CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

DEPARTMENT OF MECHANICAL ENGINEERING

ME 5741

BIOMECHANICAL ROBOTS

Instructor: Dr. Carlos Castro

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Assignment # 3

Design and Fabrication of Series Elastic Actuator for Humanoid Robot Applications

By

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1 Introduction

1.1 Review of Our Custom Gripper

Previously we took inspiration from the human biology and design a cable driven anthropomorphic robotic end effector. End effectors allows robots to interact with their environments, like how human uses their hands. Our gripper consists of a two double hinged finger, servo actuators, and an LCD user interface as seen in figure 1.

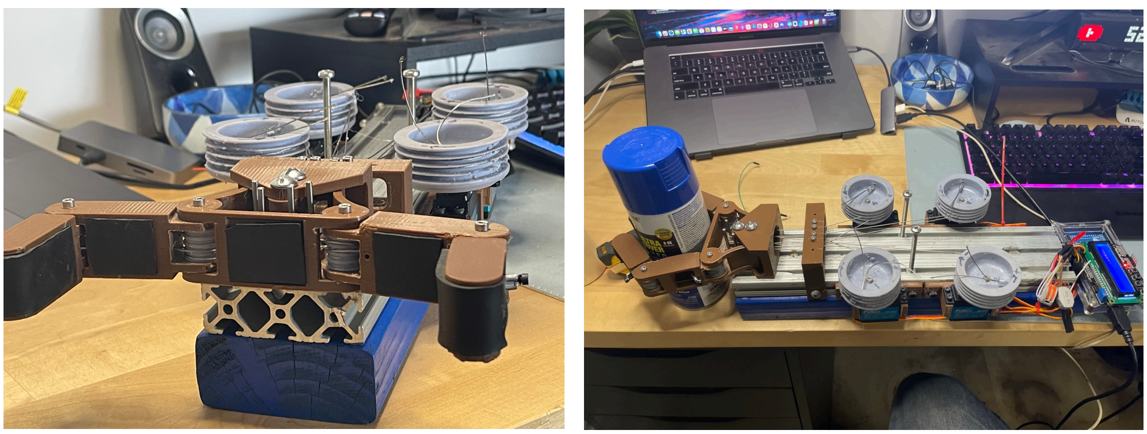


Figure 1 Custom Gripper

Overall, the system works as designed. The gripper successfully interacted with objects in the desired size range of 4 inches and at weights up to 1 lb. However, the system was far from perfect. Many modifications can be made to improve the durability, accuracy, and the strength of the design, but two key design flaws were highlighted.

First was the design of the control wire and how they connect with the actuator. Because of the anchoring method used it was quite difficult to ensure even tension of the cables. Loose cables will lower the control the actuator had with the desired joint. Loose control cables negatively affected the accuracy, repeatability, and the holding force of the finger. A different tensioning system/ anchoring method would be recommended to solve this problem.

The second design flaw was the direct connection between the cable and the actuator. The direct connection gave the servo a negative mechanical advantage, limiting the maximum amount of payload the gripper could carry. The pulley itself was also poorly supported and could not sustain the maximum load without deforming the mounting structures. Lastly, the system was not properly compliant. All the compliancy in this system was due to the poorly tensioned cables. At the correct tension all force is directly transformed into the motor and structure with no proper compliant mechanism. This would not be acceptable for a humanoid robot. Compliancy is needed to avoid damaging the key internal mechanisms and the object the robot is interacting with.

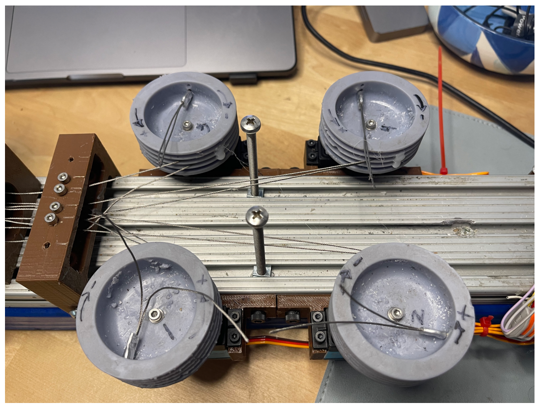
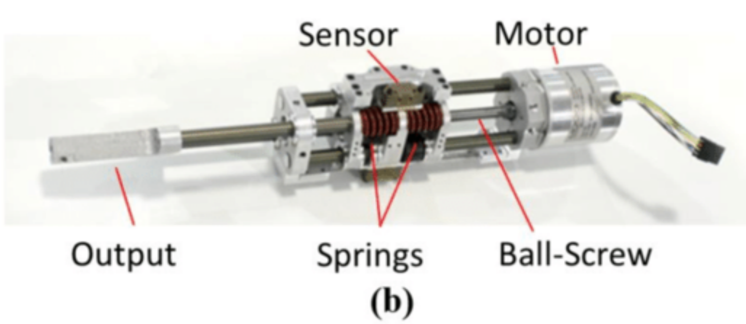


Figure 2 Gripper Actuator and Control Cables

1.2 Series Elastic Actuator

Unlike the rigid actuators previously used a new compliant actuator called a series elastic actuator (SEA) will be developed. SEA contains an elastic element in series with the mechanical actuator. The elastic element gives the actuator a level of mechanical compliance. This allows the actuator to have impact load tolerance, low mechanical output impedance, and increased power output.



