Dexterity

Robotic Armature for Hazardous Materials Manipulation Operated via Haptic Interface Glove

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Abstract

This project aims to develop a haptic finger-tracking glove that controls a robotic hand, enabling safe manipulation of hazardous materials while maintaining human-like dexterity. The system consists of a glove that tracks the user's finger movement, coupled with inertial measurement units (IMUs) to monitor hand and forearm orientation. This motion-tracking system drives a robotic arm based on the open-source Dexhand project. We will integrate touch sensors on each robotic fingertip that activate the glove's electromagnetic brake system. These brakes create tactile feedback by restricting finger movement, simulating the sensation of object manipulation. This haptic feedback, combined with the precise motion tracking, allows for intuitive and accurate control of the robotic hand in hazardous environments.

Background

The increasing need for safe and cost-effective solutions in laboratories handling hazardous materials has driven our team to develop a haptic finger and forearm-tracking glove system that controls a robotic hand. This system is designed to enable researchers to interact with toxic substances while maintaining human-like dexterity and without the need for expensive fume hoods or overly complex robotic setups. The core innovation of our project lies in creating a much more affordable and user-friendly alternative compared to existing commercial solutions, making this technology accessible to a wider audience of researchers and laboratories.

Prior Work

Commercial products such as HaptX [1], SenseGlove [2], and Weart [3] have set the standard in the haptic feedback and remote manipulation market, offering highly immersive and precise systems. These technologies allow users to interact with virtual environments or robotic systems while experiencing realistic tactile feedback. However, these products are often prohibitively expensive and primarily serve industrial applications, limiting their accessibility to smaller research labs and educational institutions.

In the open-source space, projects like LucasVR [4] and Nepyope's VR Glove [5] have demonstrated innovative solutions for hand-tracking and haptic feedback. These projects offer promising foundations, especially in terms of making the technology more accessible. However, they lack the focus on safe, real-world interaction with hazardous materials, as their primary use cases lie within virtual reality environments.

Our project differentiates itself in two key ways: **cost** and **target audience**. By leveraging open-source designs and affordable components, we aim to drastically reduce the overall cost of the system, making it viable for smaller research institutions and universities. Our system also targets laboratories that require safe manipulation of hazardous materials. Unlike existing virtual reality or industrial solutions, our glove allows researchers to remotely control a robotic hand to handle toxic substances with haptic feedback, improving both safety and ease of use without the need for costly equipment or infrastructure.

Coursework Preparation

Our coursework at the University of Virginia has provided a strong foundation for this project. Several key courses have directly prepared us for the technical challenges involved:

- **Intro to Embedded Computing Systems** has given us a solid understanding of microcontrollers and real-time systems, both critical for the responsive control of the glove and robotic arm.
- **Electromagnetic Fields** helped us understand the fundamentals of how electromagnetic braking systems can be implemented to simulate tactile feedback in the glove.
- **Intro to Control Systems** and **Signals & Systems** laid the groundwork for developing the precise control algorithms necessary for converting user hand movements into corresponding robotic arm movements.
- **Electronics** provided us with the skills to design and integrate the necessary hardware components, such as sensors and actuators, into a compact and efficient system.
- **Computer-Aided Design** has allowed us to design and/or modify existing models of both the glove and robotic arm components in a way that is both ergonomic and easy to manufacture, ensuring that the final product is as user-friendly as it is functional.

By applying the principles and techniques we have learned in these courses, we are well-equipped to develop a system that not only tracks hand movements accurately but also provides real-time, tactile feedback to the user. This combination of coursework and innovative design will allow us to bring a cost-effective, high-functioning tool to laboratories where safety and precision are paramount.

Description of Project

How it Works/Technical Details

Overview

As can be seen in Figure 1 below, the Dexterity system consists of a user-worn glove consisting of a suite of sensors with a haptic interface and a robotic arm controlled by the glove. At a high level, there sensor signals from each of the fingers and the forearm are processed into movement commands sent to the robotic arm. Upon receiving these commands, the robotic arm fingers and forearm are manipulated to match that of the glove as close as possible. The robotic arm has a suite of touch sensors, whose data is processed into haptic commands sent back to the glove. The glove processes these haptic commands and restricts movement of the user's fingers.

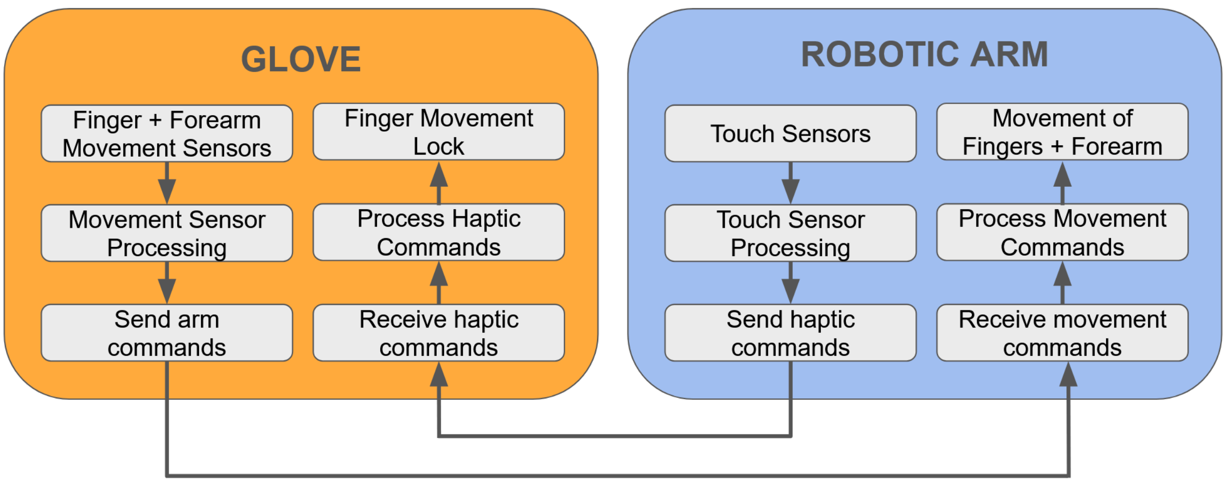

Figure 1: Complete System-Level Diagram

Robotic Arm

Our robotic arm is based on the open source project called the Dexhand [6]. The arm, up to the elbow, has 19 degrees of freedom that are controlled by servo motors. The fingers will account for 16 of these: 3 per finger and 4 for the thumb. The wrist has 2 degrees of freedom, and the rotation of the forearm accounts for the last degree of freedom. One modification we are making to the design is adding an elbow base with 2 degrees of freedom. This base will be securely attached to a table or rolling cart to provide stability to the rest of the hand. With our modifications, the hand will have a total of 21 degrees of freedom. An overview of the CAD can be seen in Figure 2.

