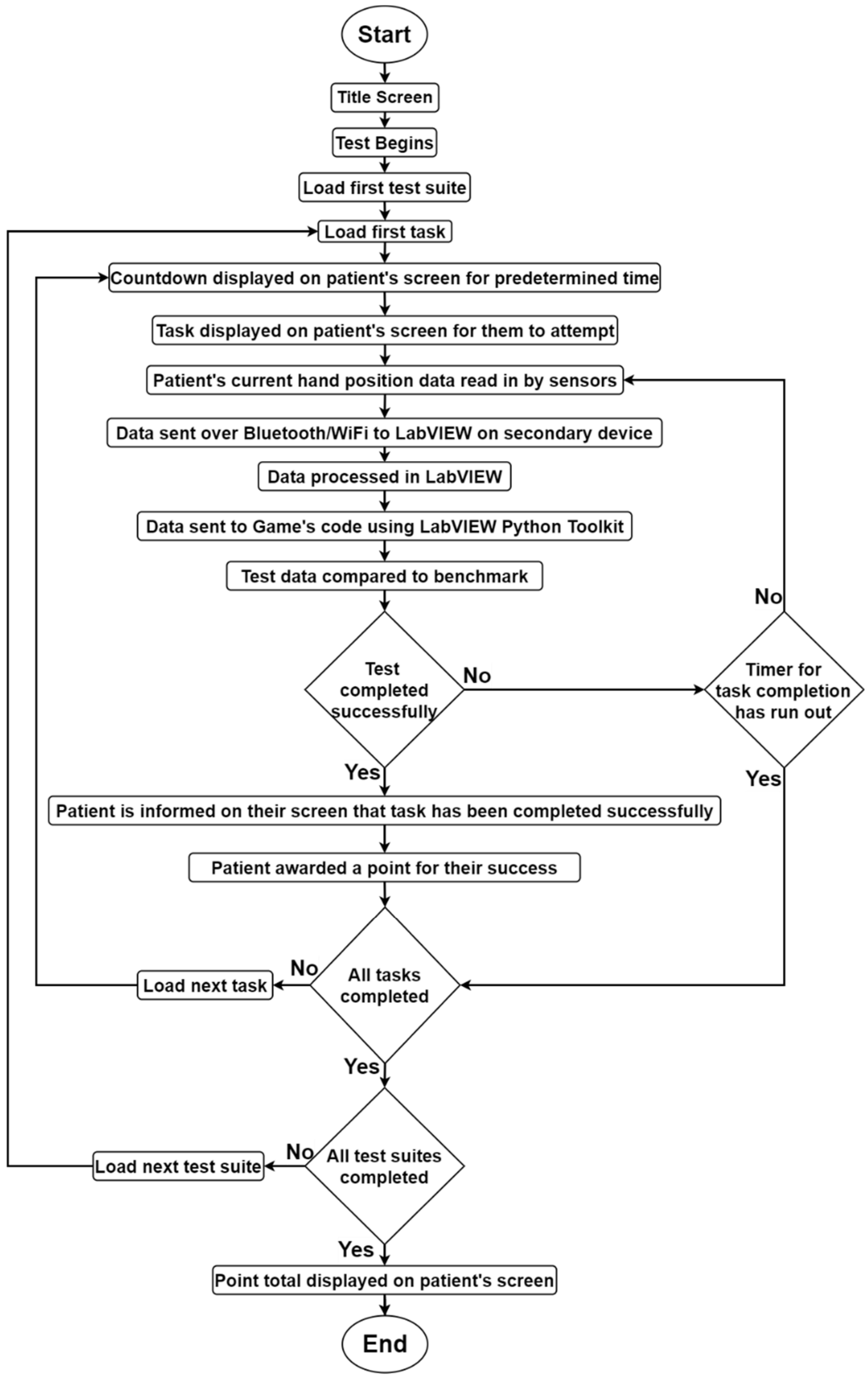

Figure 4.6 Overall Test Flow

4.4 Subsystem Description

4.4.1 Glove Design

4.4.1.1 Material of Glove

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 4.9. 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.

Table 4.9 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	2.30	0.314
3	Smoothness	0.50	1.00	7.00	3.00	0.33	1.28	0.175
5	Cost	0.13	0.14	1.00	0.25	0.11	0.22	0.030
4	Cleanable	0.25	0.33	4.00	1.00	0.11	0.52	0.071
1	No Impairment	1.00	3.00	9.00	9.00	1.00	3.00	0.410
Sum		2.88	6.47	29.00	17.25	2.55	7.32	1.00

Shore hardness is used to measure and indicate the flexibility or stiffness of a material [17], with materials being on three different scales depending on the material as seen in Figure 4.7. Shore 00 Hardness Scale is for rubbers and gels that are exceptionally soft like a marshmallow or gummy candy. Shore A Hardness Scale is for flexible mold rubbers that can be anywhere from unbelievably 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 [18], 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 [19].

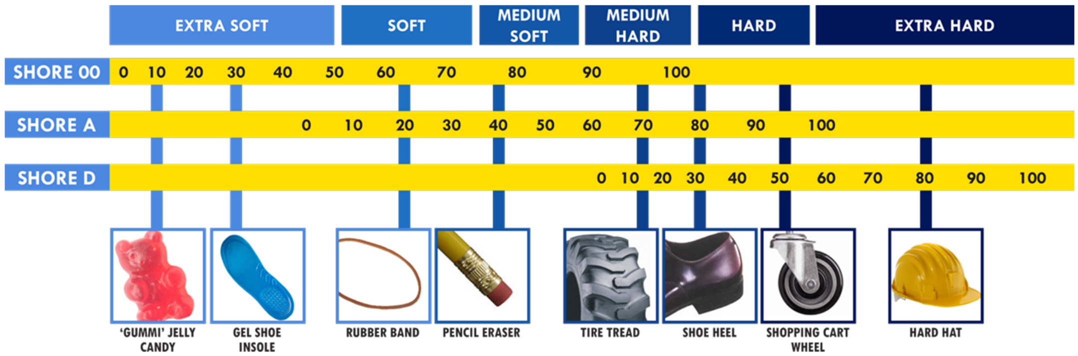

Figure 4.7 Shore Hardness Scales **[17]**

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 [20] as shown in Figure 4.8 following the steps outlined from Learn Adafruit [21] 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 4.8 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 4.9 and Figure 4.10 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.

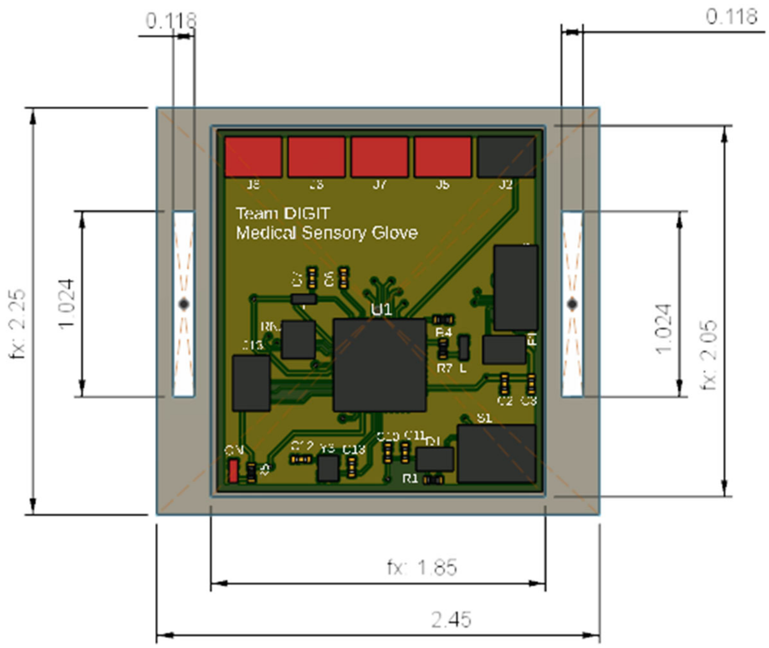

Figure 4.9 Birdseye View of Base

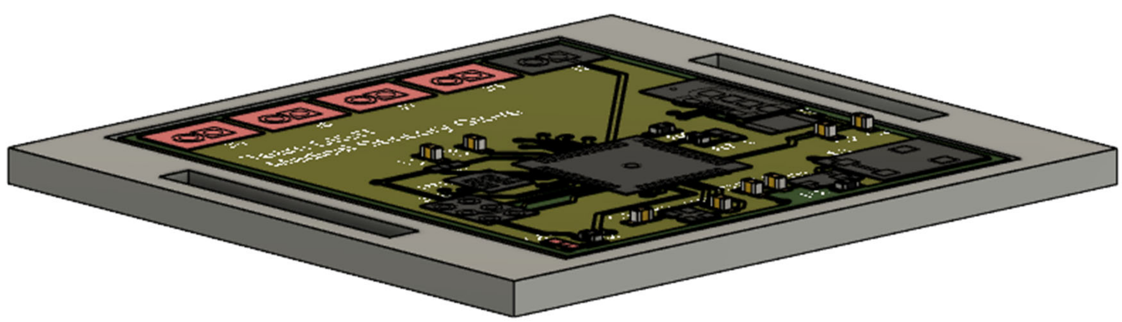

Figure 4.10 Side View of Base

4.4.1.2 Design of Glove

Team DIGIT is changing the type of glove being made from a basketball shot tracking glove to a medical sensory glove for stroke and hand impairment rehabilitation. The previous iteration of the glove by Team SCREEN was made with a fingerless glove, which was a stretchy knit winter glove [8]. 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. Depending on the severity of a patient's hand impairment, it can be difficult to put the glove on. After talking with our sponsor, she expressed an interest in having an exoskeleton glove that would just be on top of the hand with straps to hold the glove to the hand around each finger. Table 4.10 is showing the three main characteristics that the glove should have. With our sponsor putting emphasis on how hard it can be to put a glove on a patient that has limited mobility, ease of putting the glove on is weighted the most. Due to every patient having different sized hands, flexibility of the glove to fit multiple sizes and stretch over a hand while not being too tight was the next most important characteristic of the glove. Finally, the glove should be comfortable and not cause chafing or itchiness to the patient while doing the tasks asked of them as they will be wearing the glove for at least two 60-minute sessions.

