ECD526
Techworks! Robotic Arm Controller
Project Report

Client: Techworks!

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Abstract

This report presents the design and development of a glove-based controller for a robotic arm, undertaken as a Senior Capstone Project between Electrical and Computer Engineering (ECE) and Mechanical Engineering (ME) teams. The project draws inspiration from the Nintendo Entertainment System (NES) Power Glove, an iconic piece of gaming history, to create a modern interface that replicates human hand and arm movements. The goal is to develop a functional system that preserves the quality and usability of the original Power Glove, while allowing users to engage with an interactive robotic arm exhibit at TechWorks!, a Central New York State innovation center dedicated to showcasing technological achievements.

The Glove Controller enables precise control over the Robotic Arm's movements, including individual finger articulation, wrist roll, arm pitch, and yaw, all executed smoothly and with minimal lag. This project builds upon the groundwork laid by ECD416 (2023–2024), which demonstrated the feasibility of a robotic arm system controlled by a glove. ECD526 refines and enhances the system by focusing on improved responsiveness, compatibility with the Robotic Arm, and expanded communication capabilities.

Ultimately, this project highlights the convergence of historical gaming innovation and contemporary engineering design. By integrating advanced control systems with mechanical design, the resulting system will offer museum visitors an engaging and interactive experience while showcasing the evolution of both gaming and robotics technologies.

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1 Introduction

1.1 System Overview

This report outlines the ECD526 TechWorks! Robotic Arm Controller project for 2024-2025. TechWorks! is a Central New York State innovation center showcasing advancements in technology. IBM Endicott historically contributed semiconductor chips integral to game consoles and controllers, including the NES Power Glove. TechWorks! has acquired an NES Power Glove, a historic gaming innovation, and aims to showcase its legacy by enabling public interaction through a Robotic Arm manipulated via a newly developed Glove Controller. This project continues the work of ECD416 (2023–2024), which built and demonstrated the initial Robotic Arm System, consisting of a Glove Controller and a Robotic Arm. ECD526 focuses on evaluating the performance of the ECD416 system while advancing the design and development of the Glove Controller. A separate Mechanical Engineering (ME) Capstone project is responsible for building the Robotic Arm. The ECE team is focused on developing the Glove Controller, designed to seamlessly integrate with the Robotic Arm built by the ME team. Together, these systems will provide an interactive experience that highlights the evolution of gaming technology while preserving the original NES Power Glove for exhibit purposes.

1.2 Document Overview

This report provides a thorough examination of our project's design and development efforts, detailing the current progress of our project and outlining the path forward as we shift into the Spring semester. It begins by defining the initial problem statement and objectives, offering a simple understanding of the challenges the project seeks to address. The report explores the system-level interactions that guide the integration of hardware and software, presenting a clear outline of the project's functionality. Key sections include an in-depth look at the hardware and software design processes, emphasizing how these components align to achieve the desired system performance. Detailed plans for integration, testing, and system verification are outlined, ensuring that the Glove Controller meets technical specifications. Additionally, this report presents our vision for the final product, describing how the completed controller will deliver a reliable and interactive user experience.

2 Referenced Documents

The following documents of the exact issue shown form a part of this report as specified herein.

1. ECD 526 Techworks! Robotic Arm Controller Project Specification Document
2. ECD 526 Final Design Presentation
3. ECD 416 Techworks! Robotic Arm Controller Project Design Report

3 Problem Definition

3.1 Problem Scope

Techworks! is a nonprofit organization located in Binghamton, NY and is dedicated to collecting, preserving, and showcasing vintage technology that highlights the region's history of innovation. As part of their mission to share the history of technological advancements, Techworks! would like to showcase the NES Power Glove in an interactive exhibit. Although they face the worry of this piece of history getting damaged or even broken. The main objective of this project is to develop a functional and user-friendly way to control a robotic arm that mimics human hand and arm movements. The NES Power Glove is to be worn on the Robotic Arm, preserving its original quality and usability. The intention of the Glove Controller is to give the user the same feel of wearing the NES Power glove while still being able to control it. The challenge that last year's team faced and now we face lies in developing a controller capable of translating user movements into real-time commands for the robotic arm, ensuring smooth and accurate control of the first four fingers, wrist, and arm across multiple axes.

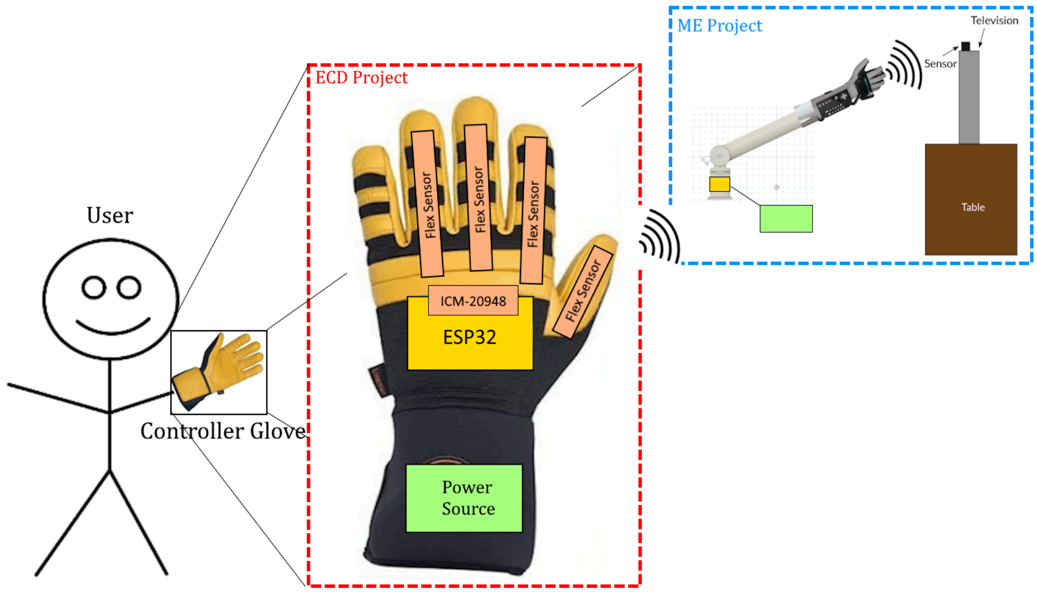

Figure 1: Context Diagram

3.2 Technical Review

Building on the foundation laid by last year's ECD 416 project, our team aims to refine and enhance the design. While the previous system was able to achieve its objectives, some technical challenges, such as Bluetooth connectivity and jittering motions in the robotic arm and fingers highlighted areas for improvement. Furthermore, the controller must be intuitive, robust, and capable of delivering consistent performance in a hands-on, museum exhibit. Addressing these issues is critical to ensuring smooth movements, increased reliability, and overall improved user experience.

3.3 Design Requirements

The following are the project requirements of the Glove Controller:

1. [ECD526-R-001]: The Glove Controller shall control the first four fingers with minimum lag.
2. [ECD526-R-002]: The Glove Controller shall smoothly curl and uncurl the first four fingers with minimum lag.
3. [ECD526-R-003]: The Glove Controller shall roll the Robotic Arm +/- 90 degrees with minimum lag.
4. [ECD526-R-004]: The Glove Controller shall pitch the Robotic Arm +/- 45 degrees with minimum lag.
5. [ECD526-R-005]: The Glove Controller shall yaw the Robotic Arm +/- 45 degrees with minimum lag.

The following are the derived stretch goals of the Glove Controller:

1. [ECD526-G-001]: The connection between the Glove Controller and the Robotic Arm should be wireless.
2. [ECD526-G-002]: There should be no exposed wires on the Glove Controller.
3. [ECD526-G-003]: The ECE and ME teams should integrate projects upon completed implementation.

4 System Design

4.1 System-Wide Design Decisions

4.1.1 Controller Design

The design of our glove-based controller, and how we got to that decision, was approached with the goal of achieving a seamless integration with the robotic arm while maintaining ease of use, reliability, and responsiveness. This process eventually led to the selection of the Glove Controller as shown in Figure 3, but not without first considering and discarding other ideas.
Our initial design concept involved using a handheld Nintendo Switch controller. The idea was to map the robotic arm's movements to buttons and joysticks. While this approach seemed straightforward, it was ultimately abandoned due to its lack of intuitiveness and inability to replicate the natural, fluid motions of the human hand and arm.
Next, we explored the possibility of using a Gripmaster – a handheld device designed for finger and grip strengthening – enhanced with pressure sensors, an accelerometer, and a gyroscope (as shown in Figure 2). This design aimed to control the robotic arm's fingers with applied pressure and arm movements with readings from the accelerometer and gyroscope. This idea was also scrapped upon further research as it became too hard to determine where to place electrical components and that it would require significant user effort, which would detract from the overall experience.