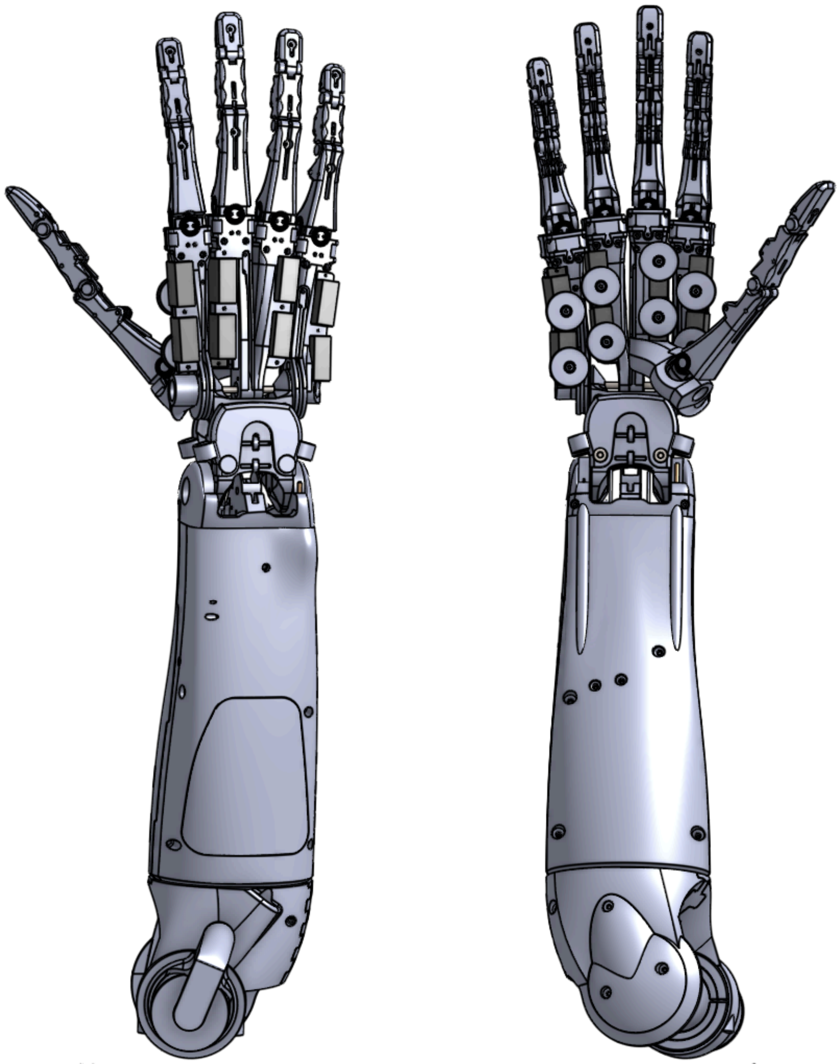

Figure 2: CAD Model of Robotic Arm

Another key modification that we are making to the original design is the integration of pressure sensors in each fingertip. These readings from the pressure sensors will be transmitted to the control glove to engage haptic feedback to create the sensation of holding an object in the user. Additionally we are adding two IMUs: one on the back of the robot hand and one on the back of the forearm. These sensors will be in the same locations on the control glove. To create wrist, forearm, and elbow movement, the robot hand will try to match its IMUs readings to the control gloves IMU readings by moving the wrist and forearm in the appropriate direction. This will be accomplished using PID (proportional integral derivative) [7] loops to control the servos.

This robotic arm control system is built around an ESP32S3 DevkitC microcontroller. It's powered by two Li-ion cells and uses DC-DC converters to regulate 6V for the digital servos and 3.3V for the ESP32. The control glove sends ESP-NOW [8] data packets containing IMU and finger angle data. After processing this data, the ESP32 sends digital signals to control the 16 finger servos and serial data to control the 5 serial servos. The ESP32 will read the pressure sensor values using ADCs and send this data to the control glove using ESP-NOW. A diagram of this system is shown in Figure 3.