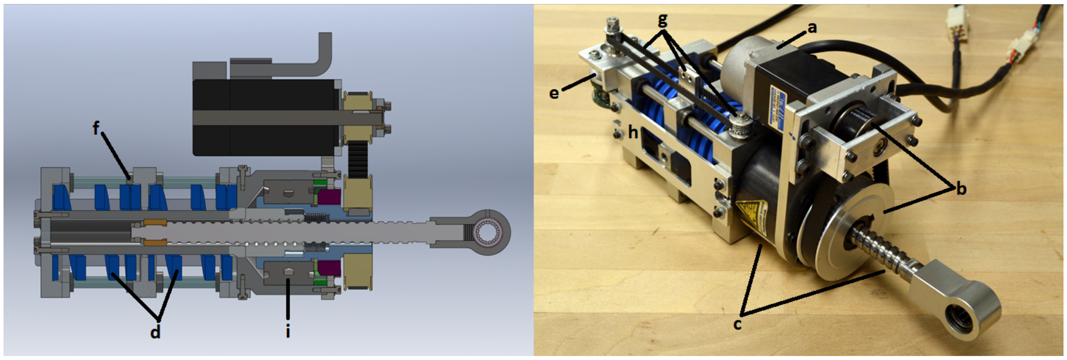


Figure 3 Series Elastic Actuator

As seen in figure 3 a SEA actuator consists of a motor with gearbox to provide the power, a ball screw that would provide better mechanical advantage to transfer the power to the load. A carriage with springs that allows displacement between the output shaft and ball screw. A output shaft that is either directly connected to the desired joint or indirectly connected by a control wire. Lastly series elastic actuator contains supporting electronics that controls the unit and measured the active load of the system allowing dynamic control of the output force.

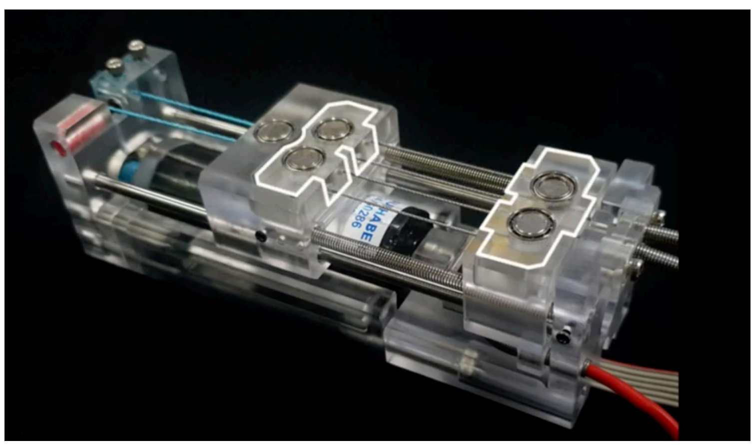


Figure 4 Series Elastic Actuator with Control Wire

1.3 Objectives

The objective of this project is to design and fabricate a custom series elastic actuator that could be used on humanoid robot. Our series elastic actuator will be designed to be used for the bicep of a humanoid robot. To successfully perform the desired task the actuator needs to meet certain requirements. The actuator requirements include the following:

- Ability to lift a mass of 25 lbs force.
- Ability to hold said mass for 1 minute.
- Incorporate active force compliance via sensor
- Compact size and low weight

Our custom series elastic actuator will be built into a test stand. On this test stand a series of trials will be conducted to test different subsystems and identify areas of potential improvement. As shown in figure 5 our actuator will be connected to a load arm that will be representing the robot's future forearm. A load will be placed at the end of the forearm and the actuator will need to actuate the arm to the desired angle and maintain the desired holding force. External forces will be applied to the actuator to test the system mechanical compliancy. We will also test difference active feedback compliancy modes that necessary for future robotic development.