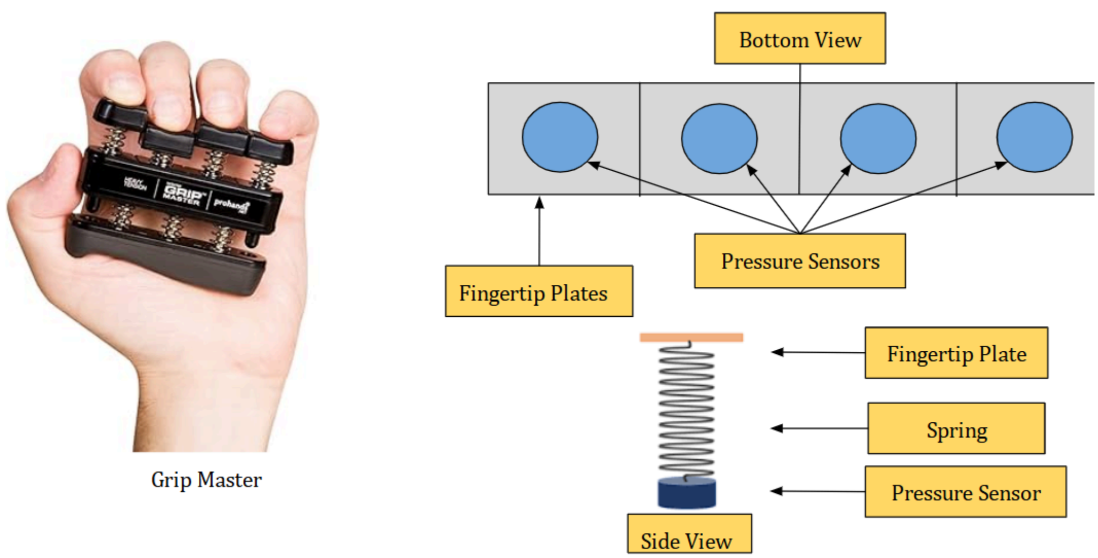

Figure 2: Gripmaster Alternative Design

Recognizing the limitations of the previous designs, we shifted focus to a glove-based controller as shown in Figure 3. This design leverages the natural movements of the hand and fingers, offering an intuitive interface that directly translates user gestures into the Robotic Arm's movements. By incorporating flex sensors, the glove captures precise bending motions of the fingers, while additional sensors track wrist and arm movements. The decision to adopt the glove design aligns seamlessly with the project's objectives, has the abilities to address key challenges, and provides a user-friendly and immersive experience that preserves the functionality of the NES Power Glove.

Figure 3: Glove Controller

4.1.2 Microcontroller

Our design requires seamless communication between the Glove Controller and the Robotic Arm in addition to fitting the integration with the glove. For these reasons, we chose our microcontroller based on its size and wireless communication capabilities. We had several ideas from our research and narrowed it down to the Arduino Nano and the ESP32. Both microcontrollers are relatively small and compatible with the sensors. The main advantage of the Arduino Nano is our familiarity with the program. Attempting to meet one of our stretch goals of having the system be wireless, wireless connectivity played a big role in our choice. Ultimately, we went with the ESP32 because of its higher processing power and integrated Bluetooth Low Energy system. The integrated bluetooth was a major factor in our decision as the Arduino Nano would require an external bluetooth module, physically taking up more space on the glove. The ESP32 is also compatible with the Arduino IDE, giving us some familiarity and place to begin.

4.2 System Components and Interfaces

The system is designed to translate user hand and arm movements into precise commands for the Robotic Arm. As illustrated in Figure 4, there are two main subsystems: the Glove Controller and the Robotic Arm. The Glove Controller is worn by the user and serves as the primary interface for capturing hand and arm movements. Key components include:

- **User Wearable**: Embedded with flex sensors and ICM-20948 to detect arm, finger, and hand movement.
- **Microcontroller**: ESP32 processes sensor inputs and translates them into control signals. Built-in bluetooth capabilities ensure wireless transmissions of commands to the Robotic Arm.
- **Power Source**: The battery pack provides sufficient power to all components, ensuring the system's functionality while allowing the wearable to remain portable and free from restrictive wiring.

The Robotic Arm (ME Capstone Project) will receive commands from the Glove Controller and execute the corresponding movements. Key components include:

- **Microcontroller**: ESP32 processes commands received via Bluetooth from the Glove Controller's ESP32 and controls the Robotic Arm's movements.
- **Shoulder Mechanism**: Controls the pitch and yaw motions.
- **Arm & Hand Mechanism**: Controls wrist and finger articulation, replicating natural human movements.
- **Power Source**: Supplies adequate power to all components of the subsystem.

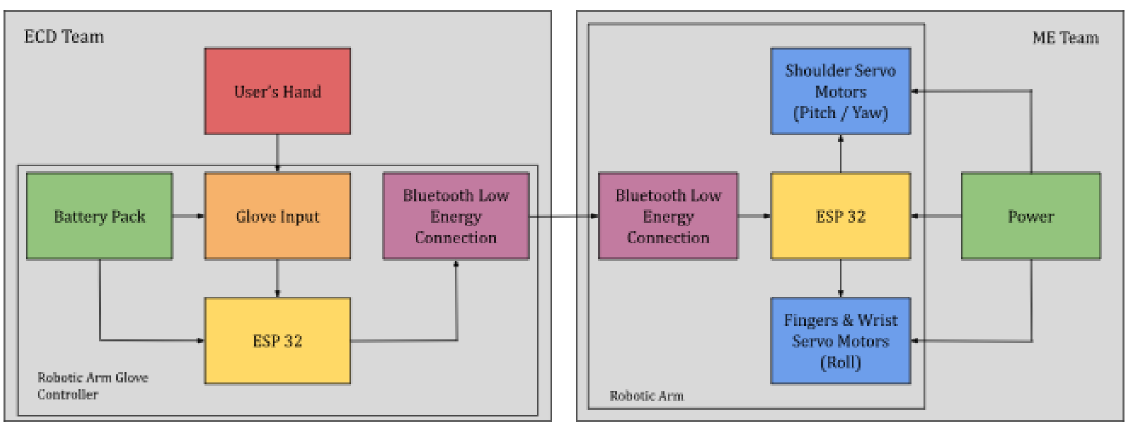

Figure 4: Simple System Block Diagram

4.3 Concept of Execution

As shown in our Context Diagram in Figure 1, the user will be wearing the Glove Controller with all of the components and sensors integrated within. As the user is moving their arm, wrist, and fingers, the Glove Controller will be reading the movements and processing them for the mechanical arm to use. The data will then be sent wirelessly to the microcontroller on the mechanical arm, which will copy the user's movements. The Robotic Arm will be wearing the NES Power Glove and will be playing a game designed for the device. Ultimately, the goal of our project is to accurately read the user's arm movements and transfer the data wirelessly with minimal lag time.

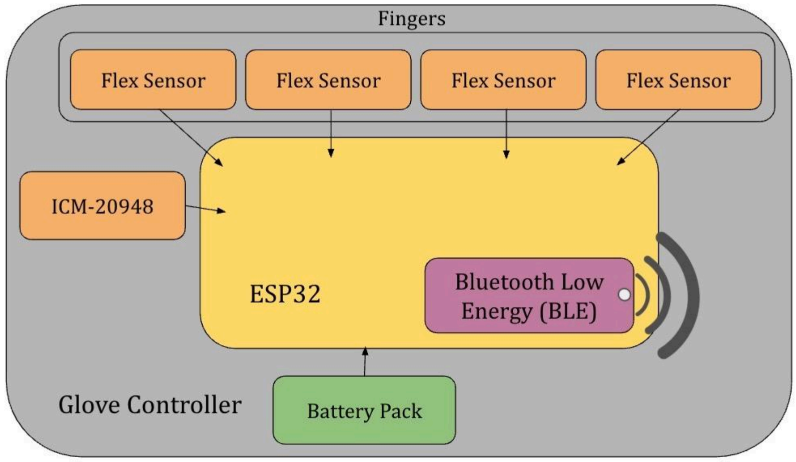

Figure 5: High-Level System Diagram

4.4 Electronics Design

The electrical system shown in Figure 6 is designed to capture user inputs from the glove's sensors, process the data, and wirelessly transmit control signals to the Robotic Arm. The focus is on achieving responsiveness, accuracy, and smooth integration with the ME team's system. Core components include:

- **Power Supply**: This battery pack powers the Glove Controller, providing a stable 5V output at up to 2A and has a rating of 5000mAh. It ensures reliable operation of the ESP-32, ICM-20948, and other components while maintaining portability.
- **Flex Sensors**: These sensors are embedded in all four fingers of the Glove Controller, acting as variable resistors. Their resistance increases as they bend, allowing for precise tracking of finger movements.
- **Accelerometer and Gyroscope**: ICM-20948 is an electromechanical device that allows for 9-axis motion detection. It works alongside the ESP-32 to detect roll, pitch, and yaw movements, enabling accurate motion tracking.
- **Microcontroller**: ESP32 serves as the processing hub, handling sensor data acquisition, signal processing, and Bluetooth communication.