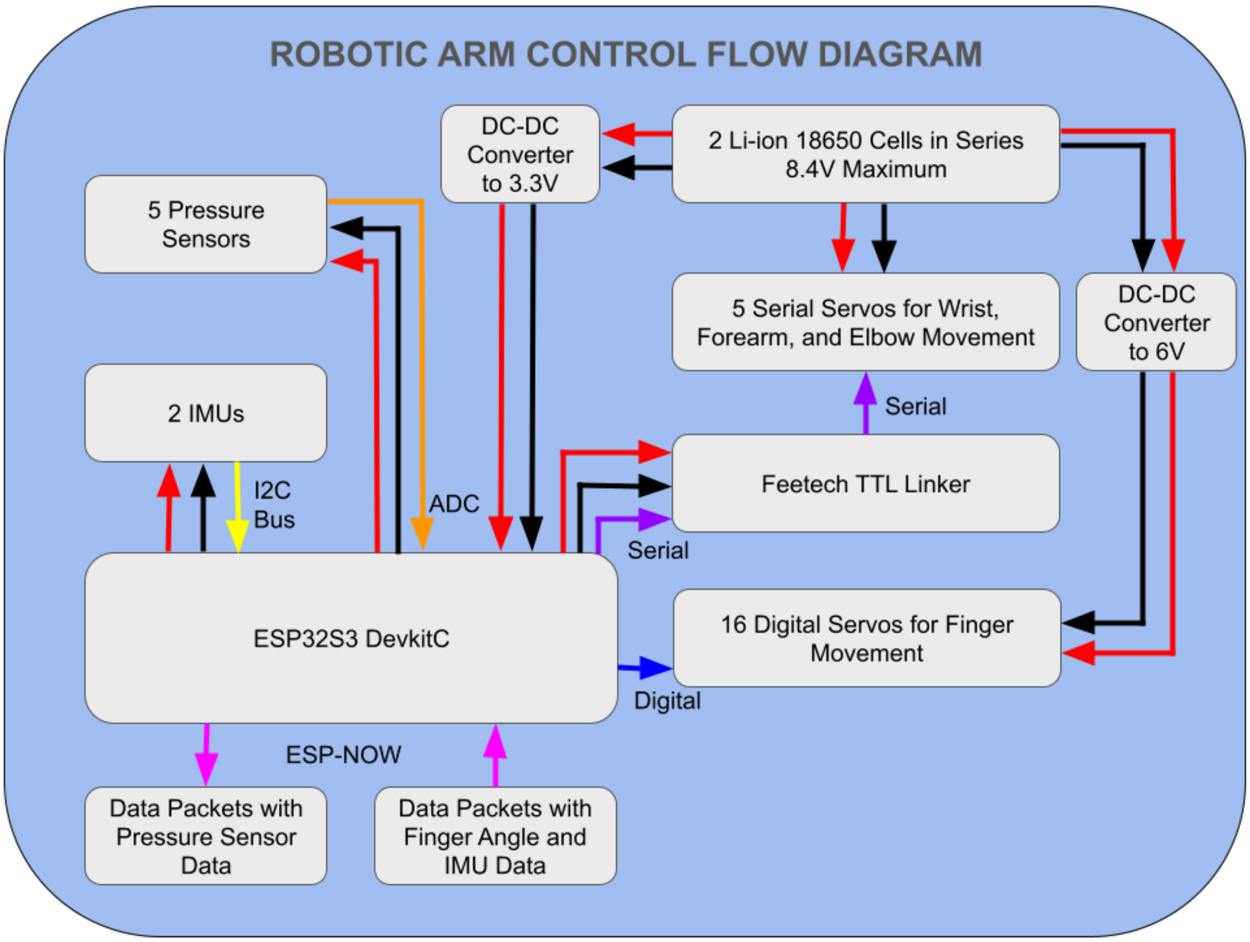

Figure 3: Robotic Arm Control Flow

Control Glove

For sensing motion of the user's hand and forearm, the glove consists of 16 hall-effect sensors [9] and two IMUs. Hall-effect sensors have an output voltage correlated with the strength of the magnetic field at its location. By positioning a small magnet near each of the hall-effect sensors such that the dipole of the magnet rotates as the joint is, we can capture an output voltage correlated with the degree to which that joint has moved. The IMUs are used to capture acceleration and angular velocity data from the wrist and forearm. There are also 4 electromagnetic brakes on the gloves that attach to lines connected to the top of the fingers. The microcontroller is placed on the forearm of the glove and connected to the IMU and power source via a drop-in PCB. A PCB on the back of the hand holds an IMU and a digital multiplexer. The two PCBs are connected via a ribbon cable, which has power, hall-effect sensor selection lines, data lines for the hall-effect sensors, two lines for communication with the IMU, and command lines for the electromagnetic brakes. Communication between the two IMUs and microcontroller will be mediated by I2C [10], a communications protocol with the advantage of requiring only two lines for communication between an arbitrary number of devices.

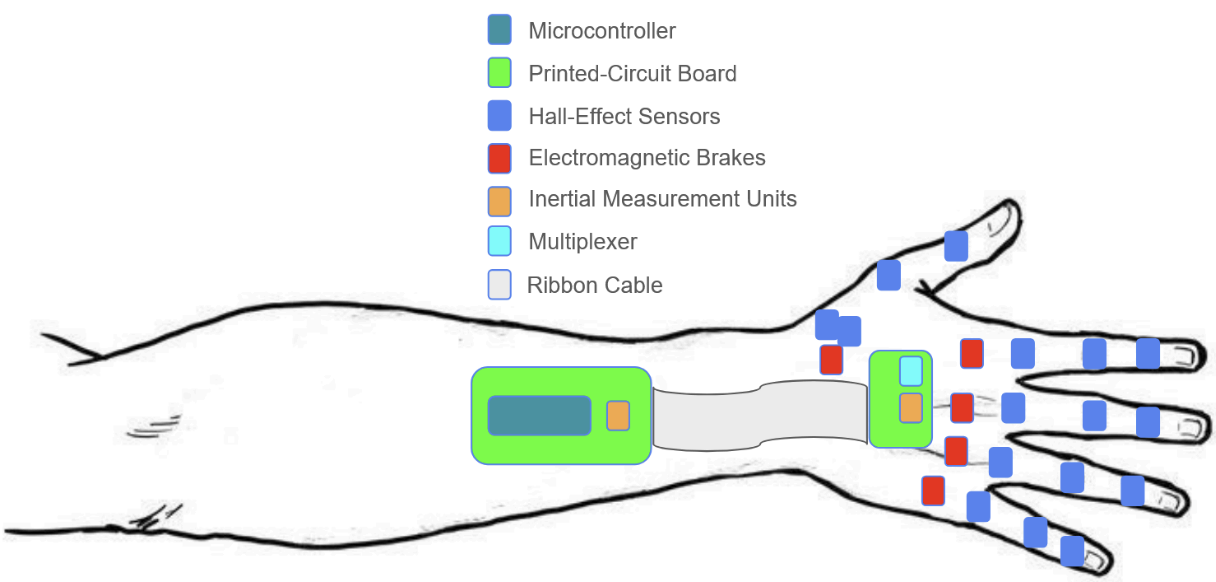

Figure 4: Control Glove Component Overlay

Each finger, not including the thumb, has 3 hall-effect sensors. These are used to measure the degree with which the finger is adducted, abducted, and flexed, which is demonstrated in Figure 5 below. For each finger, one sensor is placed just over the knuckle joint whose output voltage is highly correlated with the degree of abduction and abduction. The upper and lower joints on the fingers each have a sensor whose output is correlated with their degree of flexion. The digital multiplexor on the back of the hand is used to select which hall-effect sensor to read data from using minimal selection lines. To aid in visualization of this aspect of the glove, a glove prototype consisting only of the microcontroller in a small form factor, all hall-effect sensors, and the multiplexor is shown in Figure 6 below.