Table 4.10 Design of Glove AHP

	Flexibility	Ease of putting on	Comfort	GM	Weight
Flexibility	1.00	0.25	2.00	0.79	0.218
Ease of putting on	4.00	1.00	3.00	2.29	0.631
Comfort	0.50	0.33	1.00	0.55	0.152
Sum	5.50	1.58	6.00	3.63	1.00

Table 4.11 compares an exoskeleton glove, fingerless glove, and fingered glove based on the characteristics in Table 4.10. For each characteristic, each glove is numbered one through three with one being the best and three being the worst of the three. When the columns are averaged, it shows that given the characteristics Team DIGIT is looking for in a glove, the exoskeleton is the best, followed by the fingerless glove.

Table 4.11 Glove Design Comparison

	Exoskeleton	**Fingerless**	**Fingered**	**Weights**
Flexibility	1	3	3	0.218
Ease of putting on	1	2	3	0.631
Comfort	2	1	1	0.152
Average	1.33	2	2.33	

To start out with designing the glove, different types of existing 3D printed hands/gloves were researched on Thingiverse [22] and Printables [23]. The Flexi Hand [24] shown in Figure 4.11 is a popular design when searching for flexible hands. While this is not a glove it was used to get an idea of how to print something that bends like the fingers on a hand should. The team considered making a thinner version of the flexi hand to sit on top of the hand but struggled with figuring out how to secure it to the hand of the patient. The next thing researched was 3D printed gloves which provided a lot of gauntlet type designs [25] like Figure 4.12 and Figure 4.13 however most of the designs were to worn with the person's hand in a fist sitting in the palm area of the 3D printed glove. The other type of design that results from searching 3D printed gloves is the Iron Man Glove [26] shown in Figure 4.14. This design is intended for a person to be able to put their whole hand inside and move around with no trouble. However, this design would be hard to make so that it fits multiple sizes of hands as it would most likely be too tight or too loose on different patients if printed as one size, but the wrist and palm part of the design provided ideas for ways to encase the PCB while keeping it out of the way of the patient.

Figure 4.11 Flexi Hand

Figure 4.12 Gauntlet Glove

Figure 4.13 Gauntlet Glove Palm Up

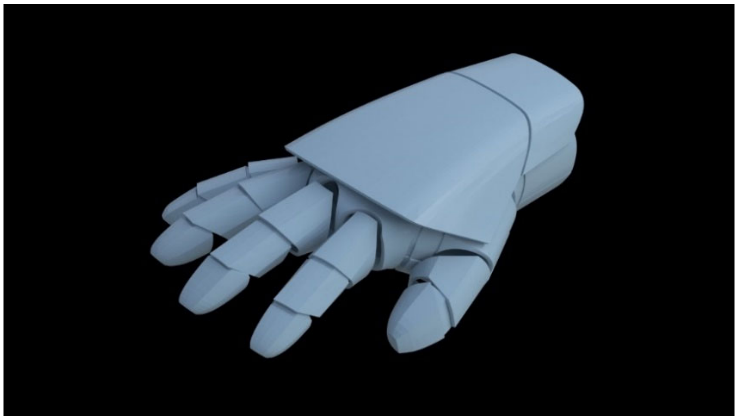

Figure 4.14 Iron Man Glove

Our sponsor, Madison Bates, shared some research articles and publications that she had read about 3D printed gloves that were really useful because they were designed specifically for medical uses like what Team DIGIT is trying to create. The most helpful article that she provided showed that what Team DIGIT was trying to create was possible and helped aid in creating a better design than what Team DIGIT had been creating. The article was from an IEEE Engineering in Medicine & Biology Society Conference [27] which showed a 3D printed exoskeleton glove made from TPU. This glove has the sensors and wires embedded into the material as they paused the printer to insert the flex sensors and wires. While this is an amazing concept, they took multiple measurements on one person’s hand so the glove could be custom fitted and the wires and sensors could be the exact length that is needed. Team DIGIT does not think it will be able to embed the sensors as the glove needs to fit multiple sizes of hands, but this article provided ideas of how to hold the sensors to the patient’s hand and make it flexible at the same time.

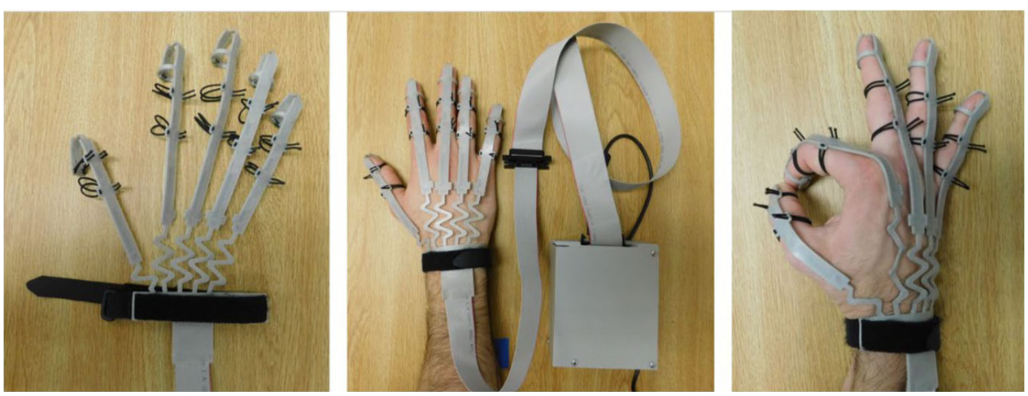

Figure 4.15 3D Printed Exoskeleton Glove

4.4.2 PCB

The PCB design targets to meet Engineering Requirements 3, 4, 5, 6, 9, 10, and 18. Since Engineering Requirements 1 and 2 are shoulds, this design focuses on producing a stable and cost-efficient custom PCB that satisfies the shalls of the Engineering Requirements. Therefore, the PCB will be a wired connection. The goal is to design and create a small-scale light-weight custom PCB that LabVIEW [28] can target. The sponsor of team DIGIT, Madison Bates, used National Instrument’s USB-6211

[29], which is a Multifunction I/O Device, that weighs a total of 7.2 oz. This device is far from meeting the engineering requirement 18. However, a LabVIEW add-on was discovered which allows LabVIEW to target Arduino boards. Additionally, Arduino offers Autodesk Eagle [30] CAD files to the community so that Arduino based custom PCBs can be developed. There are many different types of Arduino microcontrollers to consider. A few worth noting is Arduino Micro [31], Arduino Nano [32], Arduino Uno Rev 3 [25], and Arduino Nano 33 BLE [33].

As mentioned earlier, this design will focus on the shalls of the Engineering Requirements. Engineering requirements 1 and 2 are shoulds that implement a wireless battery powered PCB. Since the patient using the medical sensor glove will be seated and wired up to an EEG cap, a wireless PCB wouldn't make a huge difference, it would only add weight to the device due to the battery (the battery weighs 1.2oz). The wireless PCB will need to be operated at 3.3V to keep the weight of the battery relatively low so that it is not intrusive to the patient. Additionally, there is concern for the battery life and stability of the clock speed of the microchip as the battery depletes. For example, according to the ATMega32U4 datasheet, the operating voltage of a 16Mhz crystal requires a continuous 4.15V minimum. Therefore, the clock speed of the microchip would need to be downgraded to a much lower crystal. The next standard external crystal is 8MHz. The minimum operating voltage for this clock speed is 2.4V. The last concern for this design is the battery life. To calculate the battery life, the total current consumption would need to be calculated. A Bluetooth module to connect to the software to send data readings. The Bluetooth module that was considered for this design was the Adafruit Bluefruit SPI Friend [34] that consumes around 15mA. The flex sensors from SpectraSymbol have a flat resistance of 9k ohms have a current draw of 0.17368 mA as seen from the Multisim [35] simulation in Figure 4.16. Lastly, the ATmega32U4 can consume up to 200 mA from the power source. Therefore, the total current draw would be $I_{total} = 11\ x\ 0.17368 + 15\ mA + 200\ mA = 216.91\ mA$. Equation 1 is used to calculate the total battery life with the total load.

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

Equation 1: Battery Life

Using the battery life equation, equation 1, the total battery life of a 2000mAh would be $Battery\ Life = \frac{2000mAh}{216.91mA} = 9.22\ Hours$ until the battery is completely drained. While this is enough for the ATMega32U4 and 8Mhz crystal, the concerning part is whether the 3.3V LDO regulator will have enough power. The maximum dropout voltage (the supplied current must be greater than the 3.3V + 450mV to produce a clean 3.3V from the regulator) for MIC5225-3.3 is 450mV. Therefore, a larger battery voltage would be required to have a wireless PCB, and that means adding more weight to the glove. So, the medical sensory glove will consist of a wired PCB to satisfy the engineering requirements.

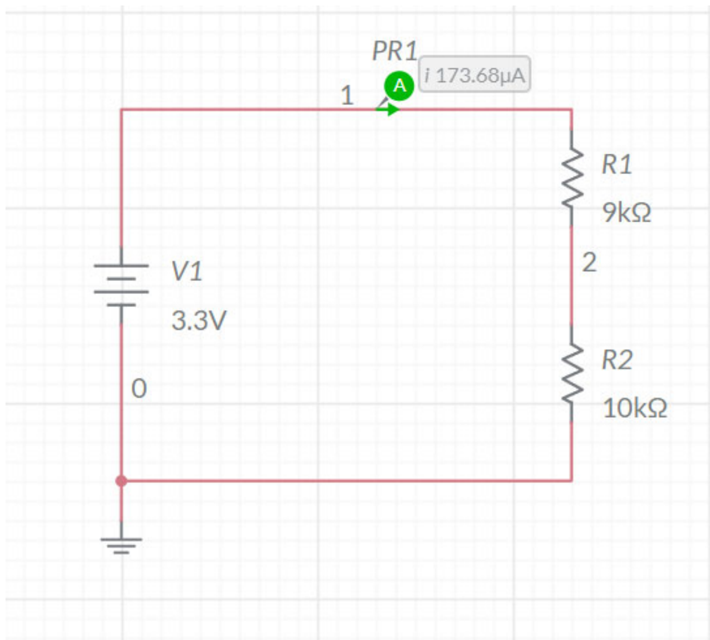

Figure 4.16 Multisim Flex Sensor Simulation

4.4.2.1 Microcontroller

The brain of a PCB is the microchip. When designing a custom PCB to fit the needs of the requirements and the sponsor, a few things must be considered. First, the number of ADC pins must be taken into consideration. The sponsor has requested a minimum of 8 sensors but has plans to upgrade to 10 sensors. Since the PCB will be wired to a computer via USB, the operating voltage range isn't a big factor in choosing a microchip since the USB provides a consistent 5V to the system. Next, the microchip must be LabVIEW compatible (able to be targeted by the software). Lastly, the microchip must have a built-in UART for this will save space and cost for buying a separate UART chip. Table 4.12 summarizes the different specifications for each microchip along with the Arduino controllers that uses it. Given the table below, the microchip that satisfies these requirements is the ATMega32U4. The AHP table, Table B.10 in Appendix B shows the importance of each feature.