A DC signal of 3.3V from the ESP-32 is utilized to power the flex sensor subsystem. This voltage signal is passed through a voltage divider circuit composed of one 10k-ohm resistor per finger, flex sensors, and an op-amp wired as an impedance buffer. When the flex sensors are bent, resistance changes and translates into measurable voltage readings. The voltage divider allows for better control over the voltage of the output signals by setting a distinct range based on the resistors chosen. The signals are then sent through a feedback circuit to smooth out flex sensor outputs, reducing sensitivity to minor bends and improving accuracy before being processed by the ESP-32. The ICM-20948 tracks all the user's movements and sends all the signals to the ESP-32 before being transferred by bluetooth to the client.

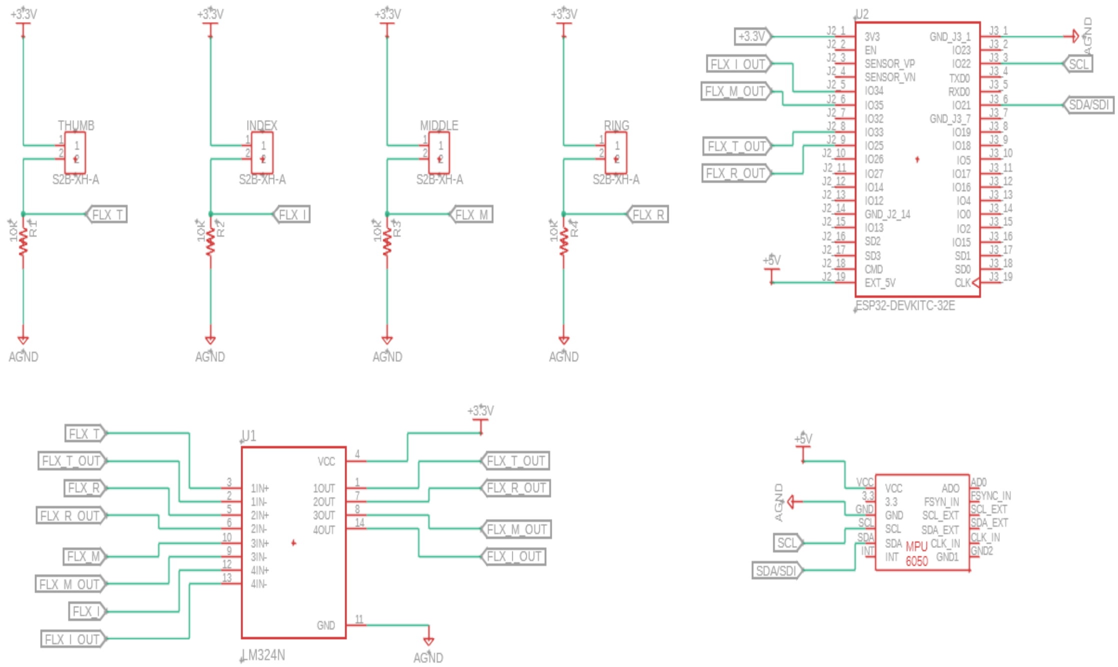

Figure 6: Schematic of Glove Controller

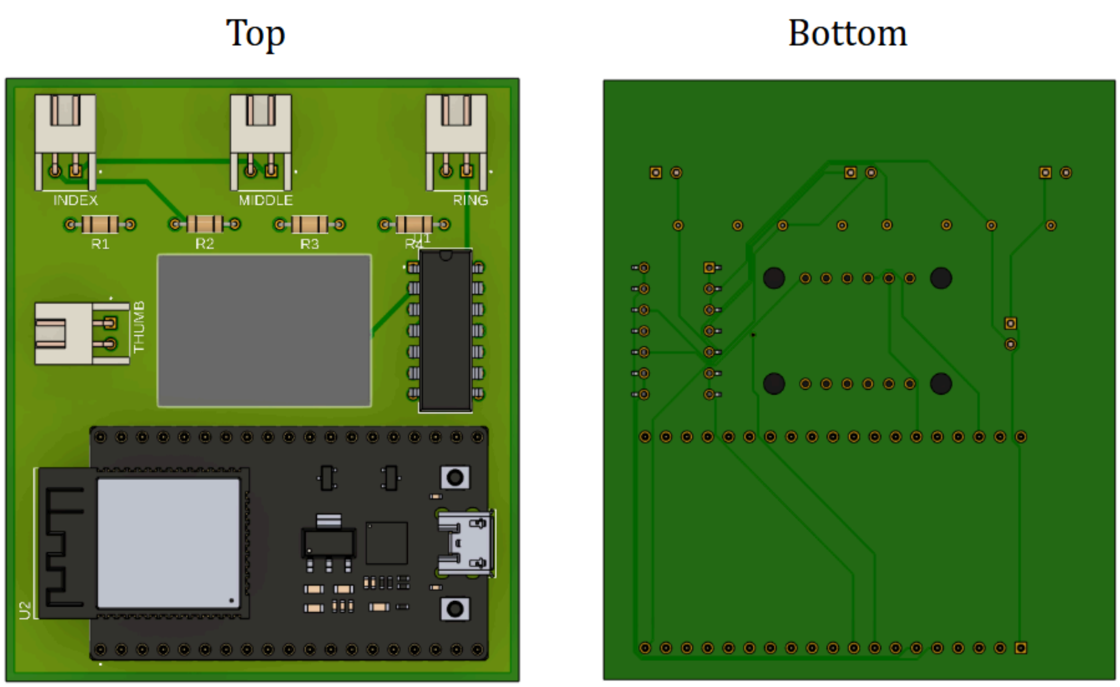

Figure 7: Glove Controller PCB

4.5 Software Design

The software for this project is designed in C++ programming using Arduino IDE. Since ESP-32 is used as the microcontroller, Arduino IDE provides many built-in libraries that are compatible with ESP-32. It provides library functions for BLE communication which makes it easier to establish communication and transfer data over the microcontroller. It also provides a serial monitor useful for tracing and debugging.

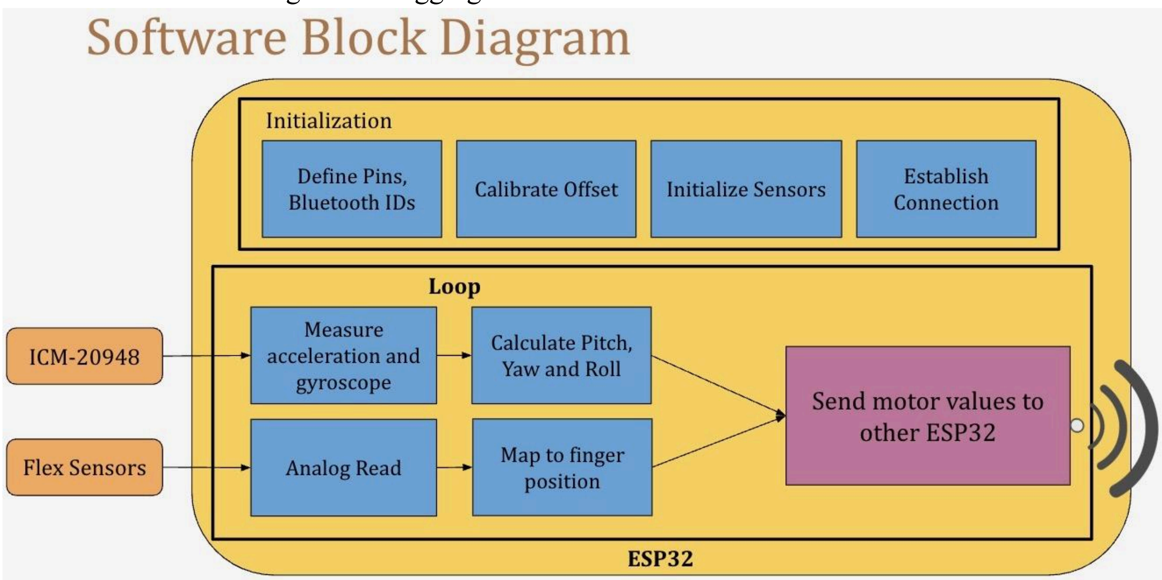

Figure 8: Software Block Diagram

The software design for the controller glove focuses on real-time acquisition and processing of hand motion and finger position data. Using the ICM-20948 sensor, roll, pitch, and yaw angles are calculated through a complementary filter, combining accelerometer and gyroscope readings. Flex sensors map finger bending to analog values, which are then processed and transmitted to the robotic arm over BLE. The software is modular, with dedicated components for sensor initialization, data processing, and communication.

