Robotic Manipulator with User Force-Feedback

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ECE 445 Design Document

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Group 3

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1. Introduction

1.1 Problem

A common need in Industry, and especially in today's increasingly virtual world is to interact with objects where it may not be possible from a logistic or health standpoint to do so. We have robotic manipulators and virtual simulations, but there is still a huge gap between real life and these current solutions. In a setting where an object is hazardous and may be fragile, it is paramount to be able to control how much pressure one is applying to the object, and be able to adjust it quickly and in a way that feels natural.

1.2 Solution

We would like to make two devices that work together to solve this issue. We want to create a manipulator that mirrors the user's movements and can accurately communicate the amount of force being exerted back to the user. The user would wear a glove that can track each finger's movement independently and apply the force experienced by the manipulator back to the user's hand. This would allow the wearer to easily discern the amount of force they are applying to an object without actually touching it themselves. This both solves the issue of being able to quickly and easily feel the force they are applying, as well as increasing user immersion, as wearing a glove is much more natural than using a different control mechanism. It would also allow a user to differentiate between objects quickly, for example the feeling of a foam ball vs a solid one.

1.3 Visual Aid

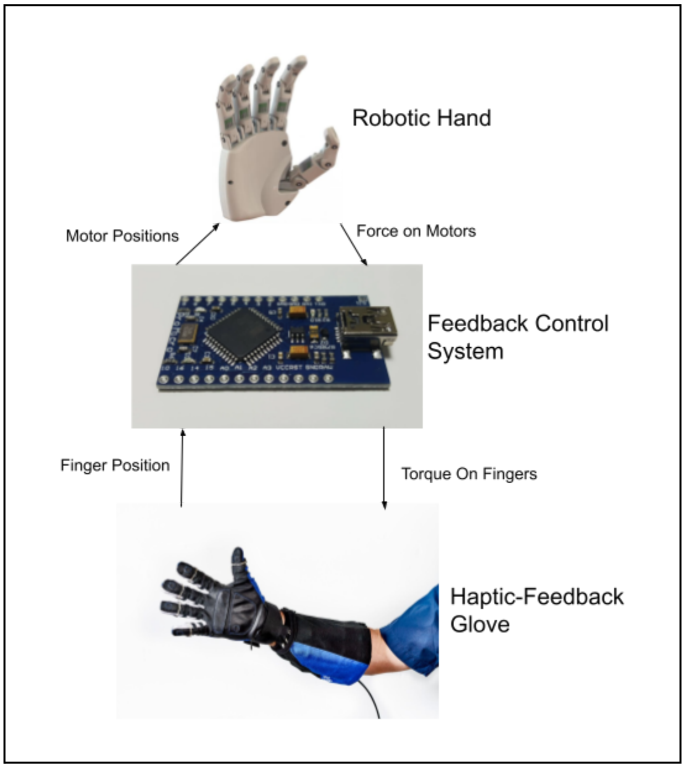

Figure 1: Visual aid of control flow for feedback system

1.4 High Level Requirements

For our project to be successful, it must:

- Measure and apply forces back to user's hand to at least 10 pounds of force
- Have a latency of less than 1 second
- Support dynamically changing the force to match anything from slight resistance to fully stopping movement