Table 4.12 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

The custom ATMega32U4 QFN44 PCB was designed to contain and measure 11 resistive sensors. The overall design of the PCB consisted of components selected to operate the medical sensory glove efficiently and safely. The following is a detailed description of each component selected.

Each sensor for this project has a 2-pin, 2mm pitch male, wired-to-board connector. This connector is in a voltage divider circuit to calculate the resistance of the sensor. The fixed resistor in the voltage divider circuit is a surface mount 0603 resistor. Given the component size selected is a market standard size, this will give the sponsor the ability to select different fixed resistor values for the voltage divider circuit. The sensors the medical sensory glove will use are flex sensors and potentiometers. This design includes a 3x2 header pins for AVR boot-loading in the case that the PCB malfunctions. To enable this feature, the pins SCK, MISO, and MOSI must be accessible. The pin AVCC must be connected to a low pass filter to enable the supply voltage pin for all A/D converter channels on the ATMega32U4. The PCB has two 0603 LED chips used as indicators for debugging purposes. The on-board USB reciprocal is connected a 2A fuse in the case of a surge from the PCB to protect the computer. Additionally, two varistors are connected to the data pins of the USB as ESD protection to protect the device from current surges. Varistors are voltage-dependent resistors. When the voltage across the varistor exceeds a certain value, the resistance falls to a low value and allows a current to flow, thus providing overvoltage protection to the device. Furthermore, the PCB contains a 16 MHz external crystal. An external crystal is what determines the clock speed of the microchip. This crystal requires an operating voltage of at least 4.15V to stabilize the external crystal. Additionally, this circuitry also has two decoupling capacitors on the crystals to keep the power to the crystal stable. Figure 4.17 is the Eagle schematic. Figure 4.18 is the Eagle board layout, and Figure 4.19 is the 3D model of this PCB.

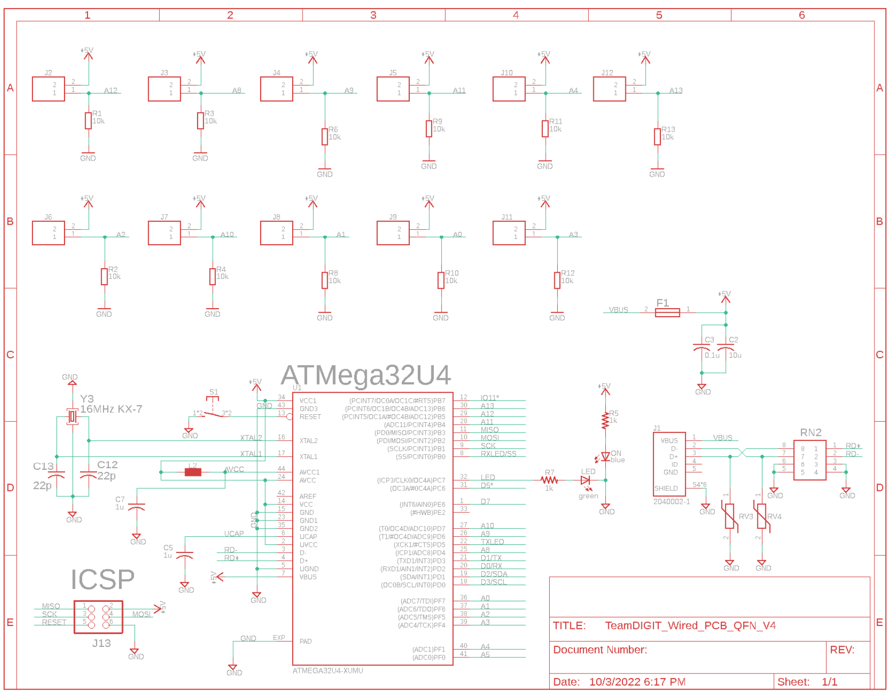

Figure 4.17 Eagle Schematic

The PCB layout of this design is a 4-layer board with dimensions 1.4” x 1.6”. The goal is to design a board that is within the dimensions of 1.95” x 2.0” since that was the previous version’s dimensions. To achieve this, the board must be 4 layers.

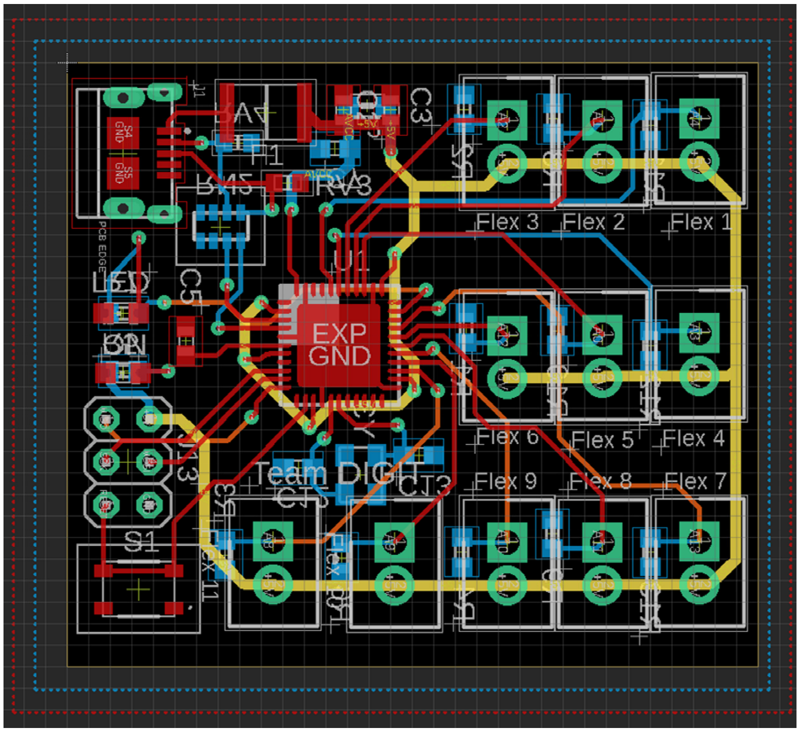

Figure 4.18 Eagle Board Layout

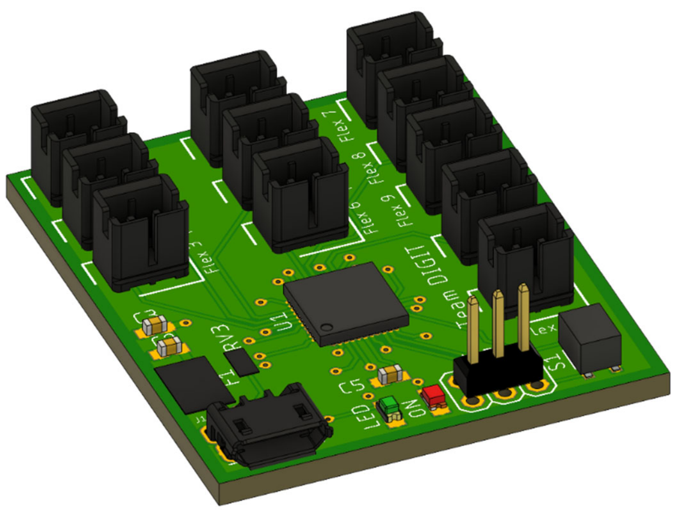

Figure 4.19 3D Model of PCB

4.4.3 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 in Table 4.13 below.

Table 4.13 Power Supply Criteria AHP

Rank		Weight	Rechargeable	Cost	Voltage	Capacity	GM	Weight
4	Weight	1.00	0.33	7.00	0.33	0.25	0.72	0.108
1	Rechargeable	3.00	1.00	6.00	2.00	3.00	2.55	0.383
5	Cost	0.14	0.17	1.00	0.14	0.14	0.22	0.033
3	Voltage	3.00	0.50	7.00	1.00	1.00	1.60	0.241
2	Capacity	4.00	0.33	7.00	1.00	1.00	1.56	0.235
Sum		11.14	2.33	28.00	4.47	5.39	6.65	1.00

For the overall project, an environmental design impact was discussed on how we hoped to minimize our electronic waste by using rechargeable batteries if the PCB was going to be wireless. 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.

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.4 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 a wireless PCB that 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. As discussed in section 4.4.2, Team DIGIT has determined it is not reasonable to make the glove wireless since the patient is already sitting down in front of the computer and will be connected with multiple wires for the EEG cap.

4.4.4 Sensors

Various sensors were investigated to determine if they would be good for measuring the bend of fingers and/or the separation of fingers. The sensors examined for finger bending motion included flex sensors which were used on the previous version of the glove and a Conductive Rubber Cord Stretch Sensor from Adafruit [36]. For finger separation, the sensors that were investigated were two range finding sensors, the Adafruit Time of Flight Distance Sensor [37] and the Adafruit Proximity and Lux Sensor [38], and a potentiometer-based sensor. Flex sensors have been chosen to be used on the glove to measure the finger bending motion.

The flex sensors were chosen to measure finger bend. Flex sensors were the easiest to test and implement into the glove. They have repeatable measurements for relative motion. Five flex sensors, one for each finger, were tested to verify their ability to measure the movement of each finger. These five flex sensors were set up and connected to the Arduino micro. Then, as seen in Figure 4.20, five traces were 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. The flex sensors were chosen as the sensor to measure finger bending based on the criteria in the AHP Table B.1 in Appendix B. The flex sensor compared to the other sensors can be seen in Table 4.14. One consideration was the size of the sensor. The flex sensors are very thin and lightweight, which allows it to measure finger bend without interfering with the patient's movement. The flex sensors also functioned well and were easy to connect to the Arduino micro allowing finger bend data to be brought into MATLAB and easily displayed on a plot in real time. Although flex sensors are not the cheapest sensor, they do not cost an extravagant amount. Because these sensors are pretty durable this helps justify the slightly more expensive cost. This sensor durability, along with the fact that the physical connections to the flex sensors themselves were also more durable, indicates that they won't need to be fixed or replaced as often. In contrast to this, the rubber stretch sensors were very difficult to connect leads to and they ended up having a lot of connectivity issues which would manifest as a reliability problem especially compared to the flex sensors. Since the flex sensors were tested while wired, the amount of power needed for them was not observed. This is not an observation that is currently needed since this sensory glove does not need to be wireless and the other criteria were more important.