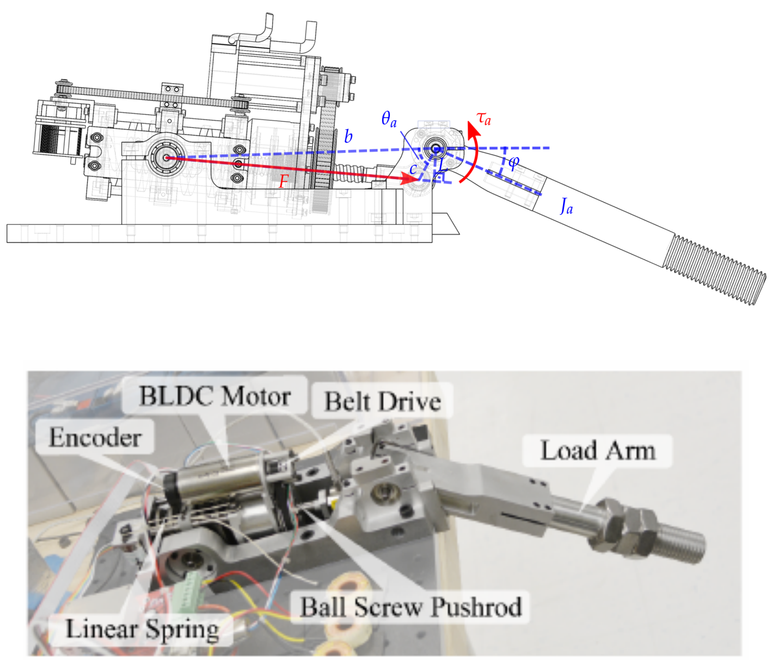


Figure 5 Test Bench

2 SEA Test Rig Design

2.1 Control Unit

The completed series elastic test rig consists of 3 key systems the control unit, the actuator arm, and the actuated forearm. The control unit is the brains of the device. It contains the 24-volt DC power supply, an upgraded Arduino uno called Romeo BLE, a stepper motor driver, an OED screen, and a LED neopixel ring. The Romeo microcontroller runs the code that controls the actuator output. The led screen and neopixel ring are used as a user interface for the operator to control the test rig. Lastly the stepper motor driver supplies the motor with the necessary commands and to control the motor in the desired direction and speed.

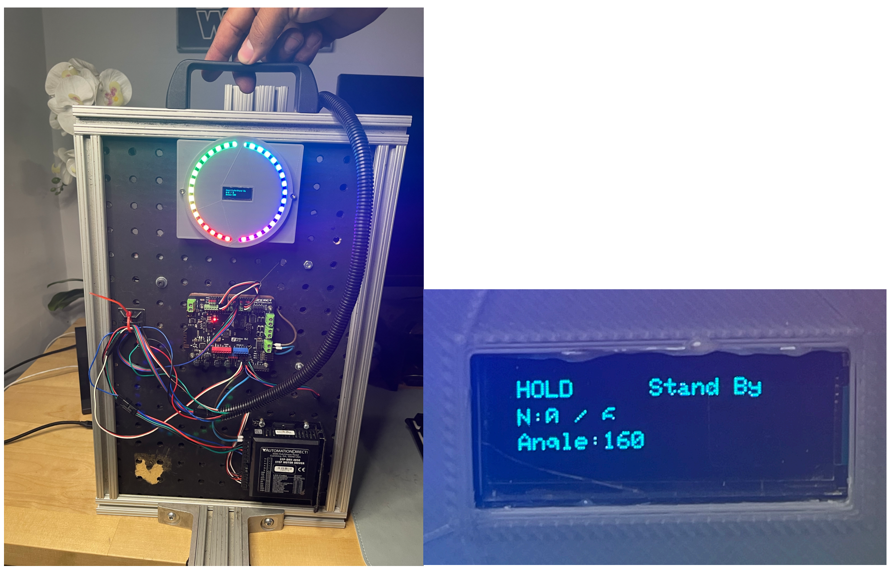


Figure 6 Control Unit

2.2 Actuator Arm

The actuator arm contains the custom series elastic actuator used for this project. The arm consists of 5 main components:

- Nema 17 stepper motor connected to a ball screw linear rail
- 10 KG load cell with analog to digital converter
- Bidirectional spring
- Stainless steel cable

The actuator arm produces the force that controls the forearm motion. The linear actuator with the nema 17 motor was capable of a lifting maximum of 20 KG. The loadcell measures the tension of the control cable that connects the actuator to the forearm. By measuring the cable tension, we can calculate the amount of load on the actuator and detect external interaction onto the forearm. For example, 5 KG payload of weights was placed on the end of the forearm and the load censor was zeroed to the known weight. If the load on the sensor increases, we know additional force is being exerted down onto the forearm. If the load cell measures less force it can be inferred that an external force is pushing up on the forearm.