Figure 5: Demonstration of Measured Degrees of Freedom

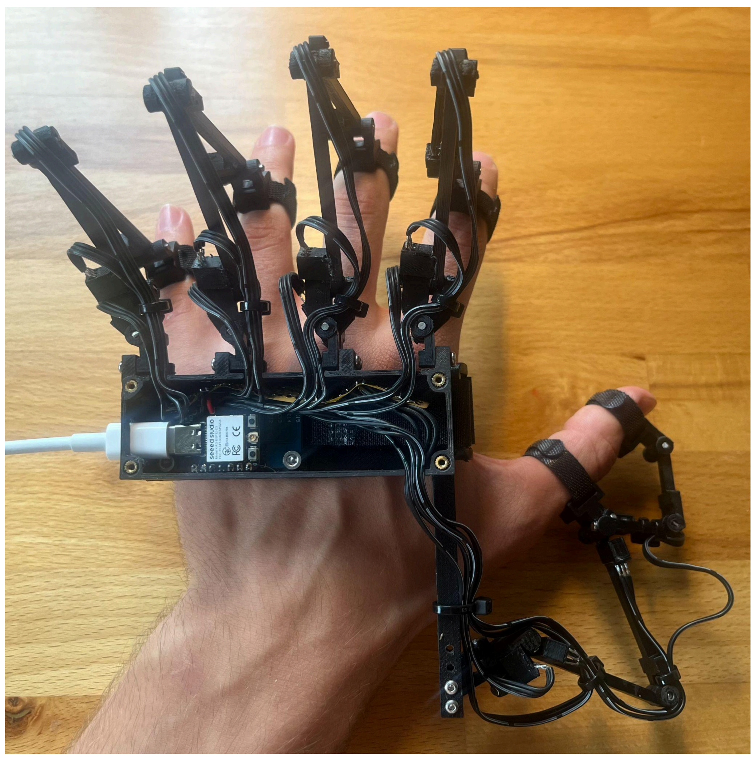

Figure 6: Control Glove Prototype (Max's hand included)

In the control glove, we read raw hall effect sensor values using an ADC. These values are not linear in relation to the angle the sensor is to the magnet. In order to linearize the data, we will take raw readings at several joint angles and create a polynomial fit. An example of the sensor readings to angle conversion data from the prototype glove is shown in Table 1 below.

Table 1: Example Hall-Effect Sensor Readings to Angle Conversion Data

Raw Value	Angle of Joint
2040	30
2110	60
2220	90
2370	120
2500	150

Using a polynomial fit calculator, we created the following polynomial for a joint on the pinkie, where y is the angle of the joint and x is the raw value:

$$y =- 0.000204869x^2 + 1.18023 - 1522.07$$

After doing the above steps on all 16 joints, the control glove produces linearized data that corresponds to the actual angle of each joint. This can be seen in Figure 7.

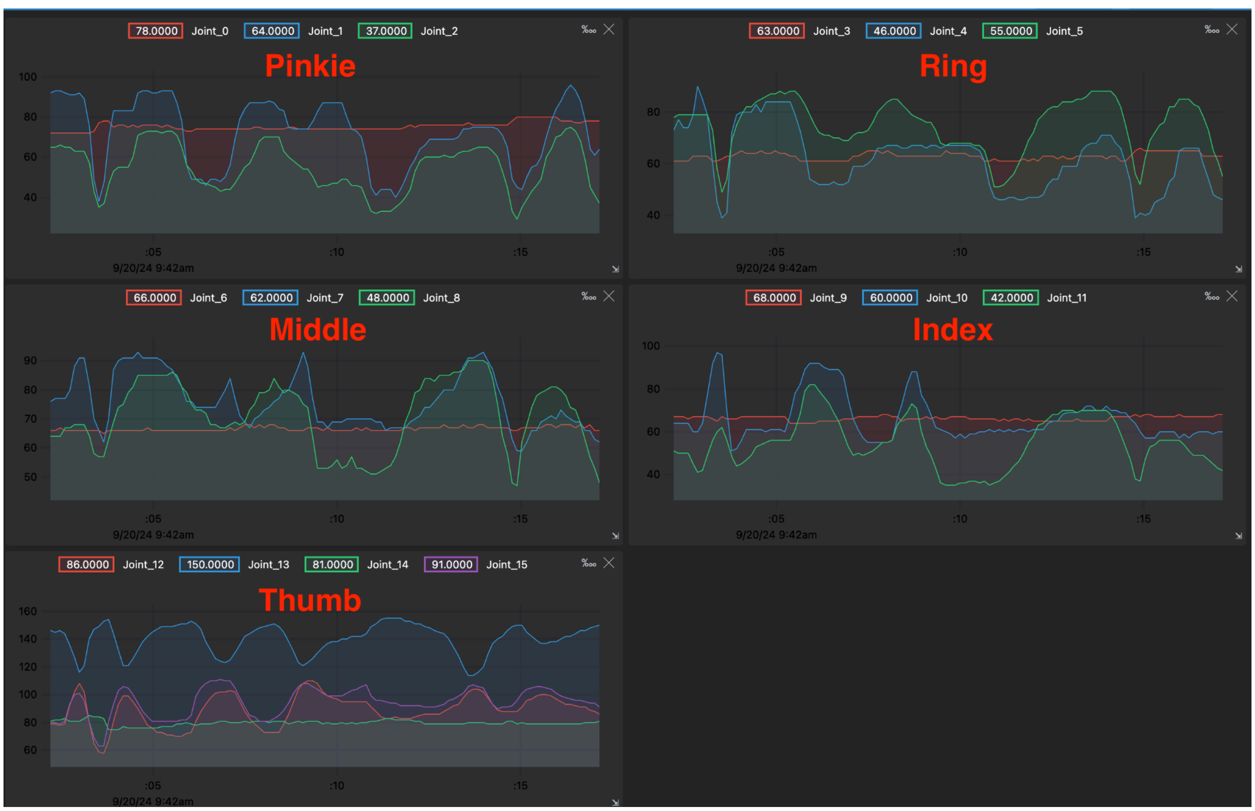

Figure 7: Finger Tracking Measurements via Hall Effect Sensor

The wrist and forearm both have an IMU that captures their acceleration and angular velocity in the X, Y, and Z directions defined by the unit itself, depicted in Figure 8 below. The MEMS (Micro-Electronic Mechanical Sensor) accelerometer output from the IMUs consist of the gravity vector no matter if the IMU is stationary or moving. Thus, because the IMU outputs the X, Y, and Z directional component of the gravity vector as the wrist and forearm rotates, we can back calculate the angle of rotation of the wrist and hand relative to that vector when the IMU is stationary or accelerating significantly slower than gravity. When the IMU is accelerating closer to the rate of gravity, then the acceleration and gyroscopic measurements can be used to calculate the angles of motion.