2. Design

2.1 Block Diagram

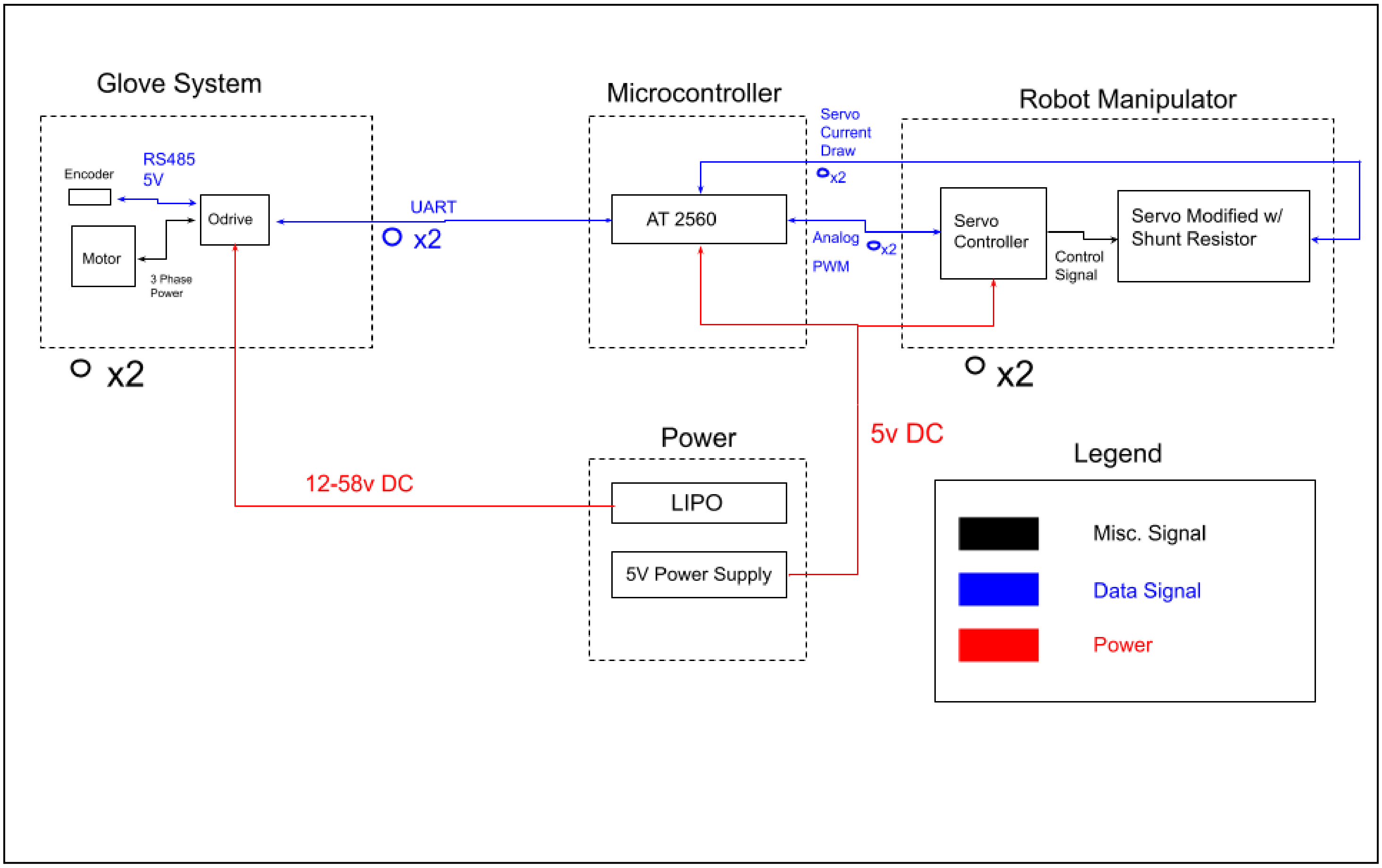

Figure 2: Block diagram of the entire system

2.2 Physical Design

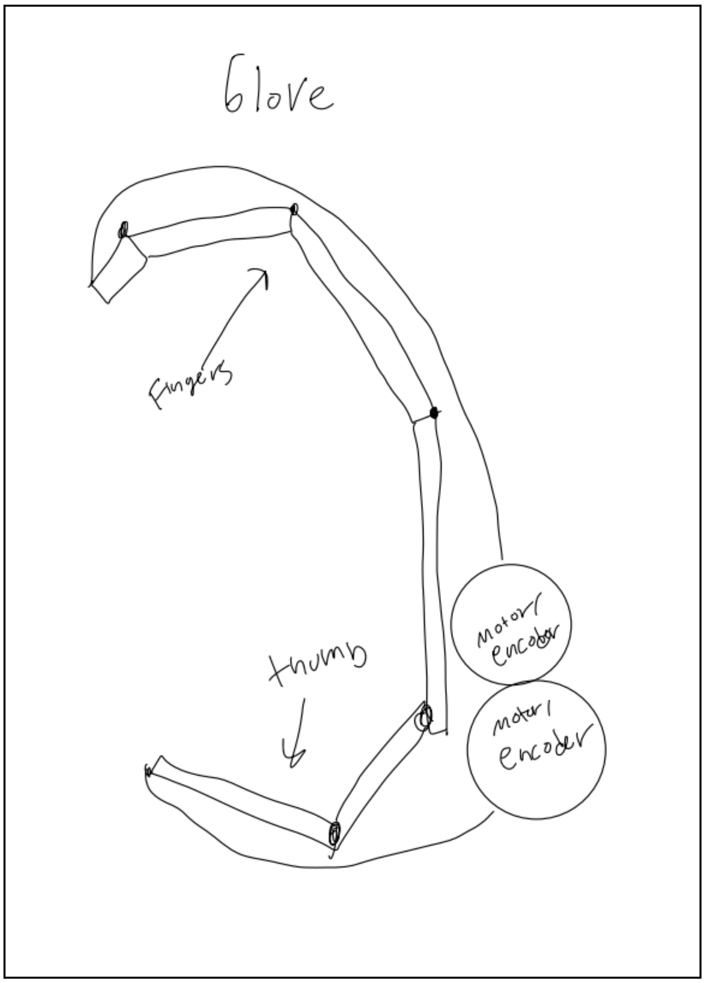

Figure 3: Physical sketch of glove subsystem

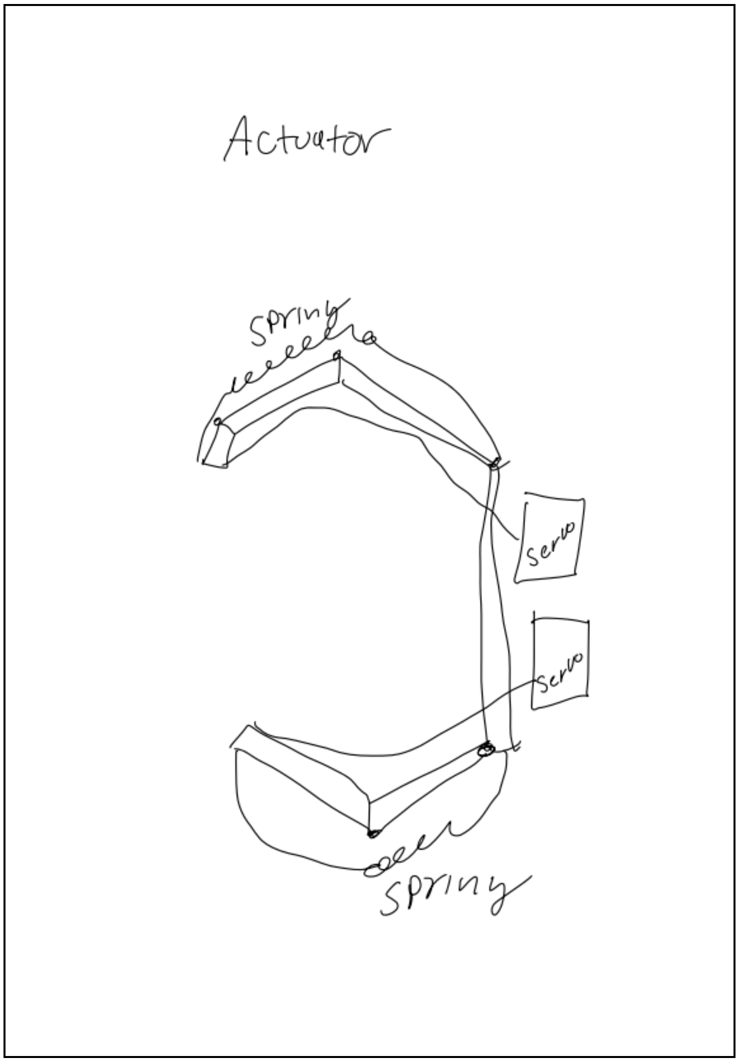

Figure 4: Physical sketch of manipulator subsystem

2.3 Glove Subsystem

This subsystem will be what the user actually wears, and will both track movements of each finger as well as apply the forces back to the wearer. It will need to support a wide range of resistance to motion, from light resistance as if one was squishing a foam ball, to being able to fully stop the fingers from moving. This connects to the microcontroller subsystems via UART, the microcontroller sits between this and the manipulator. This subsystem is vital to the operation of the project, as it allows the user to control the manipulator and feel the forces.

Requirement	**Verification**
Must send position information and receive force information via UART	Using an Arduino MEGA, confirm test program functionality. Read encoder positions and send force data to board and manually confirm forces.
Variable Resistance from 0 to 10lbs	Using ODrive [1] Current control, adjust the target torque value and confirm motor resistance changes to match the input
Completely Arrest hand movement and hold in place	Using ODrive [1] position control, set a target position and try to move the manipulator from the set position, +/- 10° of deflection is acceptable

2.4 Manipulator Subsystem

This subsystem will be what interacts with the object and relays resistance encountered by it to the glove. It will use servos that have been modified to support current detection with low side shunt resistors. This current will be used to determine the amount of resistance the manipulator is encountering. The manipulator itself will be 3D printed from inexpensive plastic such as PLA. The mcu will communicate to this through analog pins

Requirement	**Verification**
Must be controlled via servos and have 180° of motion	Using an Arduino MEGA, control each servo independently and confirm that each one reaches 180° (+/- 5° on each side) even after the entire hand is assembled.