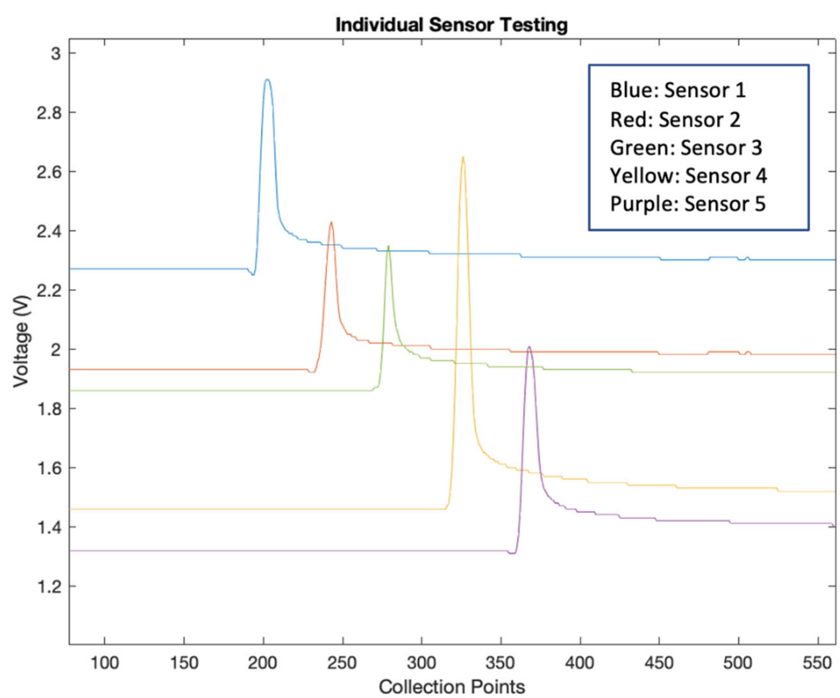

Figure 4.20 Testing 5 flex sensors, one for each finger, for measurement for finger bend

Table 4.14 Sensor Comparison for Measuring Finger Bend

	Flex Sensors	**Rubber Stretch Sensors**
Functionality	Good performance and connectivity to PCB	Difficult and poor connectivity to PCB
Size	Small, lightweight, and flat, flat shape is easier to put on glove	Small, lightweight, and cylindrical, rounded shape harder to put on glove
Cost	Slightly more expensive ($12.95)	Slightly cheaper ($9.95)
Power	Not currently applicable	Not currently applicable

The potentiometer-based sensors were chosen to measure finger separation. The potentiometer-based sensor, which can be seen in Figure 4.21, is composed of a potentiometer with a 3D printed structure (white piece) designed to attach to the glove and the sensor in order to hold the potentiometer in place while another flexible 3D printed torque arm (blue piece) is attached to the top part of the potentiometer. This torque arm, which can be seen in Figure 4.22, is designed to be flexible, so the patient is still able to bend their finger with as little interference as possible. This sensor is a self-designed sensor since sensors of a similar design that could measure finger separation with many different movements were not found. The torque arm was designed to be longer and have ridges across the length of the piece. These ridges were designed so that the torque arm is even more flexible along the length of the finger. These ridges act as a joint allowing the piece to bend more easily. The ridges are cylinder shaped, rather than triangular, to evenly distribute the stress from bending the piece so that the piece does not break. The piece can now bend completely in half very easily. When the structure of this piece was tested while attached to the potentiometer on a finger, the torque arm was still able to move the potentiometer when the finger moved.

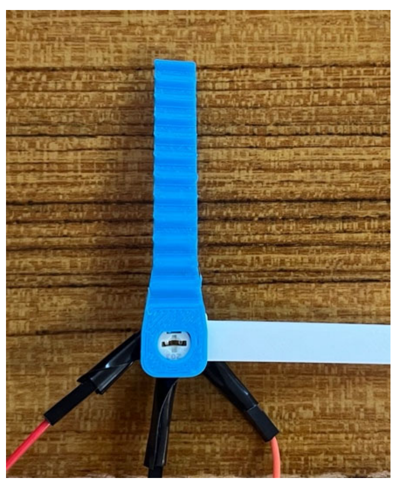

Figure 4.21 Potentiometer-based sensor with torque arm (blue piece) and stabilizing piece (white piece) attached to potentiometer

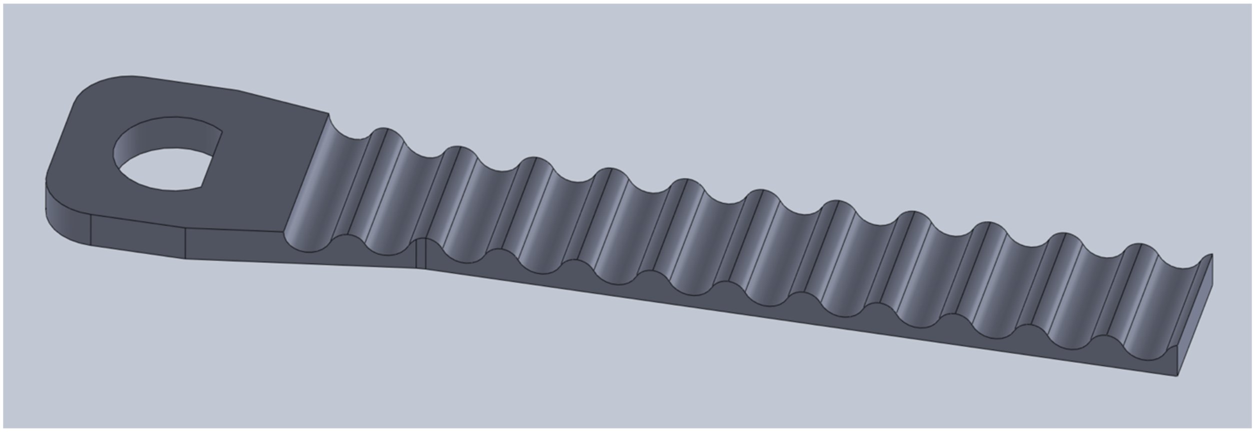

Figure 4.22 3D drawing of torque arm attached to potentiometer

The potentiometer-based sensors were tested using the Arduino Micro connected to MATLAB. Various torque arms with different lengths, widths, and fit to the potentiometer were 3D printed for the sensor out of flexible filament. The potentiometer-based sensor was assembled and attached to a regular fingerless glove that was left over from the previous version of the glove to begin testing this design. For testing, wires were soldered onto the potentiometer to create a smaller and more secure connection. Once the pins were connected, the potentiometer-based sensor was connected to the Arduino Micro and the torque arm was moved back and forth and that movement was plotted in MATLAB. To test the actual finger movement with the sensor, I wore the glove with the sensor taped to the glove and moved my pinky side to side while watching the value of the plot in MATLAB change simultaneously. The MATLAB plot of this finger movement can be seen in Figure 4.23, where the plot goes up and down based on finger separation. This sensor seemed to have consistent movement and measurement each time it was moved. One small issue currently with the sensor is the movement on the graph is pretty small. This issue still needs to be addressed. Testing with the plot scaled up or the value of the potentiometer adjusted will be tested in the next few weeks to fix this.

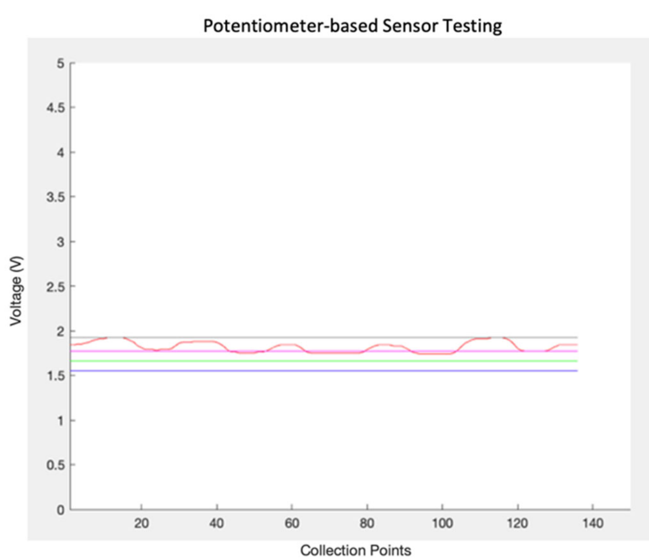

Figure 4.23 One potentiometer-based sensor tested for measuring finger separation

The potentiometer-based sensor was chosen out of the flex sensors and the time-of-flight sensors based on the criteria in the AHP Table B.1 in Appendix B. The potentiometer-based sensor can measure finger separation even when the finger it is attached to is bent. It can also accurately measure figure separation even when the figure is bent without the bending adding additional resistance and impacting the data accuracy which would then show up on the plot. It is important to ensure that the correct resistance is being plotted based only on finger separation and not anything else. The potentiometer on this sensor is very small and very lightweight. The parts attached to the potentiometer are also fairly small and light. The torque arm is very thin to allow the finger which it is attached to bend. The cost of the potentiometers is very low, and they come in a large pack. They also seemed very durable while testing, so they should be less likely to break. If a replacement is needed and because a lot of them come in a package for a low cost, they could be replaced inexpensively. Since these sensors were tested while wired, the amount of power needed for them was not observed. This is not an observation that is currently needed since this sensory glove does not need to be wireless and the other criteria were more important.