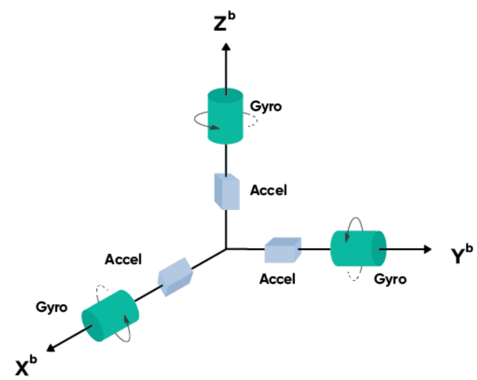

Figure 8: Wrist and Forearm Movement Axes

Each digit on the glove will have a haptic interface via an electromagnetic brake system. The brake system will lie at the base of each finger on the glove. When the robotic arm touches a physical object or obstruction, a current will be sent to the electromagnet to induce a magnetic field, causing the electromagnet to hit the braking surface. This will cause the tendon, in the form of a retractable nylon tether extending to the fingertips, to resist further extend, ultimately providing haptic feedback. The electromagnet components we will be using, developed by Adafruit Industries LLC [11], have a 5V nominal voltage and draw 0.22 A at 5V, as well as 2.5 kg holding force.

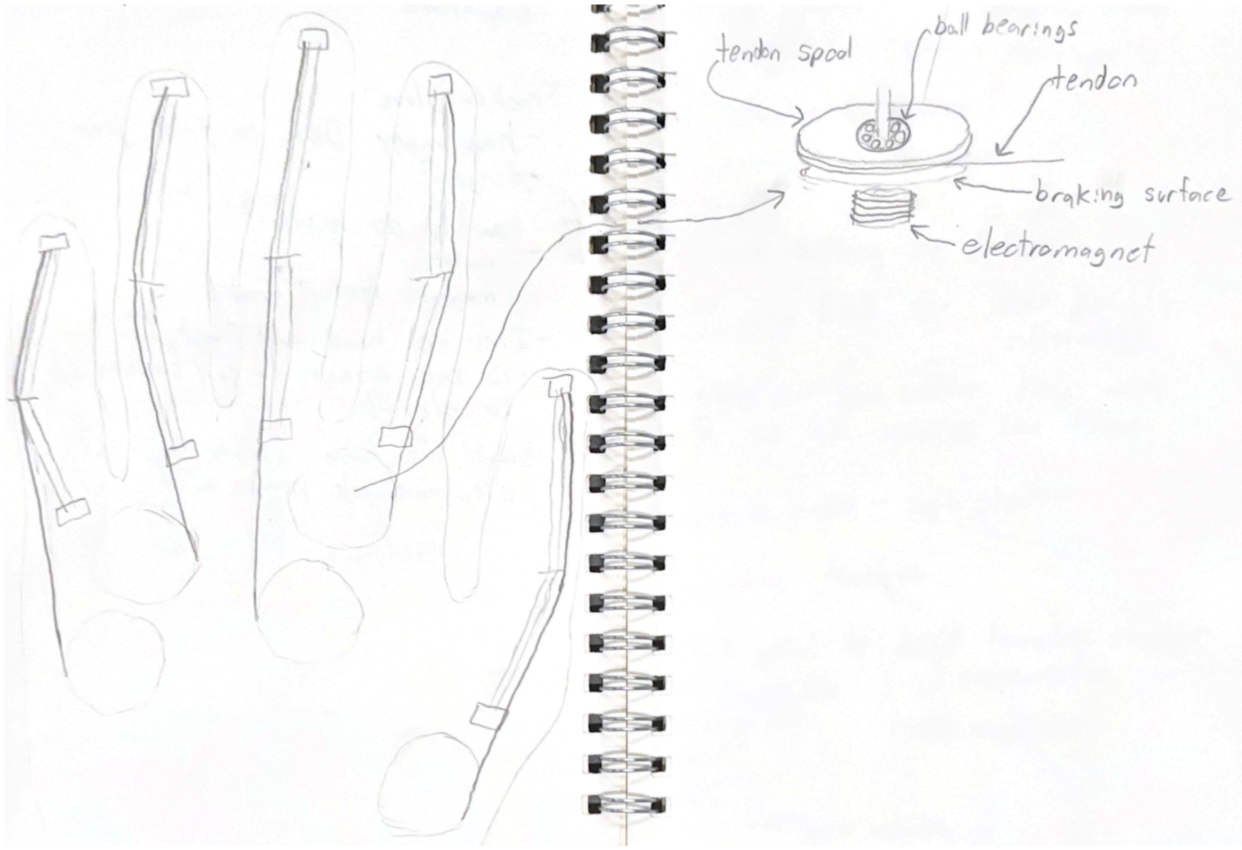

Figure 9: Initial Sketch of Haptic Brake System

Major Challenges

One of the major challenges associated with this project is the assembly of the robotic arm. Since the project group working on this has expertise in electrical and computer engineering, the mechanical aspects of the robotic arm will be a larger difficulty due to our smaller breadth of mechanical knowledge. Another major challenge is the design and calibration of the control systems between the robotic arm and the haptic glove. The group has some theoretical knowledge of control systems, but very limited application of this knowledge. Even with a well designed control system, the latency between the movement of the hand in the haptic glove and the robotic arm will be a limiting factor and a challenge. This is simply due to the difference in capabilities of the muscular systems in the human hand and the servo motors inside the robotic arm. It will be a challenge to identify how to implement an intuitive interface such that the robotic arm performs all of the important movements that the user's arm makes, and it feels to the user like the robotic arm is mirroring the glove's movements within a reasonable delay. An expected challenge is interference between the electromagnetics of the haptic interface and the Hall effect sensors. However, the group has planned for the event that the Hall effect sensors and electromagnets simply will not be able to operate within their necessary proximity, and a motor-driven braking system is reserved as a backup.

Applying standards mentioned in a later section will be another major challenge. While applying standards serves as an excellent guide for manufacturing a functioning and reliable product, ensuring that the standards are met can be rather difficult. The standards that we are applying relate to the integrity of our enclosures, electromagnetic compatibility, requirements of haptic interfaces, and minimizing robotic hazards.

Test Plan

This test plan outlines the systematic testing procedure for both the robotic hand and the control glove in our project. The tests will focus on the individual components, their integration, and the overall system functionality to ensure proper control and feedback.

Robotic Hand Test Plan

1. Servo Functionality Testing

- Before assembling any parts, test all the servos individually to verify they are fully operational:
  - Full 180 or 360 degree rotation
  - Stall torque within spec
  - Speed of rotation within spec

2. Finger and Thumb Assembly Testing

- After assembling the finger and thumb assemblies:
  - Test 3 Degrees of Freedom (DOF) for each finger to ensure each joint can move independently and with the correct range of motion.
  - Test 4 DOF for the thumb to confirm full movement, including opposability.