Must report current consumed by servos via a shunt resistor and a high-side current sensing amplifier chip	Apply increasingly larger forces (between 0-100N) on the fingers of the manipulator. At each 5N increment we will record the output of the amplifier chip so that we know what kind of force to apply back to the glove at that voltage.
Receive position commands via PWM and mimic finger positions of the glove subsystem	Using an Arduino MEGA and the Arduino servo library [3], send position commands to each servo and ensure that each servo is not restrained by its spring. We will check that each servo's position is correct within 5° of expected orientation. Then with the glove, ensure that actual finger placement versus manipulator finger placement is within 5° of each other.

2.5 Microcontroller Subsystem

This is the brain of our project, it will be a microcontroller based device that can process the raw data coming from both the glove and manipulator, then facilitate the communication between the two. It will communicate with the other subsystems via UART and analog PWM control. It will contain circuitry to convert the voltage drop from the shunt resistor to a range where the ADC will have sufficient resolution.

Requirements	**Verification**
Receive analog signal and have sufficient variation for ADC conversion	Target a variation of 0-3.3v +/- .1V for the input to the ADC
Send and receive data over UART	Using a test program, verify that the Odrives are being properly controlled by the MCU
Send position data over PWM to Servo	Using a Oscilloscope, verify the correct waveform and frequency, then confirm the

	servo is moving in response to the signal.
Process data and send commands quickly (Less than 1s)	Using the glove, change the position of the encoder and verify that the time for the manipulator to move is less than 1s

2.6 Power Subsystem

This subsystem is what will power the entire project. It comes in two parts, a 5v power supply and a LIPO battery. The 5v power supply will provide power to our microcontrollers as well as our servo controllers. The LIPO will provide at least 12v to our ODrives as they consume much more power than the basic microcontrollers**.**

Requirement	**Verification**
5V power to microcontroller	Using a multimeter, confirm voltage output is within +/- .1v of 5V
12-56V 100A peak To ODrive	Using a multimeter, confirm voltage output of LiPO will not fall below 12V, and that the C rating is high enough to facilitate 100A current draw
Lipo power system must be isolated from 5v power supply	Using a multimeter, monitor the current draw in the microprocessor system as we ramp up the motor speed from rest to 30% RPM max. If the current stays under 500 mA in the microprocessor subsystem then the two power systems have been successfully isolated.

2.7 Tolerance Analysis

A block vital to the success of our project is the amplification circuit for the high side current sensing. This component is vital, as it allows us to measure the amount of current the actuators for the manipulator are using and because of that, adjust the forces applied to the user’s hand. This consists of a high side current sensing shunt resistor, an arrangement of op-amps and the MCU. The MCU has an onboard ADC, we need to amplify the voltage across the shunt resistor in order to cover more of the ADC's range, while making sure it does not go above the ADC's reference voltage as to prevent damage to the device. Furthermore, we must make sure that the analog signal input can be correctly sampled. For this, we can simply calculate the Nyquist frequency needed in order to properly reproduce our signal. We can assume that the user's hand is moving 100 times a second at most. This means our analog signal can vary by 100Hz. The Nyquist frequency required for this should be at least 200Hz. Fortunately the ADC in our MCU is capable of well above that, 15KHz across 16 pins. We want our reference voltage maxto be 5v, as that is the MCU VCC. With a targeted voltage of .1V across the shunt resistor, we want our gain to be roughly 50. This means that we need 1 Mohm and 20 Kohm resistors. This would lead us to select a TSC213 [4] current sense amplifier IC. This allows us to get the desired gain without damaging our ADC. To prevent overvoltage we plan to use a schottky diode, selected for its ability to quickly switch and prevent damage to the ADC.