Table 4.15 Sensor Comparison for Measuring Finger Separation

	Potentiometer-based sensors	**Flex Sensors**	**Time-of -flight sensors**
Functionality	Easy connection, can measure no matter the finger position	Easy connection, can still measure finger separation inaccurately in some positions	Harder to connect, goes out of range and can't measure finger separation in some positions
Size	Small, lightweight, can be placed flat on the glove	Small, lightweight, needs to be balanced	Larger sensor, needs to be balanced
Cost	Potentiometers very cheap and come in large package ($0.08)	A more expensive sensor ($12.98)	Can be less expensive ($5.95)
Power	Not currently applicable	Not currently applicable	Not currently applicable

4.4.4.1 Signal Processing

Currently, MATLAB is being used to test sensors because it is reliably and accurately plotting in real time. However, since our sponsor would like to use LabVIEW, reading data into LabVIEW is currently being explored. So far, a VI has been made in LabVIEW, which can be seen in Figure 4.24. This VI was designed to bring in serial data from an Arduino and then display that data on the front panel. Different components were placed and connected in the Block Diagram which allowed data to be connected from the Arduino. Then a shift register was added to the while loop in the project. This shift register has a size of 5, for the number of channels that are currently being plotted in the waveform graph. The output from the serial port which previously went to the waveform graph was redirected to go into the shift register. From the shift register, the data goes to a bundle function which is then sent to the waveform graph. The waveform graph was also placed inside a conditional function so that the waveform only updates when there are 5 inputs ready. Currently there is a big delay on the waveform when the flex sensors are moved on the glove. However, this VI is designed to read data from 5 channels, which is the amount we need for the main flex sensors on our glove, to measure finger bend and the waveform is currently plotting data from each of the five channels.

In order to properly display the real-time data, a scrolling MATLAB window code was written [39]. 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 [40].

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 [41]. 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. Serial communication is compatible with MATLAB, LabVIEW, and Python. All three software platforms can all utilize serial connections regardless of the transmission mechanism. Furthermore, for the glove's required data sample rate, serial data can easily be sent in real-time and does not require a complicated communication software stack. These design choices were made based on the AHP Table B.3 in Appendix B.

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.

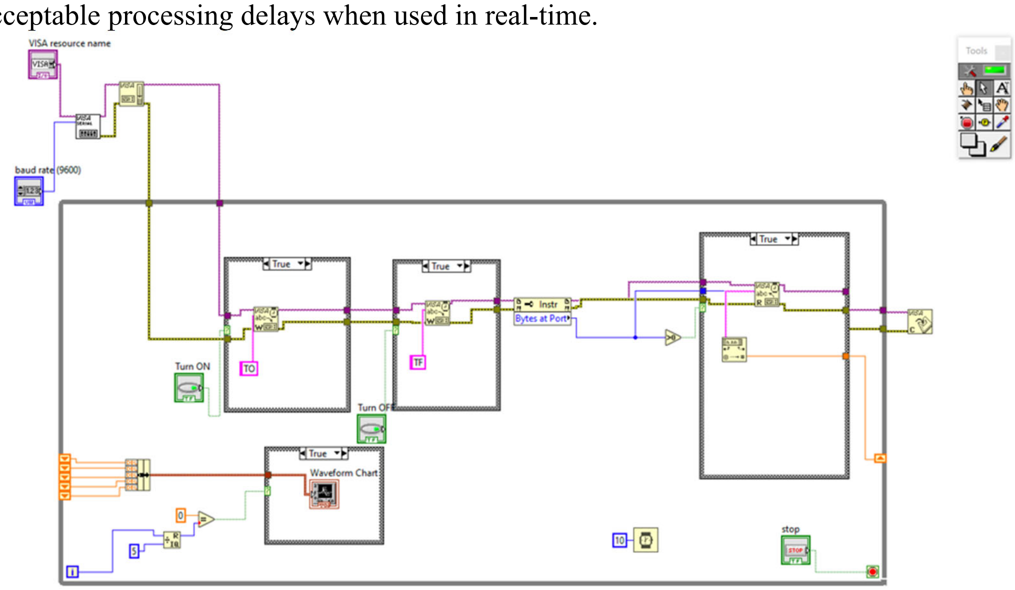

Figure 4.24 Block Diagram in LabVIEW to bring data from serial port

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 (5-Pt Avg), 3-point moving average filter (3-Pt Avg), a low pass filter (lpfx1) and a double low pass filter (lpfx2) 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 4.25. 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. From this testing the 3-point moving average is being used to filter the incoming data from the sensors. This is because the moving average filters have the least amount of delay, while also providing adequate smoothing. The 3-point moving average filter has been implemented in the Arduino and is being used to test the various sensor implementations.

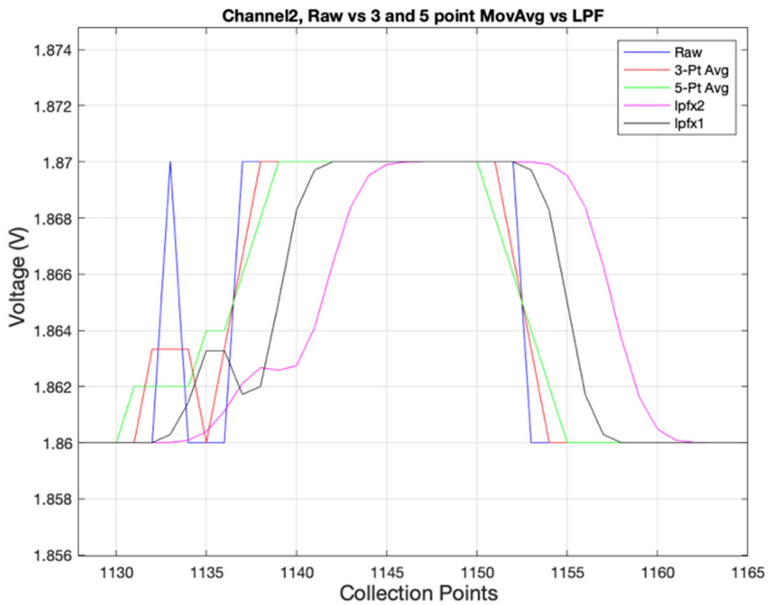

Figure 4.25 Comparison of different filters: 3-point Moving Average, 5-Point Moving Average, Lowpass Filter, and Double Lowpass Filter

The 3-point moving average filter was chosen based on the criteria shown the AHP Table B.2 in Appendix B. The accuracy for all of the different low pass filters is about the same. The 3-point moving average filter was the best for real time implementation especially when compared to the longer low pass filter and double low pass filter designed used in MATLAB. The moving average filters had less of a delay when plotting which resulted in a better in real time visualization experience for users. While the memory requirements for each type of filtering have not been specifically tested, the 3-point moving average stores the fewest values and therefore has the smallest memory footprint.

So far MATLAB is currently working properly, while LabVIEW is not. While using LabVIEW is the goal, if this doesn't work MATLAB can always be used since it is already working correctly, with only a few adjustments needed.

4.4.5 Game

The game acts as the user interface for the patient to interact with during the testing procedures. It is displayed on the patient's screen in the overall setup, as seen in Figure 4.1. The data collection and processing software we currently plan on using is LabVIEW. LabVIEW provides an easy way to integrate with external code, using the Python Integration Toolkit for LabVIEW [42]. Due to the ease and availability of this toolkit, as well as the various game development options available [43], Python was chosen as the language to develop the game in. Several Python game development packages were considered, including Pygame, Pyglet, and PyOpenGL. After applying the AHP process, PyGame was chosen as the package best fit for our purposes. The AHP process used to make this decision can be seen in Appendix BB.3.

In order to conform to our Engineering Requirements, we confirmed that every requirement related to the game was possible to achieve using PyGame. Engineering Requirement 3 says that everything should be programmed in LabVIEW and Python, which the game conforms to, as PyGame is a Python package. Engineering Requirements 7 and 16 have to do with streaming data in real-time to our secondary device, which the game is a part of. For the final product, we would like to be able to pull the already processed data from LabVIEW, using the toolkit mentioned above. Despite not being able to test this yet, we have confirmed that we can fulfill these requirements using the Arduino IDE, by streaming the raw flex sensor data from the IDE to Python code, using the PySerial package. The code for this can be seen in Figure 4.26. This also provides a good alternative option in case we are not able to set up the Python Integration Toolkit for LabVIEW.

```python
import time
import serial

ser = serial.Serial('COM4', 9600)

while True:
    value = ser.readline()
    print(value)
    time.sleep(0.5)
```

Figure 4.26 Code used to stream data from the Arduino IDE to Python

Engineering Requirement 17 says that the game should be able to display tasks for the patient to complete. We have been able to do this in PyGame, as seen in Figure 4.27. The tasks are clearly displayed and easy to read by patients. Engineering Requirement 14 ensures that patients are able to receive positive feedback when completing a task successfully. This is intended to help keep the patient positively encouraged and to keep progressing with the tests. An example of this can be seen in Figure 4.28. The game informs patients that they have completed a task successfully and are awarded points.

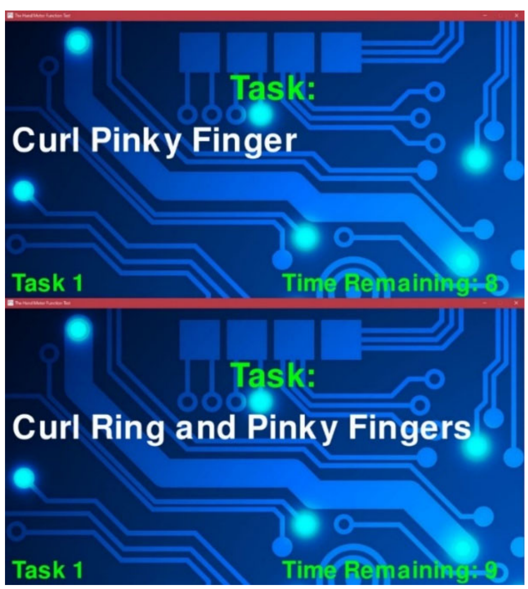

Figure 4.27 Different tasks displayed for patient to complete

Figure 4.28 Screen displayed when a task is successfully completed

Within PyGame, each section of the game, or in other words, the different physical screens that the patient sees on their display, are modeled within the code as screen objects. Therefore, in order to make the flow of the game and code smoother, each section of the game was stubbed out into its own subroutine. The list of subroutines can be seen in Figure 4.308. The overall game is controlled through the main function, which calls different subroutines as needed. The flow follows the overall testing flow seen in Figure 4.6.

Aside from the screens seen in Figures 4.25-4.26, all the other currently implemented and functioning screens can be seen in **Error! Reference source not found.**. The game first starts at the title screen, and after user input, moves onto the countdown screen for the duration of the timer. Afterwards, the task is displayed on screen for the patient to see. If successfully completed, the game moves onto the task success screen. Either after this, or if the patient could not complete a task in time, the game moves onto the next countdown. We chose to purposefully not implement a task failure screen, as this could induce discouragement in patients. Once all tests in the current suite are finished, the game moves onto the test suite complete screen. The patient then has the option to move onto the next suite if they'd like. Once all suites and tests are finished, the final screen is displayed, with the patients point total.