4.6 Safety Considerations

One of the primary safety concerns is ensuring the electrical safety of the Glove Controller. To address this, the design utilized PCB fabrication to reduce the number of exposed wires, minimizing the risk of accidental contact. Additionally, Bluetooth communication is used to eliminate the need for a physical connection between the Glove Controller and the Robotic Arm, enhancing user safety. All electrical components are to be enclosed and concealed for protection and to further prevent user interference.

Another key consideration is maintaining the sanitation of the Glove Controller. As the project is intended for use in a public exhibit, the controller will be worn by numerous users, increasing the potential for transmission of germs and illness. To mitigate this, disposable gloves and sanitation supplies will be provided, ensuring the device remains hygienic and safe for users.

4.7 Environmental Impact

N/A

5 Project Development

5.1 Risk Abatement

One significant risk is the possibility of the Senior Project Capstone Expositions for the ECE and ME teams being held at different locations on the same day, making it difficult to demonstrate the full integration of the Glove Controller and the Robotic Arm. To address this, we have developed a contingency plan to showcase the functionality of the Glove Controller independently as shown in Figure 8. The receiving ESP-32 will be connected to LEDs and servo motors, simulating the Robotic Arm's movements. The LEDs will light up synchronously to reflect finger curling, while the servo motors will visually represent the arm and hand movements. This setup will effectively demonstrate the controller's functionality and precision, ensuring the project goals are met regardless of location constraints.