3. Wrist and Forearm Assembly Testing

- After assembling the wrist and forearm:
  - Test 2 DOF for the wrist (flexion/extension and radial/ulnar deviation) to ensure it moves smoothly and with precision.
  - Test 1 DOF for the forearm (pronation/supination) to ensure proper control.

4. Elbow Base Assembly Testing

- After assembling the elbow base:
  - Test 2 DOF for the elbow (flexion/extension and rotation) to confirm smooth movement and precise control.

5. Control Function Testing

- Test controlling 1 finger with the prototype glove to ensure accurate and responsive motion tracking.
- Test controlling all 5 fingers with the prototype glove to verify that all fingers can move independently and synchronously.
- Test all 5 pressure sensors on the robotic hand to ensure they provide accurate and consistent pressure data.
- Test both Inertial Measurement Units (IMUs) for accurate hand and forearm orientation data.

6. Communication Testing

- Test sending and receiving packets between two ESP32 microcontrollers to ensure reliable wireless communication.

Control Glove

1. Hall Effect Sensor Testing

- Test the 16 hall effect sensors on a breadboard to ensure they are reading magnetic field changes accurately.

2. Finger Linkage Assembly Testing

- After assembling the finger linkages with the hall effect sensors and rotating magnets:
    - Test that the 16 hall effect sensors still work after assembly, ensuring no mechanical interference.

3. IMU Accuracy Testing

- Test both IMUs to verify that they provide accurate orientation data post-assembly.

4. Electromagnetic Brake Testing

- After assembling one electromagnetic brake:
    - Test the brake with varying degrees of braking force to ensure it responds to control signals correctly.
    - Test that the electromagnet does not cause interference with the hall effect sensor readings.
- After assembling all 5 electromagnetic brakes:
    - Test that all brakes work with varying degrees of braking force to ensure uniform functionality.

- Test that the electromagnets do not cause interference with the hall effect sensor readings across all fingers.

5. Communication Testing

- Test sending and receiving packets between ESP32 microcontrollers to verify reliable wireless data exchange.

Complete System Testing

1. Communication Testing

- Test that packets are successfully sent and received between both ESP32 microcontrollers in the complete system.

2. Control Testing

- Test controlling 1 finger with the control glove to ensure smooth and accurate finger movement replication.
- Test controlling all 5 fingers with the control glove to confirm that all fingers respond accurately to glove movements.
- Test controlling wrist movement using IMU data to ensure smooth and precise wrist control.
- Test controlling forearm and elbow movement using IMU data to verify accurate orientation tracking and motion control.

3. Haptic Feedback Testing

- Test the haptic response of 1 finger to ensure the electromagnetic brake simulates tactile feedback accurately.
- Test the haptic response of all 5 fingers to confirm uniform and reliable feedback across all fingers.

4. Calibration Testing

- Test the calibration of the control glove to the robotic arm to ensure that hand movements and forces are accurately translated to the robotic system.

Physical Constraints

Because we are building upon the open-source Dexhand project, we already have a helpful guide for constructing the robotic hand assembly. This substantially reduces the difficulty of implementing the robotic hand, arguably the least familiar and most intimidating part of this project for us ECE majors. With this obstacle removed, our project faces only limited physical constraints.

Part Availability

The vast majority of the parts required for our project are either off-the-shelf components or 3D-printed. Our PCBs are the only exception to this general rule, but they can be readily ordered for manufacturing. Therefore, lack of part availability should not constrain our project.

Manufacturability

Beyond a healthy amount of troubleshooting, assembling our project once the parts have been gathered should be straightforward. However, each of the 3D-printed parts and PCBs will require on the order of hours and weeks, respectively. Although some of this time burden may be alleviated by printed parts or ordering PCBs for manufacture in parallel, we will need to carefully plan our manufacturing process to ensure that we obtain all required parts and leave time for remaking parts if necessary.

Cost Constraints

In the absence of external funding, our maximum budget is $1,000. This consists of $500 from the ECE department in addition to $100 from each of our five group members. At the time of writing, we do not anticipate and would rather avoid spending this maximum budget, but we are ultimately willing to do so if it is required to complete our project. Thus, cost should not constrain our project.

While this is true, the servo motors used to move the robotic hand are the single most expensive component of our project. Purchasing or eschewing servos supporting a wider range of motion for the hand would make the difference between staying within the department budget and dipping into our own pockets.

Resources and Equipment

Outside of the components we purchase, we will require a 3D printer to produce arts for our robotic hand assembly, a soldering iron for assembling our PCBs, and lab equipment such as an oscilloscope to test our circuits and communications between the hand and glove. All of this equipment may be accessed in the NI Lab. Additionally, one of our group members, Max Titov, has a personal 3D printer in his shop capable of producing the hand components from resin, so other teams using the 3D printers in the NI Lab should not be a significant concern for us.

Software Tools

We will use KiCad for circuit schematic and PCB design, Visual Studio Code coupled with the PlatformIO extension for embedded code development, and SolidWorks for any required computer-aided design work. All of these software tools are either freely available for all users or free for all of our group members by virtue of being students.

Comments on a Potential Production Version

A potential production version of our project would likely bear a strong similarity to the prototype because a major factor differentiating our project from similar products is its comparably low cost. Thus, the most salient physical constraints of a production version would result from increasing the scale of production rather than changing the device itself. Producing our prototype at a commercial scale could decrease costs in some respects but increase them in others. As an illustration, purchasing components in bulk would drive down the per-unit cost of production, but license fees may need to be paid for using certain software tools for a commercial rather than purely academic purpose. Additionally, we would need access to a larger 3D-printing capacity to produce a sufficiently large number of units.

Societal Impact

The relevant stakeholders in our project can be divided into two groups: potential users and those affected by said use. Potential users include scientists managing hazardous materials in a laboratory setting. They ostensibly aim to maximize safety for themselves, members of their team, and the public.

Entities affected by the project’s use may include the public at large, businesses, and governments. All these groups are generally concerned with the dangers posed by new technology, such as misuse and environmental impacts. The public at large wants to be safe from danger, businesses want to protect their employees, limit their liability, and maintain a good image, and governments strive to regulate technologies and protect their citizens.

Safety

Although our robotic arm promises to improve the safety of those handling hazardous materials, there is nonetheless a major safety concern worth considering: communication interruptions. These could arise intentionally or accidentally.