Figure 4.29 Four different screens displayed during the game: Title screen (top left), task countdown (bottom left), next suite prompt (top right), and final screen (bottom right)

```python
def main(): ...


def title_screen(screen): ...


def benchmark_screen(screen): ...


def help_screen(screen): ...


def run_test_suite(screen, tests, points): ...


def countdown_screen(screen, task_number): ...


def task_screen(screen, task_number, task): ...


def benchmark_compare(screen, data, suite_number, task): ...


def task_success(screen, task_num, points, points_earned_for_task): ...


def suite_complete_screen(screen, more_suites): ...


def final_screen(screen, points): ...
```

Figure 4.30 Different subroutines within the game's code

5 SUBSYSTEM TESTING

5.1 Glove Design

The following tests have been performed on the various 3D printed Apple watch bands and finger designs. These tests are still in progress as the glove continues to be designed and printed. After printing with multiple brands of TPU and flexible PLA+, the team has narrowed the type of filament down to 2, the AmazonBasics TPU or the Polymaker PolyFlex TPU.

Table 5.1 Glove Design Verification Testing

Test	Verification	Result
Bend 3D printed design as far as it will go	Material was able to bend over 120° without breaking, indicating material is flexible	Works as intended
Place 3D design on various people with different hand sizes	Allowed team to see that one size would fit multiple sized hands.	Works as intended
Bend and move fingers around with 3D design on hand	Material was smooth and did not cause any scratches or itchiness	Works as intended

5.2 PCB

The following tests have been performed on the first prototype of the PCB. These tests satisfy the engineering requirements highlighted in green.

Table 5.2 PCB Verification Testing

Test	Verification	Result
Powering the PCB with USB connection	The power on led turned on after plugging in the USB, indicating that the board successfully receives power.	Works as intended
Connecting the PCB to a computer	Plugged in the PCB to connect to the Arduino IDE where the COM port shows up.	Works as intended
Programming the PCB with Arduino IDE	The Arduino example program Blink.ino was able to be flashed onto the PCB. The on-board LED connected the digital pin 13 blinked at the specified rate of 1 second.	Works as intended
The size of the PCB is below 1.95” x 2”	Used a dimension tool in Autodesk Eagle to measure the size of the PCB. The PCB is 1.4” x 1.6”	Works as intended
The sensors are connected to ADC pins on the microchip	The PCB contains 11 sensor on-board connectors that is connected to 11 ADC pins available from the microchip	Work as intended

5.3 Power

As stated in sections 4.4.2 and 4.4.3, Team DIGIT has decided to go with a wired PCB and glove so the power will be supplied by the computer or secondary device. Therefore, no testing has been performed to verify that the power supply meets the Engineering Requirements. If a wireless glove were to be designed, the team would connect the battery to an empty circuit board and use a voltmeter to read the voltage the battery provides. The battery would then be connected to the PCB where each sensor would be tested to see if enough power is being supplied. Finally, the team would run through the entire game to simulate one 60-minute session. After the session is complete, the battery level would be read to determine if the battery would last for another session without needing to be recharged. Once the battery has been depleted, the battery would be plugged into the charge to charge until full while the team times how long it takes.

5.4 Sensors

Table 5.4 lists the tests performed to verify that the sensor design decisions meet the Engineering Requirements. As seen in the table, some of the testing has been completed and some of the tests are still in progress.

Table 5.3 Sensor Verification Testing

Test	Verification	Result
Move fingers with sensors attached	Sensors move properly when placed on a moving finger	Works as intended
Trying sampling rates of 10-50Hz	Can accurately collect and visualize data using a sampling rate above 10Hz	Works as intended
Data plotted in real time in MATLAB	The data on the plot varies in sync with the sensor as it is bent and unbent.	Works as intended
Data plotting in MATLAB	All data is plotting accurately in MATLAB	Works as intended
8 different sensors connected and collecting data	Can collect data from 8 different sensors	Works as intended
Data plotting in LabVIEW	Data should be plotted accurately in LabVIEW	Testing in progress
Data plotted in real time in LabVIEW	The data on the plot varies in sync with the sensor as it is bent and unbent.	Testing in progress

5.5 Game

It has been tested and successfully shown that the game code using PyGame is able to satisfy all relevant ERs. The details of this were discussed in section 4.4.5. In addition, more tests were developed in order to ensure that the game functions as properly intended. These can be seen below in Table 5.5.

Table 5.4 Game Verification Testing

Test	Verification	Result
Perform incorrect keyboard inputs on title screen	Nothing should happen unless SPACE is pressed	Works as intended
Provide input to task screen using glove sensors	Task completion only recognized when correct hand data is sent in	Not tested yet
Perform incorrect keyboard inputs on task success screen	Nothing should happen unless SPACE is pressed	Works as intended
Play through all test suites	Next test suite prompt only appears when there are suites left	Works as intended
Perform incorrect keyboard inputs on next suite prompt screen	Nothing should happen unless SPACE or 0 is pressed	Works as intended

Stream in data from LabVIEW in real time	Verify that data read by game code matches current sensor position data	Not tested yet

6 FINAL SYSTEM INTEGRATION

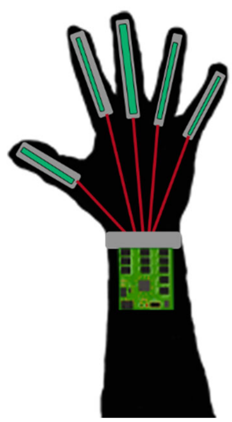

Figure 6.1 Glove Integration

The sensors will be connected to the PCB via wire harnesses. The wires will be soldered onto the sensor pins on one end of the wire and the other end of the wire will have sockets crimped onto it that will be inserted into a connector. That connector will be connected to its on-board mating part.

The PCB will be flashed it's Arduino program to read the sensors data and send that data to the serial port. Then, the PCB will be placed into a case that will sit on the wrist of the glove. The PCB will then connect to LabVIEW by plugging the USB cable into the PCB from the computer. On the computer, the LabVIEW program will be loaded and the COM port for the PCB will be selected to receive the data from the PCB through the serial port.

In order to connect LabVIEW to the game's python code, we will use the Python Integration Toolkit for LabVIEW. This toolkit allows for seamless transferring of data between both platforms, although we only require the one connection from LabVIEW to Python. Using this, the game will receive the processed input data from the sensors, and then perform the benchmark comparisons.

7 PROJECT PLAN

7.1 Work Breakdown

Table 7.1 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 who was assigned and if there were any activities that were predecessors.

Table 7.1 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 -Choose a material	7	Lili	Internet	N/A
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	-Create schematic -Create board layout	60	Jewell	Autodesk Eagle	1.3

ID	Activity	Description	Deliverables	Time	People	Resources	Predecessors
		components for this project					
2.3	Purchase and integrate PCB	Purchase the PCB and integrate it to the glove	-Order and receive PCB -Assemble PCB	90	Jewell	Oshpark	1.3
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 application	Design and code an onscreen 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	N/A
3.2	Integrate game application with data processing application	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 [42]	N/A

7.2 Gantt Chart

Figure 7.1 and Figure 7.2 are the Gantt chart for the entire project and were created using Smartsheet [44]. 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	Start	Finish	Status	Assigned to
Course Deliverables	01/18/22	12/06/22		
Requirements Report & Presentation	**01/18/22**	**02/22/22**		
~~Marketing Requirements~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~	~~All~~
~~Objective Tree~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~	~~All~~
~~Engineering Requirements~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~	~~All~~
~~Rationale~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~	~~All~~
~~Justification~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~	~~All~~
~~Testability of Engineering Requirements~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~	~~All~~
~~Verification of Engineering Requirements~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~	~~All~~
~~Impact Statements~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~	~~All~~
~~References~~	~~01/18/22~~	~~02/15/22~~	~~Complete~~	~~All~~
~~Requirements Presentation~~	~~01/18/22~~	~~02/22/22~~	~~Complete~~	~~All~~
~~Requirements Report~~	~~01/18/22~~	~~02/22/22~~	~~Complete~~	~~All~~
Preliminary Design and Research Report & Presentation	03/03/22	04/14/22		
~~Update requirements based on instructor feedback on requirements report~~	~~02/28/22~~	~~04/06/22~~	~~Complete~~	~~All~~
~~Work Breakdown~~	~~01/18/22~~	~~04/28/22~~	~~Complete~~	~~All~~
~~Gantt Chart~~	~~01/18/22~~	~~04/28/22~~	~~Complete~~	~~All~~
~~Functional Decomposition~~	~~03/01/22~~	~~03/10/22~~	~~Complete~~	~~All~~
~~Cost~~	~~03/28/22~~	~~04/25/22~~	~~Complete~~	~~All~~
~~Design Alternatives~~	~~03/28/22~~	~~04/25/22~~	~~Complete~~	~~All~~
~~PDR Presentation~~	~~03/04/22~~	~~04/07/22~~	~~Complete~~	~~All~~
~~PDR Report~~	~~03/04/22~~	~~04/14/22~~	~~Complete~~	~~All~~
Individual Research & Design	03/01/22	04/25/22		
~~Sensors~~	~~03/01/22~~	~~04/25/22~~	~~Complete~~	~~Gwynne~~
~~Power Supplies~~	~~03/01/22~~	~~04/25/22~~	~~Complete~~	~~Lili~~
~~PCB~~	~~03/01/22~~	~~04/25/22~~	~~Complete~~	~~Jewel~~
~~Glove Design~~	~~03/01/22~~	~~04/25/22~~	~~Complete~~	~~Lili~~
~~Software/Game~~	~~03/01/22~~	~~04/25/22~~	~~Complete~~	~~Bobby~~
Senior Design Day	**04/12/22**	**04/26/22**		
~~Poster~~	~~04/12/22~~	~~04/22/22~~	~~Complete~~	~~Lili~~
~~Senior Design Day~~	~~04/26/22~~	~~04/26/22~~	~~Complete~~	~~All~~
Critical Design Report & Presentation	**08/22/22**	**09/20/22**		
~~Update report based on feedback from instructors on PDR report & presentation~~	~~08/22/22~~	~~09/15/22~~	~~Complete~~	~~All~~
~~CDR Presentation~~	~~09/19/22~~	~~09/23/22~~	~~Complete~~	~~All~~
~~CDR Report~~	~~08/22/22~~	~~10/04/22~~	~~Complete~~	~~All~~