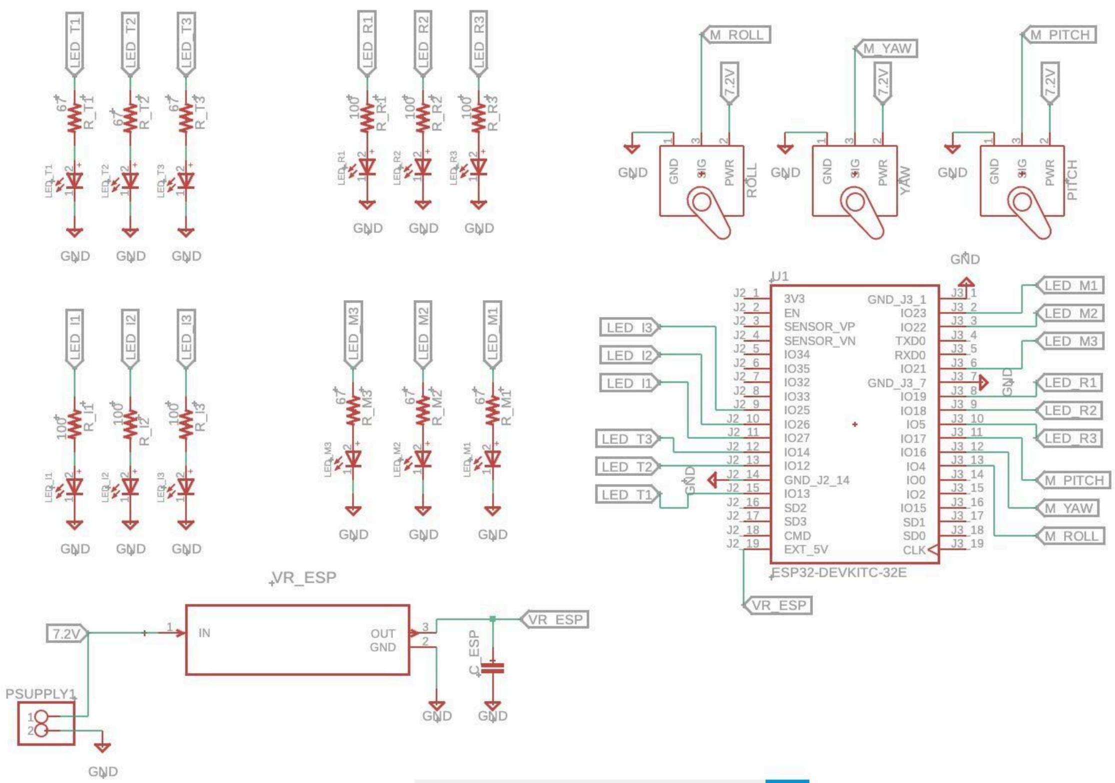

Figure 9: Schematic of Integrated Test Adapter

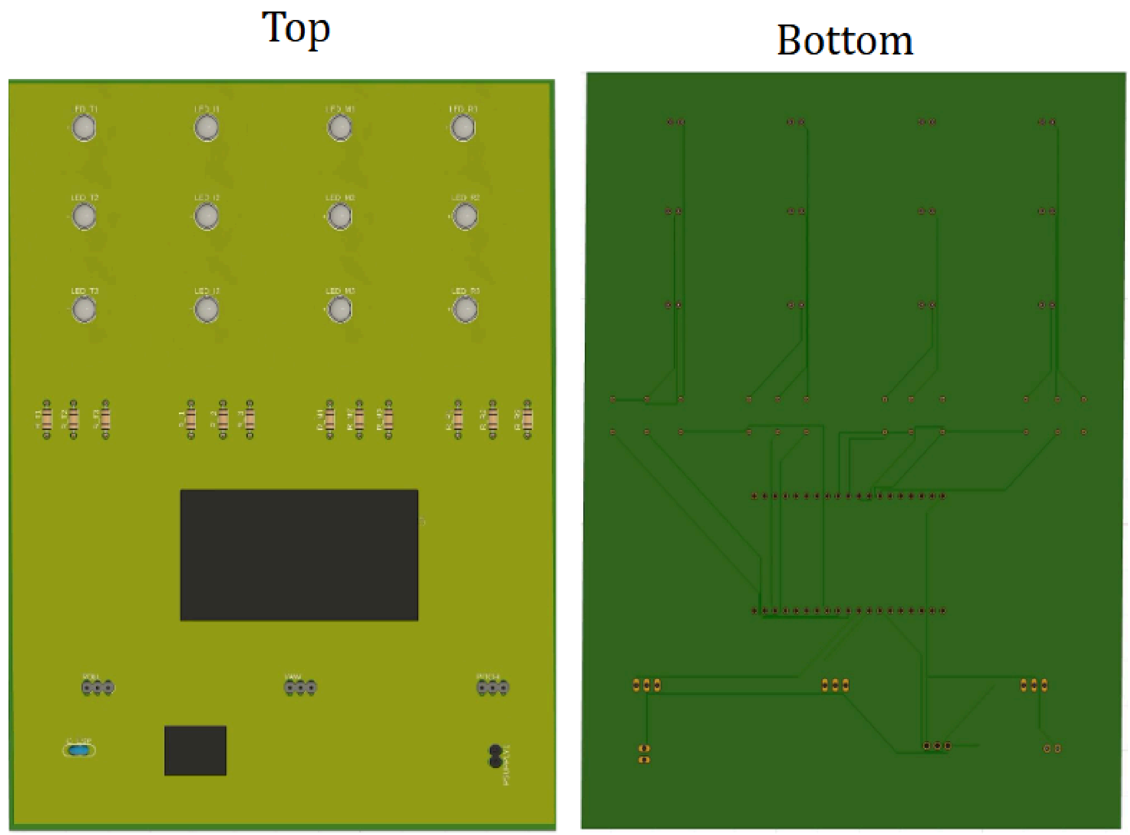

Figure 10: Integrated Test Adapter PCB

5.2 Project Schedule

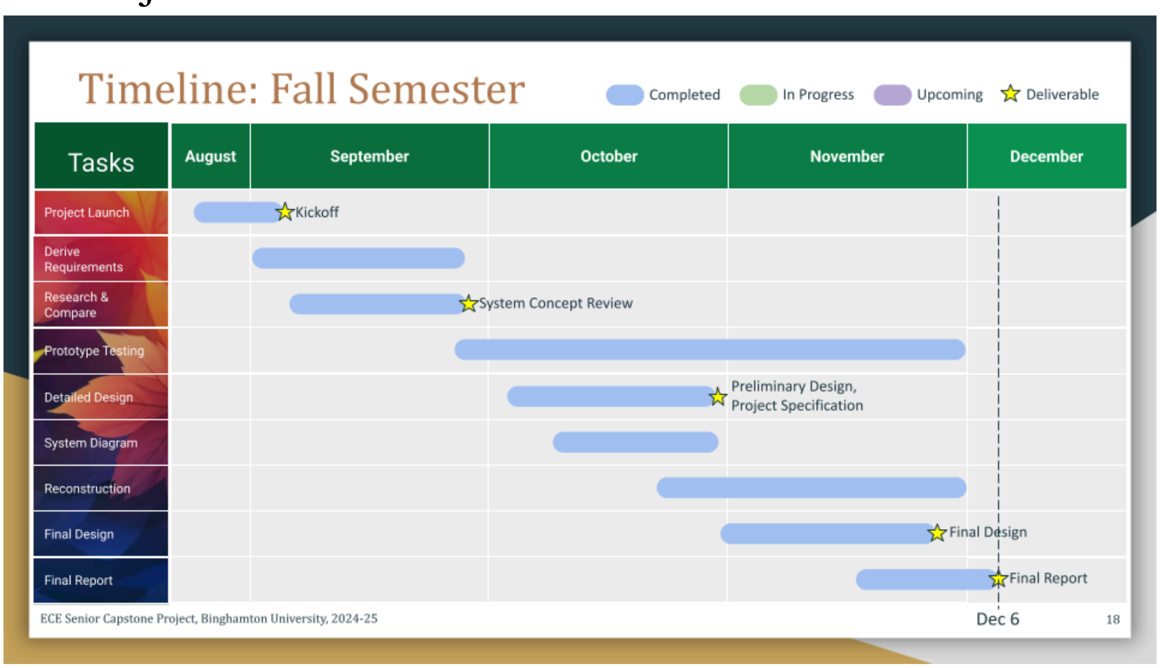

Figure 11: Fall Semester Gantt Chart

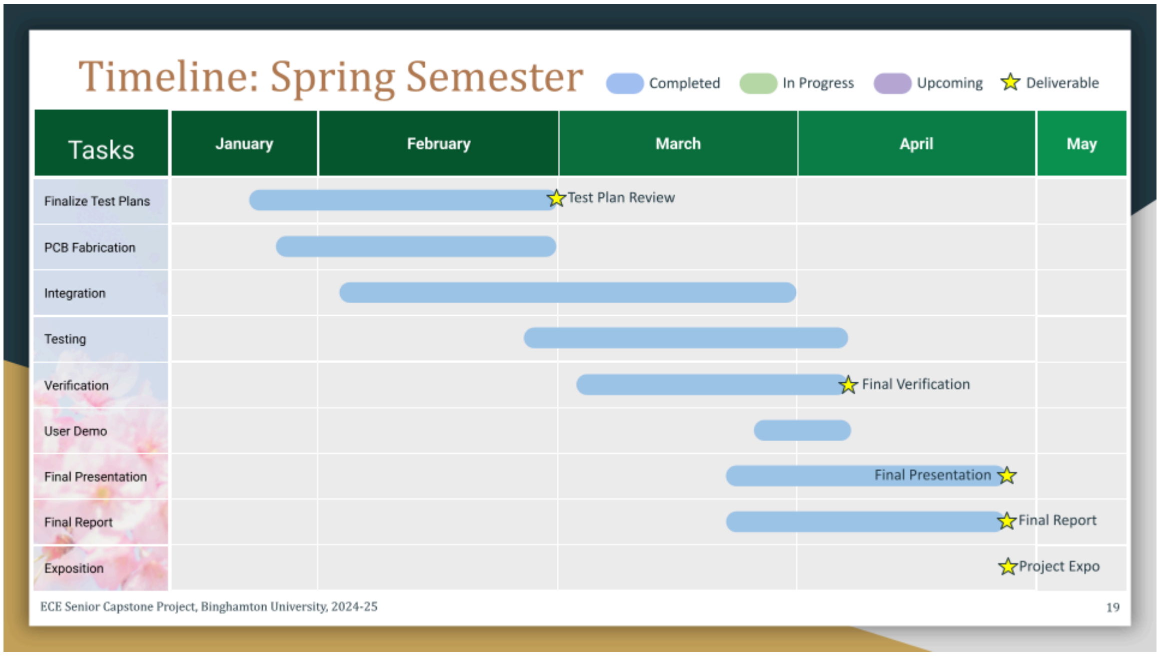

Figure 12: Spring Semester Gantt Chart

5.3 Project Finances

We spent well under our budget of $1000 with most of our spending going towards the flex sensors. Originally, we purchased 4 of the regular flex sensors for testing purposes and found that they had an inconsistent range of values. We then purchased new sensors from Spectraflex after examining their datasheet and found that they would be more accurate and reliable than the originals. After confirming the reliability and list of final parts, we ordered additional backup parts in case of hardware failure. The rest of the materials used are provided by the university and were obtained at no cost. The complete list of materials for the final device can be found in the Bill of Materials.

Item #	Description	Quantity	Unit Cost	SubTotal	Shipping Cost	Total
1	ESP32 Development Board Module	3	$6.66	$19.99	$0	$19.99
2	USB A to microUSB	2	$4.50	$8.99	$0	$8.99
3	Lineman Work Glove	1	$27.19	$27.19	$0	$27.19
4	Rechargable Power Bank 5V@2.1A	2	$26.95	$53.90	$0	$53.90
5	Spectraflex Flex Sensor	4	$17.66	$70.64	$0	$70.64
6	ICM-20948	3	$14.95	$44.85	$0	$44.85
7	Printed Circuit Boards	5	$2.64	$13.20	$0	$13.20

						$238.76

Table 1: Project Finance Expenses

Total Budget	Available Funds
$1000	$272.43

Table 2: Project Finances Budget

6 System Implementation

6.1 System Implementation Overview

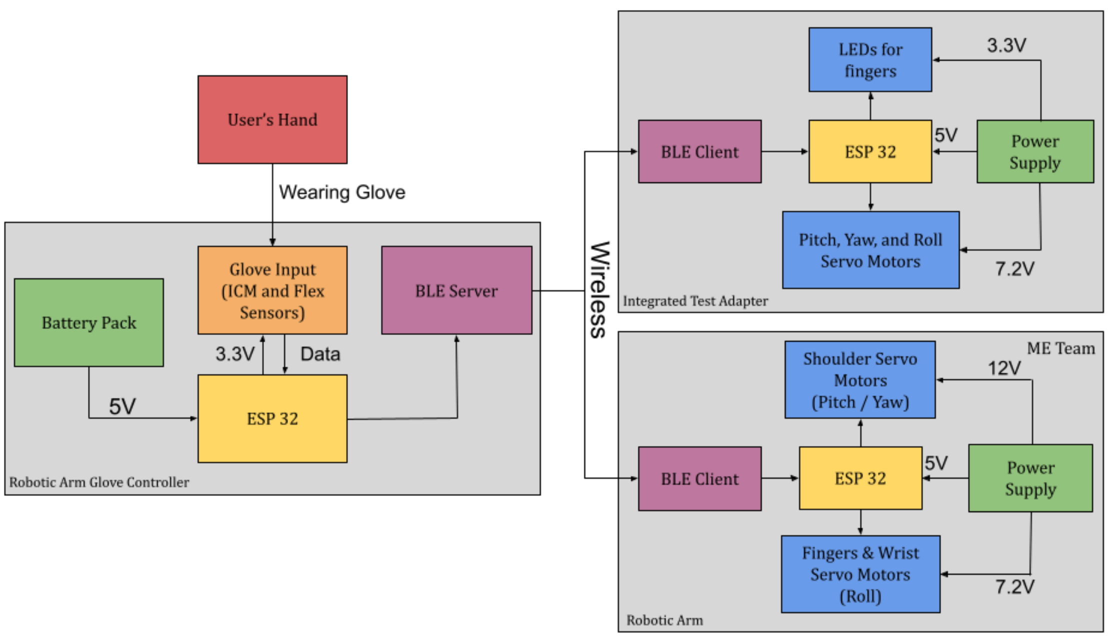

Figure 13: System Integration Diagram

6.2 Controller

The Glove Controller acts as the user interface in this electrical system and will be sending signals to the Robotic Arm as well as our Integrated Test Adapter (ITA). These signals are sent via Bluetooth and describe the changes in the user's arm and hand motions. As shown in *Figure 5*, the main components within the Glove Controller consist of an ESP-32, ICM-20948, 4 flex sensors, and a battery pack. The designed circuitry consists of a simple voltage divider between a resistor and the flex sensor which is then sent to an LM324 Op-Amp acting as an Impedance Buffer. The flex sensor acts as a potentiometer, or in other words, a variable resistor. This design was kept for the practical and effective ways of electrically representing the change in a finger's position. We chose the Spectra Symbol flex sensors specifically for their "low-drift technology" which ensures minimal signal drift when bending fingers, ultimately reducing any more potential for lag. The purpose of using the Op-Amp as an Impedance Buffer is to isolate the output of the flex sensors as well as improve accurate signals for the microcontroller to process. The ICM-20948 has the capabilities of an accelerometer and a gyroscope, both of which will be in this project. This will also be sending its ever-changing signals to the ESP-32 as the user uses the Glove Controller. All data from each component is processed through Arduino IDE and sent to a receiving ESP-32 that will be implemented into the Robotic Arm and the ITA.