In the first case, a bad actor could intercept data between the glove and hand, convincing the latter that they are the glove. By doing so, the attacker could steal control of the hand from the user and issue actions ironically resulting in a safety hazard. For example, the attacker could trigger a premature or unwanted explosive reaction. Ideally, data transfer between the glove and hand would be mediated by a communication protocol featuring message encryption and signing.

Such a protocol would ensure that third parties could neither see the contents of messages nor forge messages from the glove.

In the second case, messages between the hand and glove could be corrupted by interference. This could cause the hand to act in unexpected ways, such as freezing in the middle of pouring a volatile chemical into a reaction mixture and producing an unstable solution. Sending a checksum along with each message and comparing each message against its associated checksum upon receipt would allow the glove and hand to detect and reject corrupted messages.

While communication interruptions are problematic, it should be noted that our robot arm is, by its very nature, intended to be operated over a distance sufficient to protect the user from the hazards posed by the materials being handled. For instance, a user handling explosives with our arm would be using it to avoid working within the blast radius anyway. Therefore, communication interruptions are likely as much of an issue of wasting materials or damaging property as they are of user safety.

A somewhat less acute safety concern is the force the glove applies to the user's hand to provide haptic feedback. Care must be taken to ensure that such force is only as strong as it must be to provide feedback in order to prevent finger discomfort and injuries.

Unintended Uses

Despite our project's intended use as a method for handling hazardous materials, we ultimately cannot control how our product is used once it ends up in customers' hands. One concerning manner in which our product could be misused is the performance of medical or other procedures on humans and animals. Because we are not designing our robotic arm for the humane treatment of living things, injury could result from the device, for example, inadvertently applying too much force to a fragile limb.

Additionally, our project could conceivably be used to create hazardous materials for acts of terrorism instead of disposing of them. The robotic arm could empower bad actors to construct explosives, synthesize toxic chemicals, or extract bioweapons by making such activities safer.

These misuses will likely draw attention from the public at large who will abhor or fear them as well as governments who, feeling pressure from constituents, seek to regulate them. Hazardous materials whose creation was mediated by our robotic arm pose a national security threat for governments because such materials may be used to commit acts of terror.

Environmental Impact

Because our project largely uses off-the-shelf electrical components, its environmental impact is similar to other groups' projects. However, our robotic arm distinctly relies upon a large number of 3D printed parts. The primary environmental concerns with these parts are waste and difficulty of recycling. Firstly, printing parts that cannot support themselves necessitates the printing of support structures, which will be discarded as waste once printing is complete.

Secondly, the plastics used for 3D-printed parts, such as ABS and SLA, may either be rarely recycled municipality or not recyclable at all [12].

External Standards

There are several standards to consider when it comes to the haptic glove and robotic arm interface. To follow some general standards, all casings will follow a NEMA Type 1 [13] to protect internal components from external materials. Additionally, Electromagnetic emissions standards described in IEC61000-6-8 [14] will be met.

There are also some application-specific standards that need to be met. ISO 9241-940 [15] provides methods to establish benchmarks, establish requirements, and identify problems with haptic interfaces. This is important to confirm the usability of the haptic interface presented by the glove. ISO 10218-1 [16] lays out guidelines for safe design of industrial robots and requirements for protective measures to eliminate or greatly reduce hazards associated with the robots. This is important to prevent the robotic arm from introducing more hazardous conditions into the situations that it should be minimizing hazard by its design.

There are several standards that are met within the system that do not need to be discussed in this section, because the designers of sub-components have already ensured the satisfaction of relevant standards. For example, the ESP32 allows for data exchange through WiFi, and already has built-in compatibility with IEEE 802.11 standards for local area networks. Since we are simply using a tool that enforces this standard on its own, we do not need to worry about implementing these standards ourselves.

Deliverables

The final project deliverable will consist of two overall components: the robotic arm and the haptic glove. The haptic glove will consist of two PCBs - one on the hand and one on the forearm. These PCBs serve to house the IMUs and carry all signals along to the ESP32, which is housed on the forearm PCB. These PCBs will be housed in a NEMA Type 1 compliant enclosure. The ESP32 within the haptic glove and an ESP32 within the robotic arm will send movement commands and haptic commands, respectively, to one another through an existing wireless communication protocol that is already implemented for the ESP32s. The robotic arm ESP32 will process the movement commands and control the servo motors on the robotic arm to match the state of the haptic glove. Meanwhile, the haptic glove will process the haptic commands to match the resistance state of the robotic arm. Both the haptic glove and the robotic arm will be powered by Li-ion cells.

Overall, the user will place their right hand inside the haptic glove and control the robotic arm by changing the position of their right hand. Aside from visual sight, the robotic arm will make the user aware of resistance that it encounters through haptic feedback of the electromagnetic brakes.

Shown in Table 2 and 3 below is the cost breakdown of the robotic arm and control glove.

Table 2: Robot Hand Cost Breakdown

Robot Hand			
Part	Price	Quantity	Total
ES3352 Servo	$10.94	16	$175.04
SCS2332 Servo	$28.83	2	$57.66
SCS15 Servo	$19.88	3	$59.64
TTLinker	$5.38	1	$5.38
3.3V DC-DC converter	$5.58	1	$5.58
6V DC-DC converter	$7.95	1	$7.95
ESP32S3 DevkitC	$6.99	1	$6.99
Ball bearings 6x10x3mm pack of 10	$8.69	5	$43.45
Ball bearings 2x6x3mm pack of 10	$10.19	1	$10.19
Ball bearings 15x21x4mm pack of 10	$9.59	1	$9.59
Ball bearings 3x8x4mm pack of 10	$7.99	1	$7.99
Sufix 832 Braid 80 lb 150 yards .33mm	$16.99	1	$16.99
Micro cord 100Ft 220Lb 0.8mm	$9.95	1	$9.95
MPU-6050 IMU breakout pack of 3	$9.99	1	$9.99
1x2mm 10 feet PTFE tubing	$7.99	1	$7.99
Robot Hand Total			**$434.38**

Table 3: Control Glove Cost Breakdown

Control Glove			
Part	Price	Quantity	Total
Hall effect sensor AH49E	$0.75	16	$12.00
Multiplexer CD74HCT4067M	$1.07	1	$1.07
ESP32S3 DevkitC	$6.99	1	$6.99
MPU-6050 IMU breakout pack of 3	$9.99	1	$9.99
Prototype PCB and Final PCB	$35.00	2	$70.00
JST SH 1.0mm connectors pack of 20	$7.99	1	$7.99
Ribbon Cable	$2.33	1	$2.33
Passives (capacitors, resistors, etc)	$10.00	1	$10.00
Holding Electromagnets	$7.50	5	$37.50
Control Glove Total			**$157.87**