Figure 7.1 Gantt Chart Part 1

Task Name	Start	Finish	Status	Assigned to
Final Report & Presentation	**09/27/22**	**11/23/22**		
Update report based on feedback from instructors on CDR report & presentation	09/27/22	11/11/22	Not Started	All
Final Presentation	11/14/22	11/18/22	Not Started	All
Final Report	09/27/22	11/30/22	Not Started	All
Glove Construction	**08/22/22**	**11/14/22**		
Select and Order Components	08/22/22	09/09/22	In Progress	All
Design and fabricate PCB	08/22/22	10/03/22	In Progress	Jewell
Test Sensors	08/22/22	10/03/22	Not Started	Gwynne
Test Power Supply	10/10/22	11/04/22	Not Started	Lili
Integrate electronics and assemble onto glove	10/10/22	10/11/22	Not Started	Lili
Integrated system testing and validation	10/31/22	11/11/22	Not Started	All
Software Development	**08/22/22**	**11/21/22**		
Data collection from glove	09/26/22	11/14/22	Not Started	Bobby Gwynne
Data storage	08/22/22	10/24/22	Not Started	Bobby Gwynne
Data retrieval	08/22/22	11/14/22	Not Started	Bobby Gwynne
Data representation	08/22/22	11/14/22	Not Started	Bobby Gwynne
Integrated system testing and validation	10/10/22	11/14/22	Not Started	All
Final system software polishing	11/01/22	11/21/22	Not Started	Bobby
Senior Design Day	**11/21/22**	**12/06/22**		
Poster	11/21/22	12/05/22	Not Started	Lili
Senior Design Day	12/06/22	12/06/22	Not Started	All

Figure 7.2 Gantt Chart Part 2

7.3 Bill of Materials

Table 7.2 is a list of all materials that were bought by Team DIGIT along with the materials Team DIGIT inherited from Team SCREEN.

Table 7.2 Bill of Materials

Item	Qty	Vendor
SainSmart TPU	1	Amazon
ATARAXIA ART PLA+	1	Amazon
Lithium Ion Battery 3.7V 2000mAh	5	Adafruit
Lithium Ion Battery 3.7V 500mAh	5	Adafruit
Adafruit µ Lip – USB LiIon/LiPoly Charger	2	Adafruit
Adafruit VCLN4040 F	2	Adafruit
Adafruit VL53L4CD Time of Flight Distance Sensor	2	Adafruit
Conductive Rubber Cord Stretch Sensor	1	Adafruit
Stainless Medium Conductive Thread	1	Adafruit
Watch strap connector (42mm/44mm/45mm)	2	Amazon
Watch strap connector (38mm/40mm/41mm)	2	Amazon
100nF capacitor	20	Digikey
10k resistor	30	Mouser
10uF capacitor	10	Mouser
16MHz crystal	10	Mouser
Diode	10	Mouser
1k resistor	20	Mouser
1uF capacitor	20	Mouser
22pF capacitor	20	Digikey
3x2 header	6	Mouser
2-pin male connectors	30	Mouser
ATMega32U4 TQFP44	3	Mouser
ATMega 32U4 QFN44	3	Mouser
22 Resistor Array	10	Mouser
CG0603MLC varistor	10	Mouser
Low power op amp	20	Mouser
500mA fuse	10	Mouser
EMI suppression beads	10	Digikey
Push button	10	Mouser
USB micro	6	Mouser
Green LED	20	Mouser
CT Energy Lithium Ion 2032 Battery Charger	1	Amazon
LIR 2032 Lithium Button Battery Charger	1	Amazon
AmazonBasics TPU	1	Amazon
SpiderMaker SpiderFlex	1	Amazon
PolyFlex TPU	1	Amazon
Ninjaflex TPE	1	Amazon
Long Flex Sensor	20	Adafruit
Short Flex Sensor	10	Adafruit
Pocket AVR Programmer	1	Sparkfun

Item	Qty	Vendor
AVR Programming Cable	1	Sparkfun
A000093	2	Digikey
A000005	2	Digikey
MCP6004-I/P	2	Digikey
MCP004-I/SL	6	Digikey
Fermerry 28AWG Silicone Electric Wire	1	Amazon
Tactile Switches	5	Mouser
USB micro B	5	Digikey
SanDisk 32GB Ultra Memory Card	1	Amazon
1735801-1	100	Mouser
6-440129-2	30	Mouser
Mini µ Open Barrel Crimping Tools	1	Amazon
SM0805UBWC	5	Mouser
Items from previous Teams		
Fingerless Glove	6	Team SCREEN
DC-DC Step-up	3	Team SCREEN
Coin Cell Holder	2	Team SCREEN
Breadboard wires		Team SCREEN
RGB 5m LED	100	Team SCREEN
Ion Motor	6	Team SCREEN
Breakaway Connector for Arduino Shield	10	Team SCREEN
LEDS	12	Team SCREEN
MB12A05	2	Team SCREEN
Vibration Sensor	1	Team SCREEN
10uF 50V	2	Team SCREEN
100 uF 50V	2	Team SCREEN
Button buzzer	2	Team SCREEN
22 ceramic disc capacitor	5	Team SCREEN
104 ceramic disc capacitor	5	Team SCREEN
IN4007	5	Team SCREEN
SN74HC595N	1	Team SCREEN
SH538	1	Team SCREEN
PN2222	5	Team SCREEN
A92B331	3	Team SCREEN
S8050D331	5	Team SCREEN
Digital Battery Charger	1	Team SCREEN
Adafruit Small Enclosed Piezo w/ wires	2	Team SCREEN
Development kit	3	Team SCREEN
Arduino Nano 33 BLE Board	2	Team SCREEN
Flex Sensor w/ blue	30	Team SCREEN
Spectrasymbol	2	Team SCREEN
Spectrasymbol	1	Team SCREEN
Reachargeable 9V battery	1	Team SCREEN
9V battery	2	Team SCREEN
1 in flexpoint sensor system	28	Team SCREEN
3D black slits to hold flex sensors	17	Team SCREEN
Mini Digital Video Battery	2	Team SCREEN

7.4 Cost Analysis

Table 7.3 lists all the materials bought using the Reese Terry Funds along with the individual cost, quantity bought, where materials were from and total cost spent.

Table 7.3 Total Expenditures

Item	Individual Cost	Qty	Vendor	Cost
SainSmart TPU	$ 15.99	1	Amazon	$15.99
ATARAXIA ART PLA+	$ 39.99	1	Amazon	$39.99
Lithium Ion Battery 3.7V 2000mAh	$ 12.50	5	Adafruit	$62.50
Lithium Ion Battery 3.7V 500mAh	$ 7.95	5	Adafruit	$39.75
Adafruit µ Lip – USB LiIon/LiPoly Charger	$ 5.95	2	Adafruit	$11.90
Adafruit VCLN4040 F	$ 5.95	2	Adafruit	$11.90
Adafruit VL53L4CD Time of Flight Distance Sensor	$ 14.95	2	Adafruit	$29.90
Conductive Rubber Cord Stretch Sensor	$ 9.95	1	Adafruit	$9.95
Stainless Medium Conductive Thread	$ 9.95	1	Adafruit	$9.95
Watch strap connector (42mm/44mm/45mm)	$ 14.95	2	Amazon	$29.90
Watch strap connector (38mm/40mm/41mm)	$ 14.95	2	Amazon	$29.90
100nF capacitor	$ 0.10	20	Digikey	$2.00
10k resistor	$ 0.09	30	Mouser	$2.70
10uF capacitor	$ 0.78	10	Mouser	$7.80
16MHz crystal	$ 0.43	10	Mouser	$4.30
Diode	$ 0.13	10	Mouser	$1.30
1k resistor	$ 0.10	20	Mouser	$2.00
1uF capacitor	$ 0.12	20	Mouser	$2.40
22pF capacitor	$ 0.18	20	Digikey	$3.60
3x2 header	$ 0.46	6	Mouser	$2.76
2-pin male connectors	$ 0.04	30	Mouser	$1.20
ATMega32U4 TQFP44	$ 5.62	3	Mouser	$16.86
ATMega 32U4 QFN44	$ 5.49	3	Mouser	$16.47
22 Resistor Array	$ 0.07	10	Mouser	$0.70
CG0603MLC varistor	$ 0.37	10	Mouser	$3.70
Low power op amp	$ 0.32	20	Mouser	$6.40
500mA fuse	$ 0.26	10	Mouser	$2.60
EMI suppression beads	$ 0.08	10	Digikey	$0.80
Push button	$ 0.46	10	Mouser	$4.60
USB micro	$ 1.97	6	Mouser	$11.82
Green LED	$ 0.17	20	Mouser	$3.40
CT Energy Lithium Ion 2032 Battery Charger	$ 23.99	1	Amazon	$23.99

Item	Individual Cost	Qty	Vendor	Cost
LIR 2032 Lithium Button Battery Charger	$ 15.99	1	Amazon	$15.99
AmazonBasics TPU	$ 29.71	1	Amazon	$29.71
SpiderMaker SpiderFlex	$ 36.00	1	Amazon	$36.00
PolyFlex TPU	$ 29.99	1	Amazon	$29.99
Ninjaflex TPE	$ 33.70	1	Amazon	$33.70
Long Flex Sensor	$ 12.95	20	Adafruit	$259.00
Short Flex Sensor	$ 11.95	10	Adafruit	$119.50
Pocket AVR Programmer	$ 18.50	1	Sparkfun	$18.50
AVR Programming Cable	$ 2.10	1	Sparkfun	$2.10
A000093	$ 22.10	2	Digikey	$44.20
A000005	$ 29.12	2	Digikey	$58.24
MCP6004-I/P	$ 0.63	2	Digikey	$1.26
MCP004-I/SL	$ 0.57	6	Digikey	$3.42
Fermerry 28AWG Silicone Electric Wire	$ 10.99	1	Amazon	$10.99
Tactile Switches	$ 0.55	5	Mouser	$2.75
USB micro B	$ 2.68	5	Digikey	$13.40
SanDisk 32GB Ultra Memory Card	$ 8.99	1	Amazon	$8.99
1735801-1	$ 0.034	100	Mouser	$3.400
6-440129-2	$ 0.045	30	Mouser	$1.350
Mini µ Open Barrel Crimping Tools	$ 19.99	1	Amazon	$19.99
SM0805UBWC	$ 1.29	5	Mouser	$6.45
Total Spent				**$1,131.96**

7.4.1 Total Cost

Table 7.4 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 7.4 Total Cost

Item	Individual Cost	Qty	Vendor	Total Cost
PCB	$ 19.15	1	Oshpark [45]	$ 19.15
Sensors	$ 12.89	8	Adafruit	$ 103.15
Material of Glove	$39.99	1	Amazon	$ 39.99
Battery	$ 12.50	2	Adafruit	$ 25.00
Battery Charger	$ 5.95	1	Adafruit	$ 5.95
Total				**$193.24**

7.5 Team Member Responsibilities

Table 7.5 are the team member responsibilities. It provides the primary and secondary responsibilities of each team member along with an explanation of their tasks.