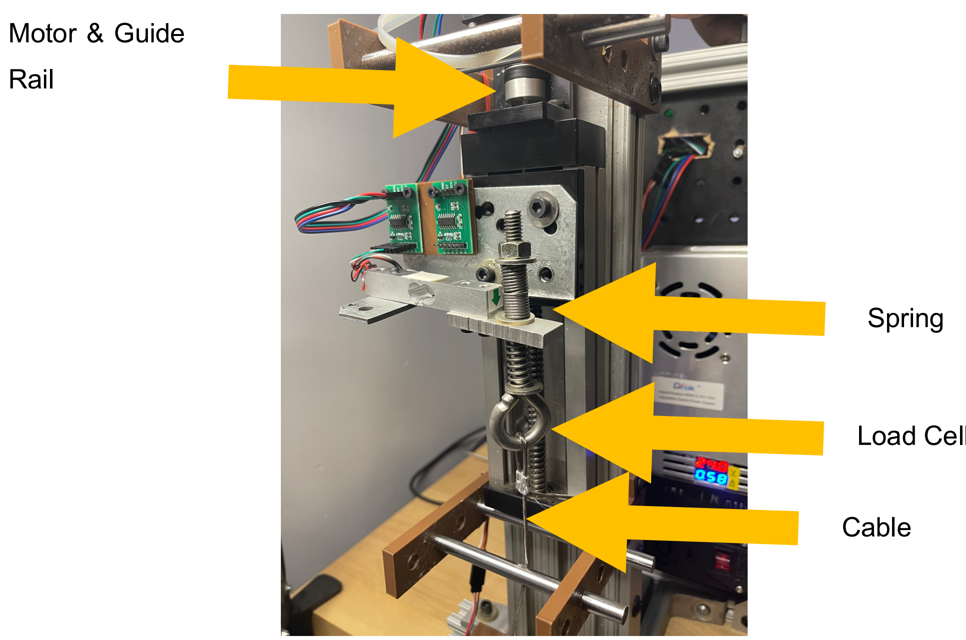


Figure 7 Series Elastic Actuator

2.3 Forearm

The Forearm is the output linkage of the test rig. External weight is placed on the end of the forearm to produce load on the actuator. An embedded potentiometer located in the elbow of the forearm is used to measure the absolute position of the arm. The data from the potentiometer can be used for position close loop control. A Control cable is anchored to the base of the forearm, connecting the arm to the linear actuator.

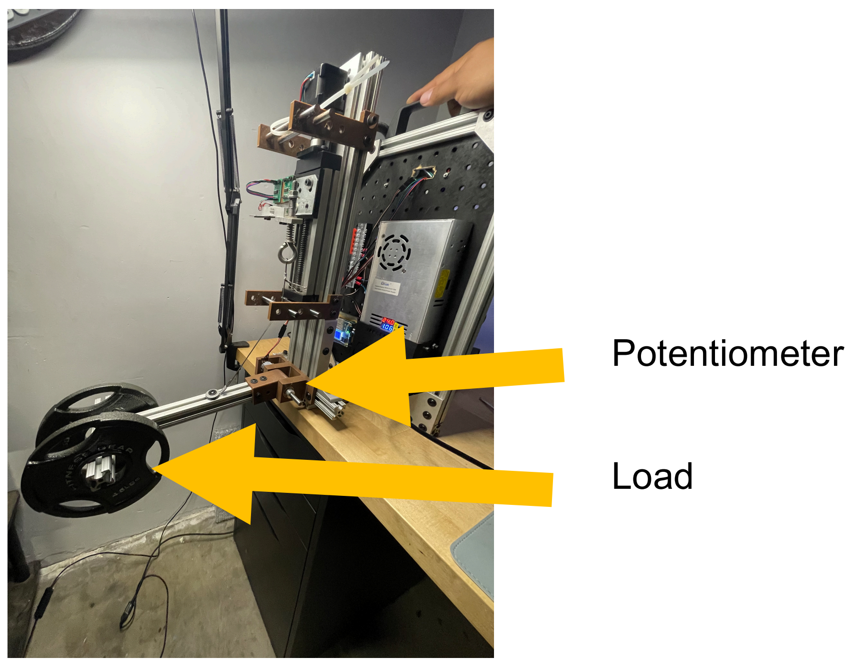


Figure 8 Forearm

2.4 Programing and Control

A series elastic actuator is used in applications that requires compliancy with the environment. To be compliant to the environment a dynamic closed loop feedback is used. A close loop feedback is created by measuring the angular position and the interactive force on the forearm and adjusting the motor output dynamically to keep the measured load close to the desired value. The Control system runs on a microcontroller and is written in the programing language C.