Timeline

Task	Person	Status	Sept 9 - 15	Sept 16 - 22	Sept 23 - 29	Sept 30 - Oct 6	Oct 7 - 13	Oct 14 - 20	Oct 21 - 27	Oct 28 - Nov 3	Nov 4 - 10	Nov 11 - 17	Nov 18 - 24	Nov 25 - Dec 1	Dec 2 - 8	Dec 9 - 15
Deliverables																
Proposal	All	Due 9/20		All												
Poster	All	Due 9/27			All											
Poster Session	All	Due 10/4				All										
Initial PCB Design (Review)	All	Due 10/14						All								
Midterm Design Review	All	Due 10/15						All								
Integration Testing	All	Due 12/5												All	All	
Final Report	All	Due 12/5													All	
Final Video	All	Due 12/5													All	
Demo	All	Due 12/9														All
Robot Hand Mechanical:																
Full Robot Armature Assembly	Max, Bhargav	Due 10/20					Max, Bhargav	Max, Bhargav								
Full Robot Hand Assembly	Max, Bhargav	Due 9/29	Max, Bhargav	Max, Bhargav	Max, Bhargav											
Pressure sensor in finger CAD	Max	Due 9/15	Max													
CAD of elbow base	Max	Due 10/6				Max										
Integration of IMUs	Bhargav	Due 10/6				Bhargav										
Testing of Robot Hand Mechanical Function	Max, Bhargav								Max, Bhargav	Max, Bhargav	Max, Bhargav					
Robot Hand Control:																
Single finger movement	Alex, Jacob	Due 10/13				Alex, Jacob	Alex, Jacob									
All Finger movement	Alex, Jacob	Due 10/27						Alex, Jacob	Alex, Jacob							
Wrist and Forearm movement	Alex, Jacob	Due 11/17								Alex, Jacob	Alex, Jacob	Alex, Jacob				
Control Algorithm Dev.	Alex, Jacob	Due 10/6		Alex, Jacob	Alex, Jacob	Alex, Jacob										
Inter-uC Communication	Alex, Jacob	Due 10/6	Alex	Alex	Alex	Alex, Jacob										
Pressure sensor communication	Jacob	Due 10/27						Jacob	Jacob							
Haptic feedback	Alex, Jacob	Due 10/17								Alex, Jacob	Alex, Jacob	Alex, Jacob				
Testing of Control Algorithms w/ Robot Hand	Alex, Jacob											Alex, Jacob	Alex, Jacob			
Glove Mechanical:																
Full Haptic Glove	Max, Bhargav	Due 11/24								Max, Bhargav	Max, Bhargav	Max, Bhargav				
Single Haptic finger with angle sensors	Max	Due 10/27					Max	Max								
CAD design of wrist and back of hand housing	Max	Due 11/3							Max							
Magnetic brake system	Max	Due 10/13			Max	Max										
Testing of Mechanical Function	Max, Bhargav											Max, Bhargav	Max, Bhargav			
Glove Electrical:																
Magnetic brake electrical	Bhargav	Due 9/29	Bhargav	Bhargav	Bhargav											
IMU Design	Jackson	Due 9/29	Jackson	Jackson	Jackson											
IMU Communication	Jackson	Due 9/29			Jackson											
Intial Glove PCB	Jackson	Due 10/13			Jackson	Jackson	Jackson									
Final Glove PCB	Jackson	Due 11/3						Jackson	Jackson	Jackson						
Sensor Signal Processing Dev.	Jacob	Due 9/29	Jacob	Jacob	Jacob											
PCB Testing	Jackson									Jackson	Jackson	Jackson				
Testing of Glove Electrical Function	Bhargav											Bhargav	Bhargav			

Figure 10: Gantt Chart

Figure 10 above showcases the Gantt Chart we will be following to keep us on track to meet our project goals. The main subtasks of our project are the development of the robot hand mechanical system, robot hand control algorithm, control glove mechanical system, and control glove electrical system.

We assigned responsibilities based on each of our strengths and knowledge bases, which led to the following. Since Max has extensive experience on the Solar Car team designing the suspension and thus sound knowledge in mechanical systems and CAD, his primary responsibility is the mechanical aspects of the control glove and robotic arm. Due to Bhargav's background in electromagnetic fields through classes and projects, his responsibility is the haptic brake system using electromagnets; his secondary responsibility will be assisting Max with mechanical design due to expressed interest. Alex and Jacob are interested in control theory and signal processing and have extensive programming experience, which gives them the responsibility of developing the control algorithms and programming the microcontrollers. Since Jackson expressed interest in designing the PCBs and has additional experience through his internships, he will be overseeing the development of our circuit boards.

Each of the respective subsystems can be developed in parallel, but within each subsystem there are tasks that must be achieved periodically before moving on to the next. For example, the electrical aspect of the haptic brake system (electromagnetic brake) must be completed before it is mechanically implemented in the glove, since the electromagnet is the core function of the haptic brake. But overall, the majority of the tasks required for this project can be accomplished in parallel, with the limiting factor being time.

Expectations

Shown in Table 4 below is the rubric breakdown for this project. Table 5 is the grading scale associated with this rubric.

Table 4: Project Rubric Breakdown

Points	Robotic Arm	Glove Sensing	Glove Haptics	Control Alg.
3	Complete movement of fingers, wrist, forearm, and elbow	Complete tracking of fingers, wrist, forearm, and elbow	The haptic glove provides real-time force feedback, replicating the resistance faced by the robotic arm.	Control algorithm allows for haptic glove mirroring and reasonably easy usage
2	Complete movement of 2 or more of the fingers system, wrist, forearm, and elbow	Complete tracking of 2 or more of fingers, wrist, forearm, and elbow	The haptic glove provides real-time force feedback, replicating the resistance faced by the robotic arm, but there is a noticeable delay in the system	Control algorithm calibration provides some control over movements (robotic arm movement varies largely from glove movement)
1	Partial movement of fingers, wrist, forearm, or elbow	Partial tracking of fingers, wrist, forearm, or elbow	The haptic response of the glove is inconsistent	Control algorithm is unstable or not robust
0	There is no movement	There is no tracking	There is no haptic response	Control algorithm is not implemented

Table 5: Grading Scale

Points	Grade
11-12	A+
8-10	A
5-7	B
3-4	C
1-2	D
0	F

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