Table 7.5 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 Design	Wireless Connection and Power	Designing a custom PCB to read sensor data and transfer sensor data via Bluetooth to secondary device.
Lili Petrowsky	Glove Design	Wireless Connection and Power	Design and 3D print an exoskeleton glove
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 [46], we took our Marketing Requirements 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 $GM = \sqrt[n]{\alpha_1 \alpha_2 \dots \alpha_n}$. 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 AHP

	Functionality	Performance	Usability	GM	Weight
Functionality	1.00	0.20	0.33	0.40	0.10
Performance	5.00	1.00	3.00	2.47	0.64
Usability	3.00	0.33	1.00	1.00	0.26
Sum	9.00	1.53	4.33	3.87	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

	Wireless	Cleanable	Battery	GM	Weight	Weighted Score
Wireless	1.00	0.14	3.00	0.75	0.17	0.02
Cleanable	7.00	1.00	5.00	3.27	0.74	0.07
Battery	0.33	0.20	1.00	0.40	0.09	0.01

Sum	8.33	1.34	9.00	4.42	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

	Track Motion	**3D Modeling**	**Real-time**	**GM**	**Weight**	**Weighted Score**
Track Motion	1.00	3.00	7.00	2.76	0.68	0.44
3D Modeling	0.33	1.00	0.20	0.40	0.10	0.06
Real-time	0.14	5.00	1.00	0.89	0.22	0.14
Sum	1.47	9.00	8.20	4.05	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

	Game	**Easy**	**No Interference**	**GM**	**Weight**	**Weighted Score**
Game	1.00	0.20	0.33	0.40	0.09	0.02
Easy	5.00	1.00	7.00	3.27	0.74	0.19
No Interference	3.00	0.14	1.00	0.75	0.17	0.04
Sum	9.00	1.34	8.33	4.42	1.00	0.25

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

	Functionality	Cost	Size	Power	GM	Weight
Functionality	1.00	7.00	3.00	5.00	3.20	0.564
Cost	0.14	1.00	0.20	0.33	0.31	0.055
Size	0.33	5.00	1.00	3.00	1.49	0.263
Power	0.20	3.00	0.33	1.00	0.67	0.118
Sum	1.67	16.00	4.53	9.33	5.67	1.00

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

	Accuracy	Real-Time	Visualization	Memory	GM	Weight
Accuracy	1.00	1.00	5.00	7.00	2.43	0.424
Real-Time	1.00	1.00	5.00	7.00	2.43	0.424
Visualization	0.20	0.20	1.00	3.00	0.59	0.103
Memory	0.14	0.14	0.33	1.00	0.28	0.049
Sum	2.34	2.34	11.33	18.00	5.73	1.00

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

	Compatibility	Real-Time	Power	GM	Weight
Compatibility	1.00	1.00	5.00	1.71	0.455

Real-Time	1.00	1.00	5.00	1.71	0.455
Power	0.20	0.20	1.00	0.34	0.090
Sum	2.20	2.20	11.00	3.76	1.00

B.2 Power

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 [47] and require a charger specifically for that battery. Table B.4 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.4 Battery Comparison

Name	Rechargeable	Brand	Cost	Approx. Weight (g)	Approx. Size	Nominal Voltage (V)	Nominal Capacity (mAh)
Lithium-Ion Battery [48]	Yes	Adafruit	$12.50	34	4”x1.4”x0.3”	3.7	2000
Lithium-Ion Battery [49]	Yes	Adafruit	$7.95	10.5	1.15”x1.4”x0.19”	3.7	500
EEMB LIR2450 Rechargeable Battery [50]	Yes	EEMB Store	$18.99	5.3	Diameter: 24.5mm Height: 5.0mm	3.7	120
Rechargeable LIR2032 3.6V Button Cell FBA [51]	Yes	Gernal	$7.19	20.13	0.79”x0.79”x0.13”	3.6	Not Provided
Lithium Ion 2032 Battery Charger for Coin Cell Rechargeable Batteries LIR20322 [52]	Yes	CT Energy	$23.99	2.8	Diameter: 20.0mm Height: 3.2mm	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.5, 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.5 Package Criteria AHP

	Simplicity	Speed	Support	GM	Weight
Simplicity	1.00	3.00	0.33	1.00	0.258
Speed	0.33	1.00	0.20	0.40	0.103
Support	3.00	5.00	1.00	2.47	0.638
Sum	4.33	9.00	1.53	3.87	1.00

The package options are compared below in Table B.6 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.6 Simplicity AHP

	Pygame	Pyglet	PyOpenGL	GM	Weight
Pygame	1.00	5.00	7.00	3.27	0.732
Pyglet	0.20	1.00	3.00	0.84	0.188
PyOpenGL	0.14	0.33	1.00	0.36	0.081
Sum	1.34	6.33	11.00	4.47	1.00

Table B.7 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.7 Speed AHP

	Pygame	Pyglet	PyOpenGL	GM	Weight
Pygame	1.00	0.14	0.33	0.36	0.087
Pyglet	7.00	1.00	3.00	2.76	0.670
PyOpenGL	3.00	0.33	1.00	1.00	0.243
Sum	11.00	1.47	4.33	4.12	1.00

Table B.8 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.8 Support AHP

	Pygame	Pyglet	PyOpenGL	GM	Weight
Pygame	1.00	7.00	3.00	2.76	0.651
Pyglet	0.14	1.00	0.20	0.30	0.071
PyOpenGL	0.33	5.00	1.00	1.18	0.278
Sum	1.47	13	4.2	4.24	1.00

Table B.9 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.9 Final Package AHP

	Simplicity	Speed	Support	GM	Weight	Weighted Score
Pygame	0.732	0.087	0.651	0.35	0.473	0.122
Pyglet	0.188	0.670	0.071	0.21	0.284	0.029
PyOpenGL	0.081	0.243	0.278	0.18	0.243	0.155
Sum	1.00	1.00	1.00	0.74	1.00	0.31

B.4 PCB/Microcontroller

In the Marking Requirements 2 and 9, Should be wireless and Should have a rechargeable battery, this schematic is the wireless PCB version as shown in the below. The design is the same as the wired version with additions to make it wireless and battery powered. Realistically the battery wouldn't be connected to the PCB if the USB was connected to the PCB, but a PMOS is put in place as a safety measure (the 5V from the USB wouldn't back-feed voltage into the battery). And an LDO (low-drop-out) 3.3V voltage regulator was added to supply the circuitry with a clean 3.3V voltage source. A few other additions are a connector for the battery along with a voltage divider circuitry to measure the voltage of the battery, and finally a 6-pin connector for the Bluetooth module. This connector may change if a different Bluetooth module is chosen. The downside to this version is that the ATMega32U4 can only run at an 8MHz clock speed due to the input voltage being less than 4.15V.

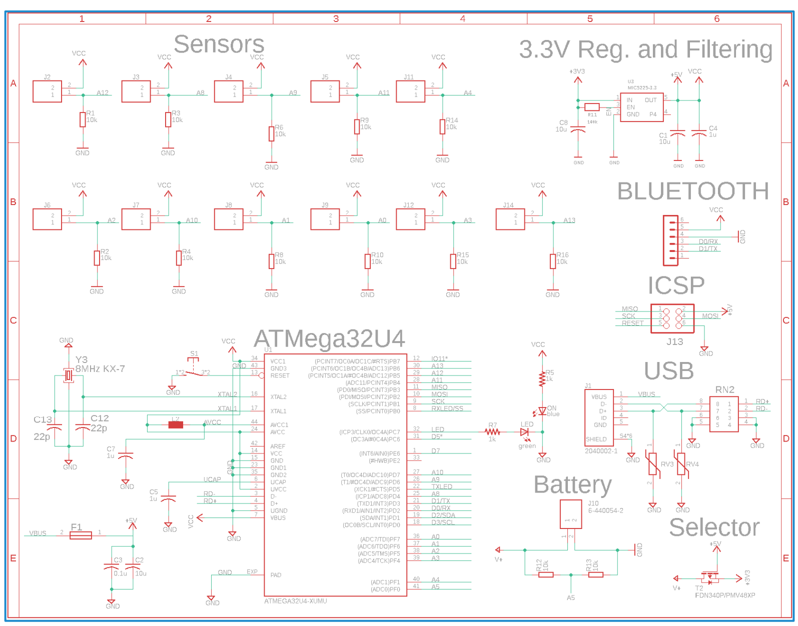

Figure B. 1 Eagle Wireless Schematic

Table B.10 shows the AHP the processor chip decision based on the AHP table and based on the processor chip comparison found Table 4.14. In Table B.10 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.10 Processor Chip AHP

	Operating Voltage	**ADC Pins**	**LabVIEW Compatibility**	**Built-In UART**	**GM**	**Weight**
Operating Voltage	1.00	0.33	0.14	0.20	0.31	0.055
ADC Pins	3.00	1.00	0.33	0.20	0.67	0.118
LabVIEW Compatibility	7.00	3.00	1.00	5.00	3.20	0.563
Built-In UART	5.00	5.00	0.20	1.00	1.50	0.264
Sum	16.00	9.33	1.67	6.40	5.68	1.00

B.5 Glove Material

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.11 compares four different flexible filaments in cost, diameter, and shore hardness.

Table B.11 Material of Glove Comparison

Name	**Brand**	**Cost**	**Diameter**	**Shore Hardness**
TPU [53]	SainSmart	$15.99	1.75mm	95A
Flexible PLA+ [54]	ATARAXIA Art	$39.99	1.75mm	89A
TPC [55]	Digi-Key	$39.99	1.75mm	95A
TPE [56]	Digi-Key	$29.99	3.00mm	Not Provided