3. Cost and Schedule

3.1 Cost Analysis

Item	**Quantity**	**Price**	**Total**
ODrive [2]	2	$200	$400
TCS213ICT (High-side current amp) [4]	4	$2.16	$8.64
12 Gauge Wire	1	$20	$20
20 KG servos	4	$15	$60
20 Gauge Wire	1	$10	$10
CUI AMT212B-V (Encoders) [5]	2	$60	$120
AT MEGA 2560 [6]	2	$18	$36
MISC Microcontroller Components	1	$50	$50
LiPo Battery	1	$80	$80
Shipping + Tax	1	$125	$125
Item Subtotal			$909.64
Labor	(10 Hours each week * 2 people * 9 weeks)	$48/hr	$8,640
Total			$9,469.64

3.2 Schedule

Week	**Task**
10/2-10/8	Design PCB (Noah) Purchase electronic components (Sohan) Purchase PLA (Sohan)
10/9-10/15	Order PCB (Sohan) Receive PLA (Noah + Sohan) Begin Printing/Designing robotic hand (Noah + Sohan) Begin Designing Glove (Noah + Sohan)
10/16-10/22	Receive electronics (Noah + Sohan) Configure ODrive (Sohan) Test Servos (Noah) Test PCB Components on a breadboard (Noah) Test Power System (Sohan) Continue designing hand (Noah + Sohan) Continue designing glove (Noah + Sohan)
10/23-10/29	Solder PCB components into the PCB (Sohan) Assemble hand (Noah) Assemble Glove (Noah)

	Combine all subsystems together (Noah + Sohan) Begin implementing finger tracking algorithm (Noah + Sohan)
10/30-11/5	Finish implementing finger tracking algorithm (Noah + Sohan) Begin implementing force feedback (Noah + Sohan)
11/6-11/12	Continue implementing force feedback (Noah + Sohan)
11/13-11/19	Finish implementing force feedback (Noah + Sohan) DEMO TO TA
11/20-11/26	FALL BREAK Last minute fixes/tweaks (Noah + Sohan)
11/27-12/3	Final Demos (FINISH)

4. Ethics and Safety

4.1 Ethics

According to the IEEE Code of Ethics section 7.8 subsection II.9, we have a responsibility to not harm others during the course of creating and also testing our project. [1] The one concern that comes with a haptic-feedback glove is that the motors will apply torque to the user's hand. In a naïve implementation, someone could maliciously bend the fingers of the robotic hand backwards and the glove would attempt to comply and forcibly bend the user's fingers backs as well. To remedy this, we will add a maximum angle to which the glove can provide torque to. Anything beyond that and the glove will no longer provide feedback as to ensure the safety of the user. Same goes for any applied torques to the user's hand. After a certain maximum torque applied to the user's fingers, the glove will either stall at that torque or stop providing feedback until the torque would go down to an acceptable range.

According to the IEEE Code of Ethics section 7.8 subsection I.5, we must always strive to seek honest and critical feedback of our ideas. [1] Hearing feedback can often be difficult, but we will keep an open mind because that feedback could lead to new avenues with the project that have not previously been considered or may bring up a valid safety concern that we did not think of.

4.2 Safety

Along the same line of injuring people comes the worry of if somebody's hand became caught or was being crushed by the robotic hand. Although realistically the hand will only apply the same force as a human hand can, during the development of our project we may make a mistake where the hand exerts too much force. As such, we will implement in our design a simple button that when pressed will completely power down the robotic hand thus disabling all of the motors that could be causing injury.

As for electronic components, the most volatile part we have is the LiPo battery. Since LiPo batteries have a tendency to combust, we will be sure to have a bucket of sand nearby during the development of our glove, thus if there were to be any fires we can safely dispose of the battery.

5. Citations

[1] “IEEE Code of Ethics.” *IEEE*, 2022, https://www.ieee.org/about/corporate/governance/p7-8.html.

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[3] “Libraries.” *Libraries - Arduino Reference*, Arduino, 2022, https://www.arduino.cc/reference/en/libraries/.

[4] “TSC211ICT STMicroelectronics: Mouser.” *Mouser Electronics*, Mouser Electronics Inc., 2022, https://www.mouser.com/ProductDetail/STMicroelectronics/TSC211ICT?qs=iLbezkQI%252BsjsYAfcpKipFQ%3D%3D.

[5] “AMT212B-V: Digi-Key Electronics.” *Digi*, Digi-Key Electronics, 2022, https://www.digikey.com/en/products/detail/cui-devices/AMT212B-V/8537386.

[6] “Atmega2560-16AUR: Digi-Key Electronics.” *Digi*, Digi-Key Electronics, 2022, https://www.digikey.com/en/products/detail/microchip-technology/ATMEGA2560-16AUR/2357022.