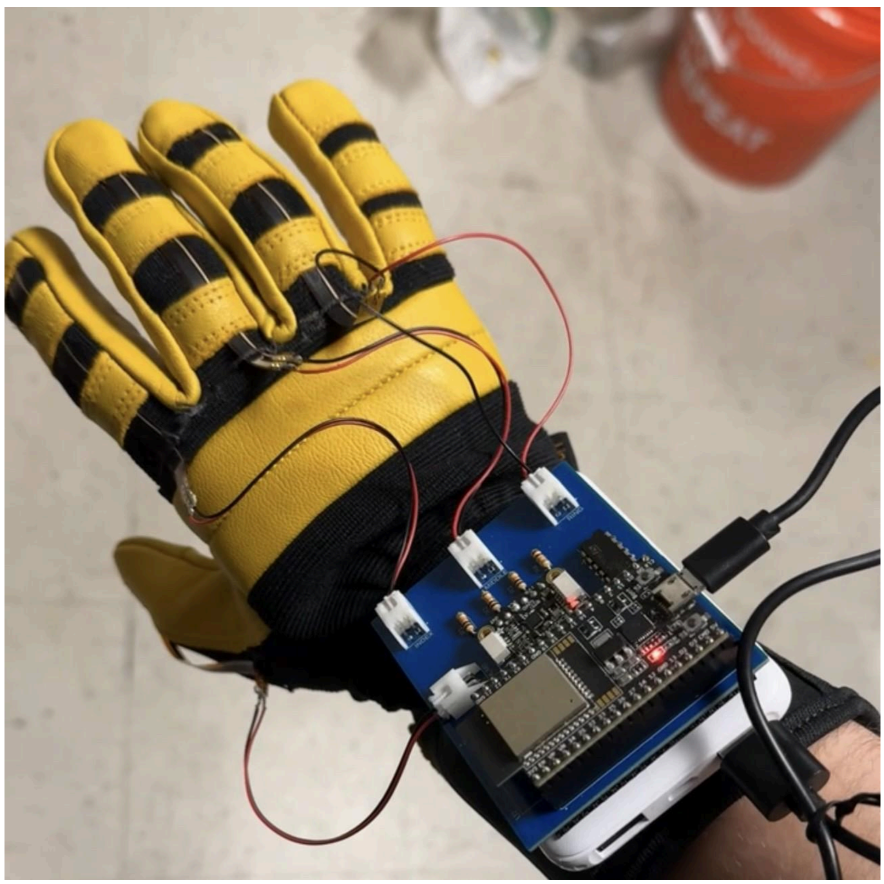

Figure 14: Glove Controller

6.3 Integrated Test Adapter

The ITA was designed as a way to demonstrate that our Glove Controller meets all project specifications and operates as intended. It also serves a purpose equal to that of a piece of test equipment in a real manufacturing environment. Like most real-world projects, there is lots of testing and integration between numerous teams of engineers, which ultimately leads to many problems between the separate systems they may be producing. In order to minimize this, the teams will usually produce a piece of test equipment along with their system to ensure its performance, reliability, and durability before integrating final systems with other teams. The ECD526 team decided to follow this practice and create our own ITA to ensure the Glove Controller's performance, reliability, and durability before integrating with the ME team, as well as a way to demonstrate our project at the Senior Capstone Exposition. This ITA consists of another ESP-32, LED lights, and three servo motors. The ESP-32 will process signals from the ESP-32 located within the Glove Controller and electronically mimic the user's movements. We demonstrate this by synchronously lighting 4 LEDs which symbolize the 4 individual fingers bending as well as rotating three servo motors which will individually rotate depending on the user's yaw, pitch, and roll motions.

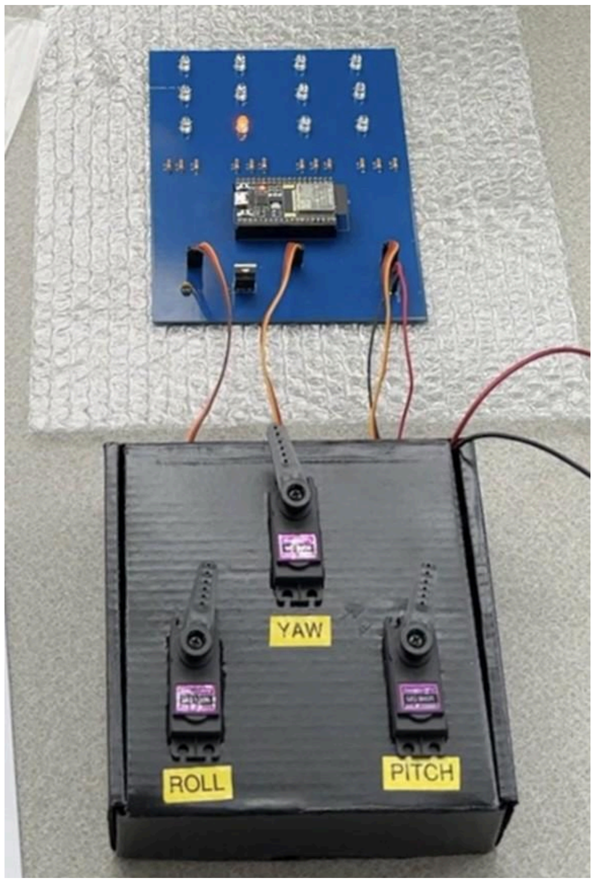

Figure 15: Integrated Test Adapter

7 Project Evaluation

7.1 Overview

The evaluation of this project focuses on verifying that all of our requirements have been met through a series of tests. All tests were completed with the complete and integrated glove controller and an integrated test adapter to visualize the effects, as well as digital monitoring for specific values. Sensor performance was assessed by comparing the calculated pitch, yaw, and roll values to their respective motors' physical orientation, ensuring accuracy and responsiveness. Bluetooth stability was also tested for up to 20 meters to confirm reliable wireless control. Tests were also performed several times over the course of several days to ensure consistency and reliability.

7.2 Testing and Results

The primary methodology for conducting tests to verify that the system meets its requirements will be system verification, as outlined by the ECD526 team. Initial calculations were conducted to give the team a rough estimate of key parameters.

7.2.1 Test Coverage

Test ID	Test Name	QM	RC	Requirements Addressed	Test Completion Date (Actual)	Test Completion Date (Deadline)
ECD526-T-001	Bluetooth Parameter Test	A	EI	ECD526-G-001	3/27/2025	04/11/2025
ECD526-T-002	Finger Curl Test	D	SC	ECD526-R-001 ECD526-R-002	3/27/2025	04/11/2025
ECD526-T-003	Roll Motor Test (+/- 90°)	T	SC	ECD526-R-003	3/28/2025	04/11/2025
ECD526-T-004	Pitch Motor Test (+/- 45°)	T	SC	ECD526-R-004	3/28/2025	04/11/2025
ECD526-T-005	Yaw Motor Test (+/- 45°)	T	SC	ECD526-R-005	3/28/2025	04/11/2025

ECD526-T-006	Robotic Arm Test	D	EI	ECD526-G-003	3/28/2025	4/11/2025

7.2.2 Detailed System Verification Tests

ECD526-T-001: Bluetooth Parameter Test

The objective of the Bluetooth Parameter Test is to verify that the connection between the two ESP-32 modules is stable. The final product is expected to operate in a museum, and this test is to ensure that the ESP-32 modules maintain connection within a reasonable distance.

Step-by-Step Procedure	Expected Results	Actual Results
Establish Bluetooth connection between the two ESP-32 modules	Motors and LEDs work as intended as in the previous tests.	Pass
User moves up to 20 feet away from the ITA/Robotic Arm while wearing the Glove Controller	Motors and LEDs continue to work as intended with minimal lag in response time.	Pass

ECD526-T-002: Finger Curl Test

The purpose of the Finger Curl Test is to ensure that the functionality of each flex sensor is stable and maintains consistent output values. The voltage value being read from the flex sensors will decrease as the user bends their finger, and three LEDs corresponding to each four fingers will illuminate synchronously depending on how much the voltage readings change.

Step-by-Step Procedure	Expected Results	Actual Results
Choose threshold voltage values per finger at 3 given points	Arduino IDE will read voltage value as the flex sensor bends	Pass
Illuminate LEDs with the given voltage values to designated I/O pin (ITA)	Each LED light in an I/O pin will illuminate when threshold voltage value is being met	Pass

ECD526-T-003: Roll Motor Test

The objective of the Roll Motor Test is to assess the Glove Controller's ability to control the roll motion of the Robotic Hand. This test aims to verify that the servo motor is capable of rotating at least 90° in both directions while being controlled by the user wearing the glove.