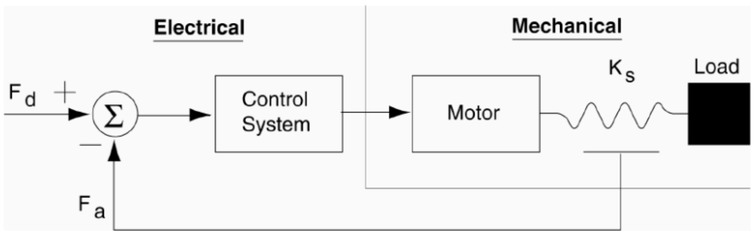


Figure 9 Close Loop Control Diagram

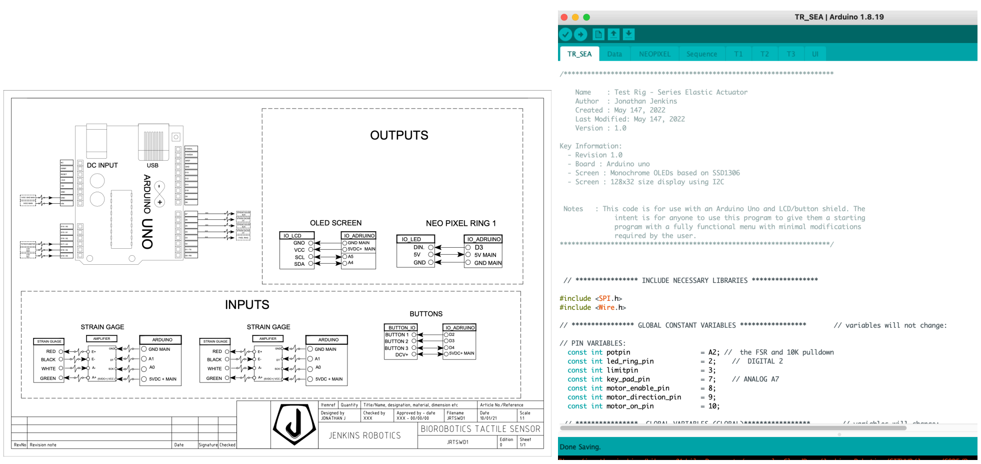
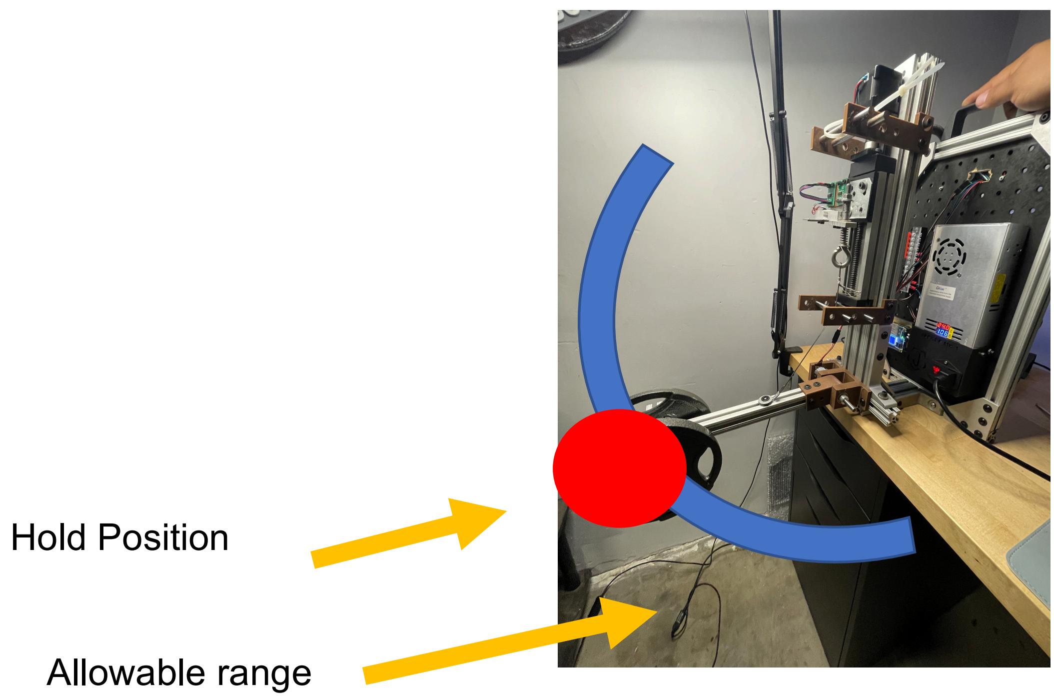