Step-by-Step Procedure	Expected Results	Actual Results
Establish Bluetooth connection between the two ESP-32 modules	Servo motor indicating Roll will reset to a default position	Pass
User moves their wrist by 90° in a clockwise motion while wearing the Glove Controller	Servo motor (roll) rotates 90° clockwise. Monitor displays exact rotational angle.	Pass
User moves their wrist by 90° in a counter-clockwise motion while wearing the Glove Controller	Servo motor (roll) rotates 90° counterclockwise. Monitor displays exact rotational angle.	Pass

ECD526-T-004: Pitch Motor Test

The objective of the Pitch Motor Test is to assess the Glove Controller's ability to control the pitch motion of the Robotic Arm. This test aims to verify that the servo motor is capable of rotating at least 45° in both directions while being controlled by the user wearing the glove.

Step-by-Step Procedure	Expected Results	Actual Results
Establish Bluetooth connection between the two ESP-32 modules	Servo motor indicating Pitch will reset to a default position	Pass
User raises their arm upward by 45° while wearing the Glove Controller	Servo motor (pitch) rotates 45° clockwise. Monitor displays exact rotational angle.	Pass
User lowers their arm downward by 45° while wearing the Glove Controller	Servo motor (pitch) rotates 45° counterclockwise. Monitor displays exact rotational angle.	Pass

ECD526-T-005: Yaw Motor Test

The objective of the Yaw Motor Test is to assess the Glove Controller's ability to control the pitch motion of the Robotic Arm. This test aims to verify that the servo motor is capable of rotating at least 45° in both directions while being controlled by the user wearing the glove.

Step-by-Step Procedure	Expected Results	Actual Results
Establish Bluetooth connection between the two ESP-32 modules	Servo motor indicating Yaw will reset to a default position	Pass
User moves their arm to the right by 45° while wearing the Glove Controller	Servo motor (yaw) rotates 45° clockwise. Monitor displays exact rotational angle.	Pass
User moves their arm to the right by 45° while wearing the Glove Controller	Servo motor (yaw) rotates 45° counterclockwise. Monitor displays exact rotational angle.	Pass

ECD526-T-006: Robotic Arm Test

The objective of the Robotic Arm Test is to assess the Glove Controller's ability to integrate with the actual mechanical arm. This test is to be done after the completion of all previous tests. The previous tests prove that our glove controller system works as expected and acts as a safety measure in case the Mechanical Team does not complete the mechanical arm.

Step-by-Step Procedure	Expected Results	Actual Results
Establish Bluetooth connection between the two ESP-32 modules	Robotic Arm will move to its initialized position	N/A
User moves their arm to the left and right like the Yaw Motor Test	Robotic Arm will mimic the users arm movements	N/A
User moves their arm up and down like the Pitch Motor Test	Robotic Arm will mimic the users arm movements	N/A
User rolls their wrist like in the Roll Motor Test	The hand on the Robotic Arm will roll and copy the users hand	N/A
User bends each finger individually (except pinky)	The fingers on the Robotic Arm will bend accordingly	N/A

7.3 Assessment

The objective of this project was to create a glove controller that can reliably and seamlessly control a mechanical arm, and we believe it was a success. We improved every aspect of the previous year's design, including flex sensor reliability, software, and overall packaging of the glove controller. We also went above and beyond to design an integrated test adapter to demonstrate and prove that our system works as intended.

Unfortunately, the Mechanical Engineering team never finished the Robotic Arm on time for us to integrate the two systems together for our exposition or theirs (their arm also broke down a short time after completion).

Overall, the project was given very positive feedback on our work throughout the year, at the expo, final demos, and other aspects. We have learned a lot by working on this project as a team and are proud of the work we have done.

7.4 Future Potential

Although we feel that we did very well with this project and have improved upon what ECD416 did the previous year, we feel that there is still room for even more improvement. These areas don't necessarily have to do with the electronics in the Glove Controller, but the actual construction of it. If possible, an enclosed package including the battery and electronics might look better, but is not that great for demonstration purposes. If there could be a combination of a packaged product with an open top, that would probably be ideal. Another area for improvement would be securing the flex sensors to the glove. We utilized a combination of super glue, along with a needle and thread to secure the flex sensors to the fingers of the glove. Although this method would suffice, we found that sometimes we could get some inaccurate/false readings on the ITA when the fingers were previously bent. Lastly, we feel that a well-packaged ITA would also be even more presentable than what we had produced.

8 Notes

8.1 Acronyms and Abbreviations

ECD ECE Capstone Design
ECE Electrical and Computer Engineering
ME Mechanical Engineering
NES Nintendo Entertainment System
PCB Printed Circuit Board
BLE Bluetooth Low Energy
ITA Integrated Test Adapter

8.2 Bibliography

N/A

8.3 References

[1]https://cdn.shopify.com/s/files/1/0578/4128/7283/files/SPECTRAFLEX_DATA_SHEET_v1.0.pdf?v=1691015077

[2]https://github.com/nkolban/ESP32_BLE_Arduino

[3]Expressif Systems, arduino-esp32, https://github.com/espressif/arduino-esp32

[4]Adafruit ICM20X, https://github.com/adafruit/Adafruit_ICM20X

9 Appendix

9.1 Appendix A - ECD 526 Project Specification Document

ECD 526 Project Specification Document
TechWorks! Robotic Arm Controller

Project Description

Summary: The goal for this project is to design a controller that interfaces and commands a mechanical arm that is an ME Capstone project. The objective of the combined ECD and ME Capstone projects is to design and implement a Controlled Robotic Arm. The idea of this project is referenced to the NES Power glove that was sold by Nintendo Entertainment Systems. This power glove is designed to make video games more advanced and intriguing in the evolution of gaming.

Client: TechWorks!

Industry Mentor: Arthur Law

Project Advisor: Arthur Law

Team: Christopher Garufi, Kevin Lin, Armani Lopez, Rakhesh Varshan Dhamodaran

Requirements

This document lists all essential project requirements for this project. A requirement is identified by “shall”, a good practice by “should”, permission by “may” or “can”, expected outcome or action by “will”, and descriptive material by “is” or “are” (or another verb form of “to be”).

The following Qualification Method (QM) is to be used:

- Demonstration (D): The operation of the system, or a part of the system, that relies on observable functional operation not requiring the use of instrumentation, special test equipment, or subsequent analysis.
- Test (T): The operation of the system, or a part of the system, that uses instrumentation or other special test equipment to collect data for analysis.
- Analysis (A): The processing of data obtained from another qualification method. For example, reduction, interpolation, or extrapolation of test results.
- Inspection (I): The visual examination of system components, documentation, etc.

The following Requirement Categories (RC) are to be used:

- System Capability Requirements (SC): Requirements pertaining to the functionality and behavior of the system.
- System External Interface Requirements (EI): Requirements based on the external interfaces of the system. Interfaces with input power, user input, or any other outside source
- Project Business Requirements (PB): Requirements pertaining to business objectives set by a sponsor such as installation requirements, requirements pertaining to specific lab access or lab equipment needs etc.
- Other Requirements (O): Safety, Security and Privacy, System Environment concerns etc.

2.1 Derived Requirement Specification

ID	QM	RC	Derived Requirement
ECD526-R-001	D	SC	The Glove Controller shall control the first four fingers of the Robotic Arm.
ECD526-R-002	D	SC	The Glove Controller shall smoothly curl any or all of the first four fingers
ECD526-R-003	T	SC	The Glove Controller shall smoothly **roll** the Robotic Arm +/- 90 degrees
ECD526-R-004	T	SC	The Glove Controller shall smoothly **pitch** the Robotic Arm +/- 45 degrees
ECD526-R-005	T	SC	The Glove Controller shall smoothly **yaw** the Arm +/- 45 degrees

2.2 Derived Stretch Goals

ID	QM	RC	Derived Requirement
ECD526-G-001	A	EI	The connection between the Glove Controller and the Robotic Arm should be wireless.
ECD526-G-002	I	O	There should be no exposed wires on the Glove Controller.
ECD526-G-003	I	O	The EECE and ME teams should integrate projects upon completed implementation.

2.3 Original Proposed Requirements

1. The Glove Controller shall be capable of individually controlling all five fingers of the Robotic Arm.
2. The Glove Controller shall output signals to the Robotic Arm to smoothly curl any or all fingers between completely curled to fully extended with minimal lag.
3. The Glove Controller shall output signals to the Robotic Arm to smoothly roll the Arm around the long axis +/- 90 degrees with minimal lag
4. The Glove Controller shall output signals to the Robotic Arm to smoothly pitch the Arm +/- 45 degrees around the horizontal axis with minimal lag
5. The Glove Controller shall output signals to the Robotic Arm to smoothly yaw the Arm around the vertical axis +/- 45 degrees with minimal lag
6. The ECE project team should work with the ME project team to integrate the Glove Controller with the Robotic Arm, once the arm is implemented. In the meantime, please refer to the work of last year’s team.
7. The connection between the Glove Controller and the Robotic Arm should be wireless.