Figure 10 Microcontroller Wire Diagram and Code

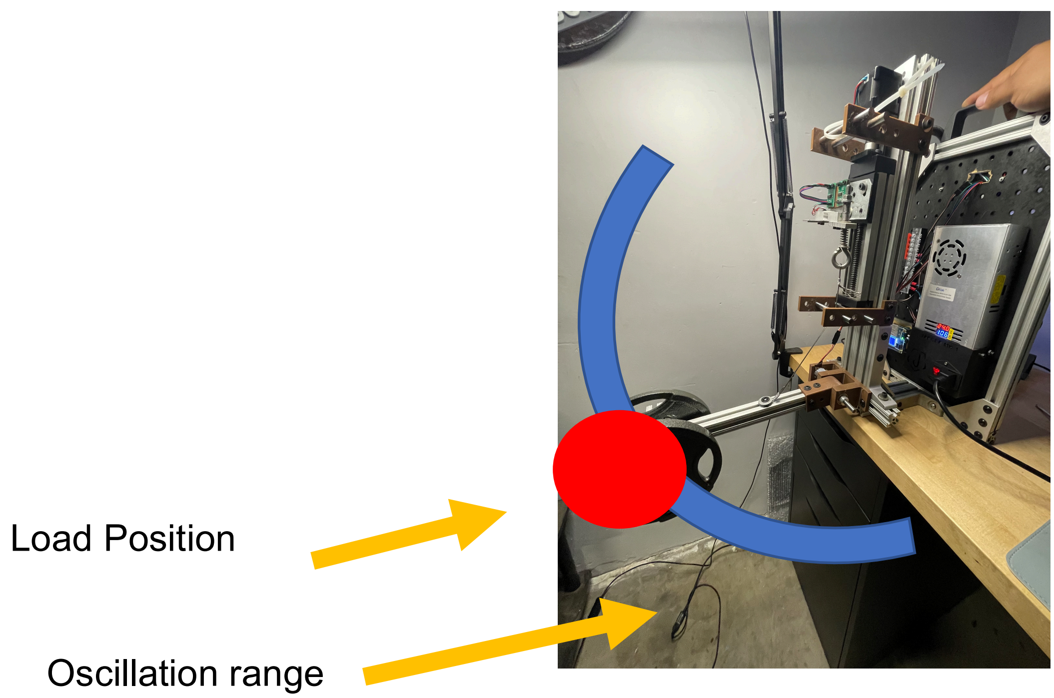
2.5 Dynamic Position Hold

The first type of close loop control that we tested is called Dynamic Position Hold. By measuring the tension of the control cable, we can continuously infer the external forces applied onto the forearm. Using that information, the actuator can resist a certain amount of external load determine by the user. Once the load is over the allowed deviation it will then be compliant to the force, moving the actuator in the directing of the load. Once the load on the forearm falls back to the allowed level it will then hold at the new position.



2.1 Dynamic Oscillation

The second type of close loop control that we tested is called Dynamic Oscillation. Like the Position hold mode, the unit continuously measures the tension of the control cable, and intern the external forces applied onto the forearm is monitored. Using that information, the actuator can determine when it has made collision with another object. During this mode the arm will oscillate between two points, as it is moving through space if the measured load changes over a certain tolerance, then it can be concluded that an impact has occurred. Once the impact occurs the unit will stop moving any farther in that direction.



3 Conclusion

The objective of this project was to design and fabricate a custom series elastic actuator that could be used on humanoid robot. Our series elastic actuator will be designed to be used for the bicep of a humanoid robot. To successfully perform the desired task the actuator needs to meet certain requirements. The actuator requirements include the following:

- Ability to lift a mass of 25 lbs force.
- Ability to hold said mass for 1 minute.
- Incorporate active force compliance via sensor
- Compact size and low weight

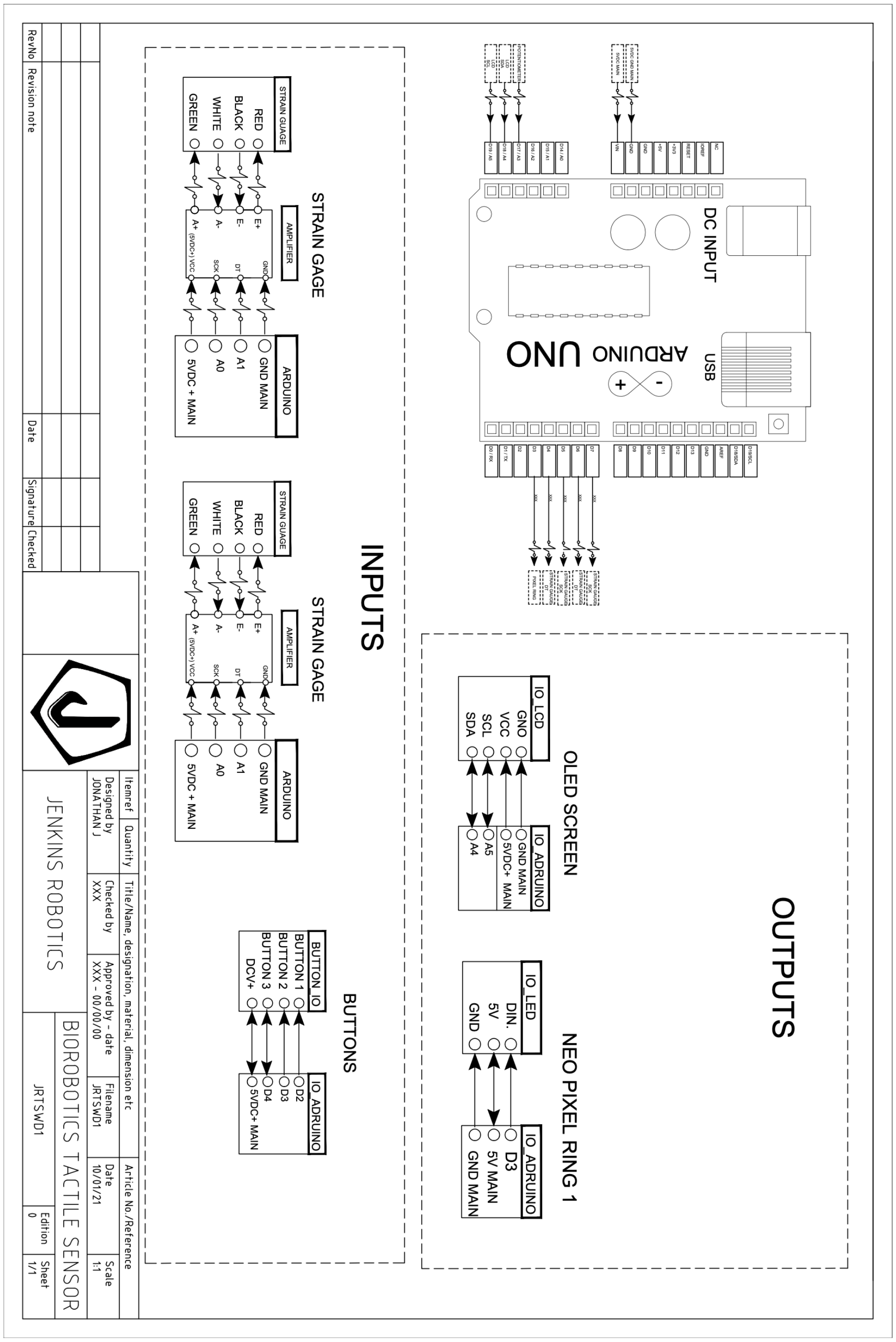
The final actuator was generally successful in meeting the desired requirements. The actuator could detect external forces and dynamically comply with external interaction. However, there are a few areas that would need improvement. First is the delay in the detection of interaction and the actuator performing the active compliance. Second is the actuator is still relatively slow and weak compared to human motion so further testing with different actuators and configurations will be necessary for future development