9.2 Appendix B - ECD 526 Final Parts List

ECD 526 Final Parts List				
Item #	**Part**	**Link**	**Quantity**	**Notes**
Glove Controller				
1	Lineman Worker's glove	https://a.co/d/7OrxUgG	1	Right handed
2	95mm SpectraSymbol Flex Sensors	https://store.spectrasymbol.com/products/spectraflex-flex-sensor?variant=40919797563507	3	Active Sensor Length: 95mm Connector Type: MP - Male Pins
3	55mm Spectra Symbol Flex Sensors	https://store.spectrasymbol.com/products/spectraflex-flex-sensor?variant=40919797399667	1	Active Sensor Length: 55mm Connector Type: MP - Male Pins
4	Glove Controller PCB		1	Refer to report for detailed schematic
5	5V @ 2.1A - 5000mAh Rechargable Battery	https://www.adafruit.com/product/4288#technical-details	1	charging cable included
6	Adafruit ICM-20948 9-DoF Accelerometer, Gyroscope, Magnetometer Sensor	https://www.digikey.com/short/n51wzdf8	1	
7	ESP32-DEVKITC-32E	https://www.digikey.com/short/8z2v7h4c	1	
8	USB to microUSB programmable cable 6ft	https://a.co/d/7Ez3vPp	1	
9	JST connectors	https://www.digikey.com/short/t01tdm5m	4	
10	10 k-ohm resistors		4	
11	LM324N Op-Amp		1	
12	Extension wires		4	
13	Velcro			
14	Needle and Thread			
Integrated Test Adapter				
15	ESP32-DEVKITC-32E	https://www.digikey.c	1	

		om/short/8z2v7h4c		
16	Integrated Test Adapter PCB		1	Refer to report for detailed schematic
17	5V Fixed Output Voltage Regulator	https://www.digikey.com/short/wn5cmbvd	1	
18	100-ohm resistors		12	
19	2.2 uF Capacitor		1	
20	7.2V Servo Motors	https://a.co/d/5kjOfu6	3	
21	LED lights		12	
22	Female to Male Jumper Wires		2	Not included (borrowed) - cleaner connection to power
23	DC Power Supply capable of 7.2V		1	Not included (borrowed)
24	Banana to Hook Wire		2	Not included (borrowed)
25	Housing for Servo Motors (We recycled a box)		1	

9.3 Appendix C - ECD 526 Finance Summary

ProjectID	Order Num	OrderDate	TotalOrder Cost	Project Budget	Available Funds	OrderRequestedBy	Contact
ECD526	1	23-Oct-2024	$89.49	$1,000	910.51	Kevin Lin	klin138@binghamton.edu
ECD526	2	7-Nov-2024	$118.35	$1,000	792.16	Rakhesh Varshan Dhamodaran	rdhamodaran@binghamton.edu
ECD526	3	30-Jan-2025	$118.05	$1,000	674.11	Rakhesh Varshan Dhamodaran	rdhamodaran@binghamton.edu
ECD526	4	19-Feb-2025	$146.82	$1,000	527.29	Rakhesh Varshan Dhamodaran	rdhamodaran@binghamton.edu
ECD526	5	25-Feb-2025	$27.67	$1,000	499.62	Rakhesh Varshan Dhamodaran	rdhamodaran@binghamton.edu
ECD526	6	27-Feb-2025	$29.90	$1,000	469.72	Rakhesh Varshan Dhamodaran	rdhamodaran@binghamton.edu
ECD526	7	28-Feb-2025	$10.00	$1,000	459.72	Rakhesh Varshan Dhamodaran	rdhamodaran@binghamton.edu

ECD526	8	6-Mar-2025	$43.18	$1,000	416.54	Rakhesh Varshan Dhamodaran	rdhamodaran@binghamton.edu
ECD526	9	19-Mar-2025	$56.73	$1,000	359.81	Rakhesh Varshan Dhamodaran	rdhamodaran@binghamton.edu
ECD526	10	20-Mar-2025	$67.38	$1,000	292.43	Rakhesh Varshan Dhamodaran	rdhamodaran@binghamton.edu
ECD526	11	28-Mar-2025	$20.00	$1,000	272.43	Rakhesh Varshan Dhamodaran	rdhamodaran@binghamton.edu

9.4 Appendix D - ECD 526 Test Results and Procedures

Test ID	Test Name	QM	RC	Requirements Addressed (Requirements ID)	Test Status	Test Completion Date	Pass /Fail	Test Results (Details)
ECD526-T-001	Bluetooth Parameter Test	A	EI	ECD526-G-001	Completed	3/27/2025	Pass	Tested bluetooth transmission and range up to 30 meters
ECD526-T-002	Finger Curl Test	D	SC	ECD526-R-001 ECD526-R-002	Completed	3/27/2025	Pass	Tested fingers bending and corresponding LEDs lit up depending on which finger and how much the finger is bent.
ECD526-T-003	Roll Motor Test (+/- 90°)	T	SC	ECD526-R-003	Completed	3/28/2025	Pass	Servo Motors follow the position of the MPU orientation as the hand moves
ECD526-T-004	Pitch Motor Test (+/- 45°)	T	SC	ECD526-R-004	Completed	3/28/2025	Pass	Servo Motors follow the position of the MPU orientation as the hand moves
ECD526-T-005	Yaw Motor Test (+/- 45°)	T	SC	ECD526-R-005	Completed	3/28/2025	Pass	Servo Motors follow the position of the MPU orientation as the hand moves
ECD526-T-006	Robotic Arm Test	D	El	ECD526-G-003	Delayed	N/A		Contruction of mechanical arm is still in progress by the ME Team.

9.5 Appendix E - ECD 526 Project Standards

ECD526 Project Standards

Adhering to industry standards is essential for ensuring the safety, reliability, and compatibility of our glove controller. These standards provide established guidelines that help improve hardware durability, software maintainability, and overall system performance. By following best practices in PCB design, wireless communication, and embedded programming, we can minimize risks, improve efficiency, and ensure seamless integration with other systems, such as the robotic arm. Additionally, maintaining compliance with industry standards allows for future scalability and ensures that our design remains structured and adaptable for potential upgrades or modifications. Below are some of the key engineering standards that we are following in the development of our glove controller:

- Electrical Design Compliance: Our team is following IPC-2221 PCB design guidelines to ensure a safe, efficient, and structured circuit layout. These guidelines help us minimize exposed wiring, reduce electrical noise, and improve the overall reliability of our design. Proper PCB design also enhances thermal management, which is essential for long-term system stability.

- Wireless Communication Compliance: The glove controller relies on Bluetooth communication to send movement data to the robotic arm. By adhering to IEEE 802.15.1 (Bluetooth) standards, we ensure low-latency, interference-free, and secure wireless communication. This prevents signal disruptions and ensures real-time responsiveness of the robotic arm.

- Electrical Equipment Compliance: To ensure that all electrical components are safely integrated, we adhere to IEC 60204-1 standards for electrical safety. These guidelines help us select the correct electrical equipment, implement proper grounding techniques, and reduce the risk of short circuits or component failures.

- Power Compliance: Given that our system operates on a battery-powered supply, it is essential to follow IEC 61558 standards to ensure that our voltage regulation and power conversion methods are safe and effective. This ensures that our battery charger, voltage regulators, and power supply components are designed to operate within safe voltage and current limits, reducing risks of overheating or power instability.

By integrating these engineering standards into our design process, we increase the reliability, efficiency, and safety of our glove controller while ensuring that it performs consistently in an exhibit setting. These standards also make our project more scalable, allowing future teams to expand or improve upon our design while maintaining a strong foundation of industry best practices.

9.6 Appendix F - ECD 526 Impact Assessment

Requirements ID	Test Status	Pass/Fail	Project Impact	Impact Assessment (Must fill out for all requirements not tested, or that failed testing)
ECD526-G-001	Completed	Pass	Medium	
ECD526-R-001	Completed	Pass	High	
ECD526-R-002	Completed	Pass	Medium	
ECD526-R-003	Completed	Pass	High	
ECD526-R-004	Completed	Pass	High	
ECD526-R-005	Completed	Pass	High	
ECD526-G-003	Delayed	Fail	Low	No impact on our project since we have an ITA to test. It is a stretch goal to integrate the 2 team projects. The schedule for the ME side is 1-2 weeks behind ECD. Unsure if they have a demo before the expo.