4 Appendix

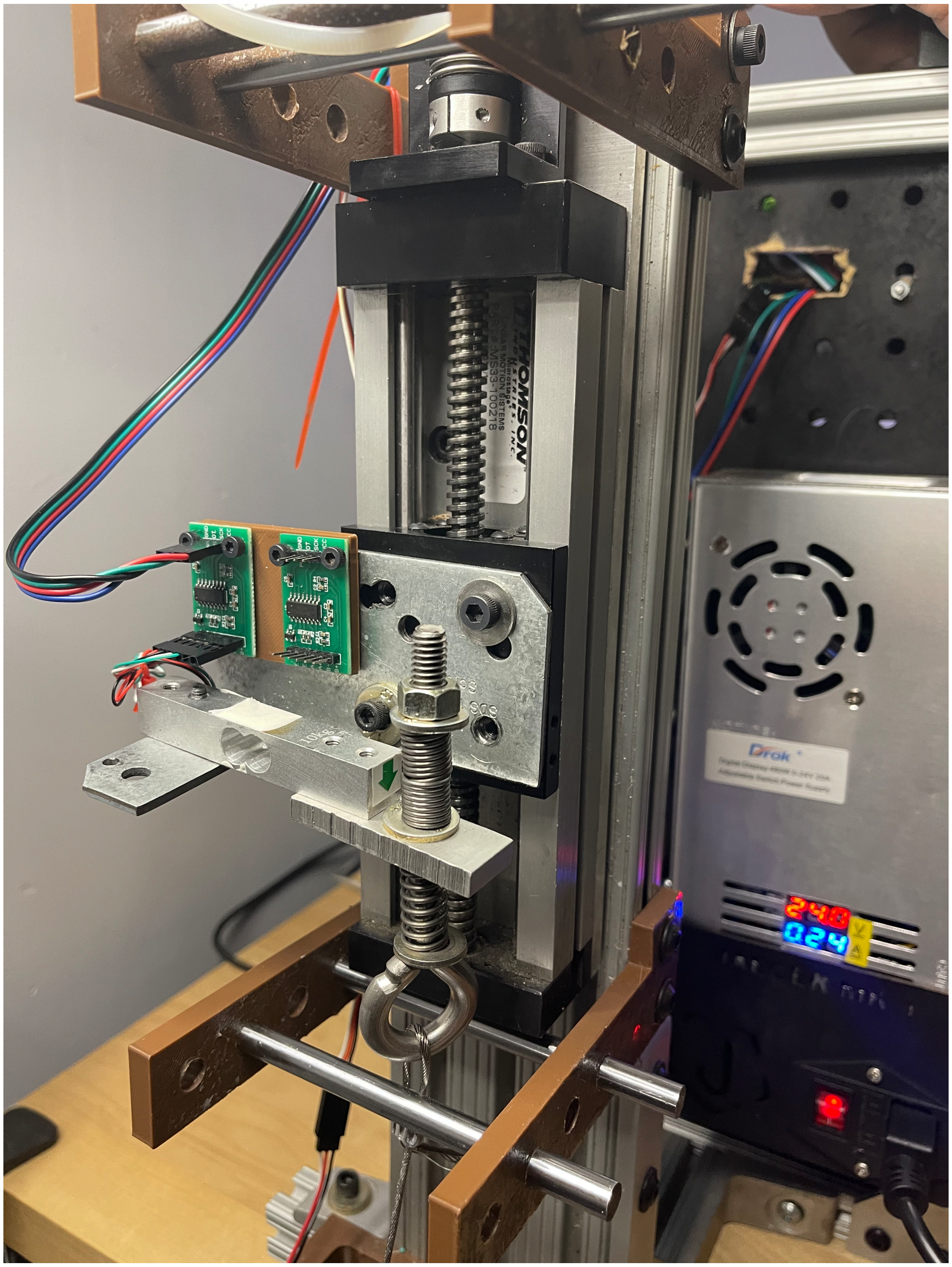
4.1 Arduino Code

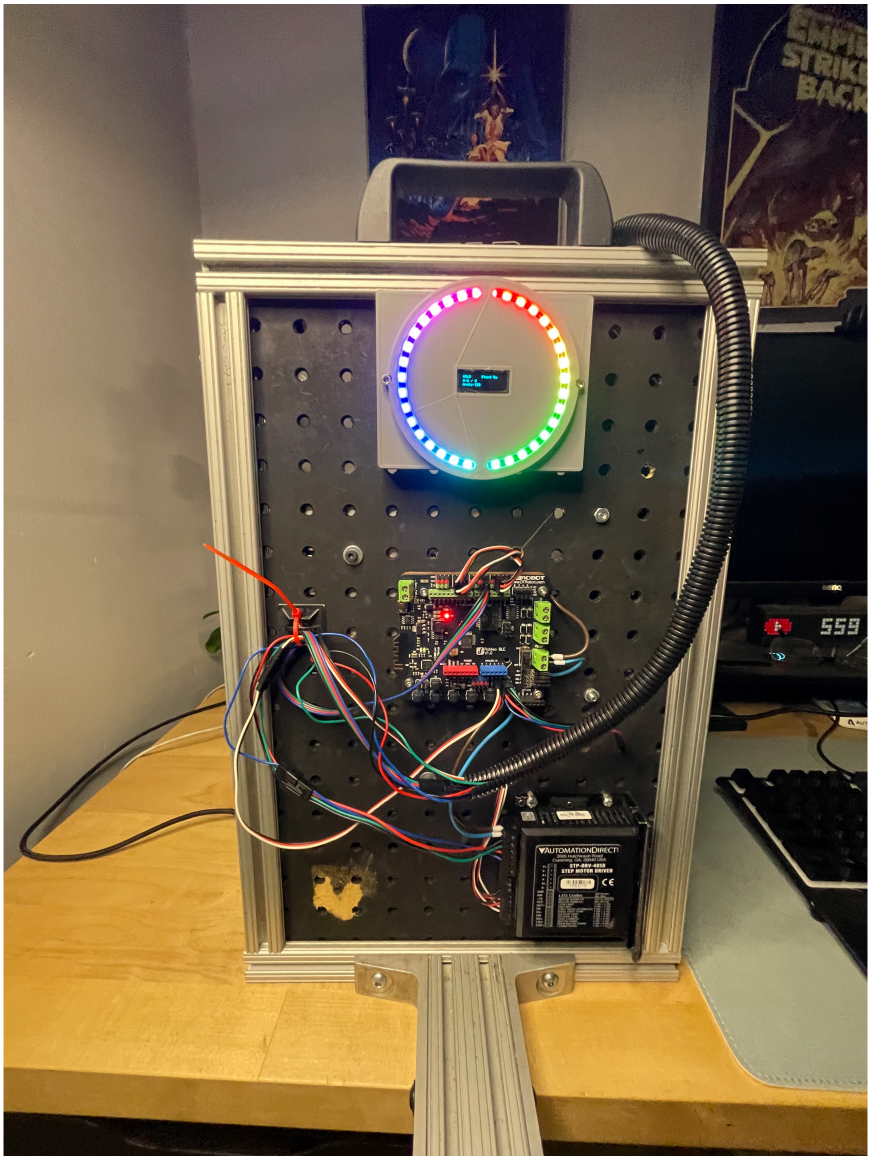
Attached is a PDF of the Arduino created for the Series elastic Actuator

4.2 Wire Diagram



4.3 Additional Picutres




AUTOMATIONDIRECT
STEP MOTOR DRIVER