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BIOMECHANICAL ROBOTS

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Assignment # 2

Design and Fabrication of Two Finger Gripper for Humanoid Robot Applications

By

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ABSTRACT

We designed an anthropomorphic gripper for unstructured hominoid robotic application using a cable driven actuator. The gripper consisted of two systems, a pair of double hinged fingers and four servo actuators. The goal was to integrate all the components to create a suitable robotic “hand” that would allow interaction with the environment.

The double hinged fingers allow for an adjustable, configurable gripping interface between the gripper and desired object. The adjustable fingers allow gripping of objects varying from 1-4 inches wide. To increase surface friction between the object and gripper a rubber pad was used like skin for the fingertips.

The servo actuator powers the control cables that are connected to each finger joint. The servos are separated into pairs where each power either the closing or opening of a finger joint. The gripper will be able to dynamically change the gripping configuration and the amount of force applied at the fingertips depending on the tension of the control cable.

Our goal was to take inspiration from the human biology and design a cable driven anthropomorphic robotic gripper. Overall, the system works as designed. The gripper successfully interacted with objects in the desired size range and at weights exceeding 1 lb. However, the system is far from perfect. Many improvements can be made to improve the durability, accuracy, and the strength of the design. This report will go into depth on the design, manufacturing, testing, and evaluation of our custom anthropomorphic gripper.

TABLE OF CONTENTS

List OF Figures

1 Introduction

1.1 Humanoid Robotics

Industrial robots can be found in many industries today, ranging from manufacturing to entertainment. In these applications most robots are programed how to complete specific tasks while operating in premade environments. These workspaces made specifically for robots to operate in are called structured environments (Bruno Siciliano, 2016). Modern industrial robots are very limited compared to humans who can operate in a vast variety of environments while performing a vast variety of complex tasks. Humanoid robots are attempting to bridge the gap between industrial robots and humans. These machines are inspired by human biology and are designed to interact in unstructured environments. There is a wide range of humanoid robots being developed, each addressing the shortcoming of current industrial robots in different ways. Humanoid robots are designed to have improved the dexterity, locomotion, sensory feedback and intelligence that the commonplace industrial robots currently lack.

1.2 Robot End Effectors

The difference that separates robots to any other computer is its ability to interact with its environment. The tool robot uses to interact with its environment are called End Effectors or grippers. There are a wide variety of grippers used in robotics each separated based on the type of actuation and the degree of freedom that they offer.

Actuation method refers to the type of mechanism used to power the movement of the end effector. Each type of actuation method uses a different working principle and is optimal for specific environments and tasks. Some of the most common actuation methods are:

- Fluidic Actuation
- Pneumatic Actuation
- Thermal Actuation
- Electric Actuators

Figure 1 Pneumatic 2-Finger Gripper 1 DOF

Figure 2 Electric 3 Finger Gripper w/ 9 DOF

Each actuation method has certain benefits and disadvantages. For example, pneumatic actuators are inherently compliant however requires additional hardware such as pressure tanks and compressors making them heavy. Electric actuators are simple and lightweight, but special design will be needed to make their mechanical systems compliant, such as sensor feedback or elastic materials.

The level of dexterity depends on the amount of Degree of freedom (DOF) offered by the gripper. Grippers can often be separated into two camps, industrial grippers and bioinspired gripers. Industrial grippers are designed to only have the level of dexterity needed for a specific task. Bioinspired grippers are design to mimic the level of dexterity of the human hand. Human hands are specially made to interact and manipulate objects with a high level of compliancy and dexterity. The human hand has 27 degrees of freedom, allowing for exceptional articulation and making complex motion possible. The human hand is powered by tendons, ligaments, and muscles. biomimetic robotic hand designed to imitate the biological design are called anthropomorphic grippers, the ligaments and tendons of the human hand are replaced with elastic elements and cables. (Yi, 2021)

Ideally each joint in a biomimetic hand would be individually powered allowing for a greater level of articulation and manipulation. However, it is often better to reduce the number of actuators in a system to simplify control and lower costs. A gripper is that has less actuators in the hand then the number of joints is called Under-Actuated grippers. (Xin Li1, 2017).

Figure 3 Link Driven underactuated anthropomorphic finger

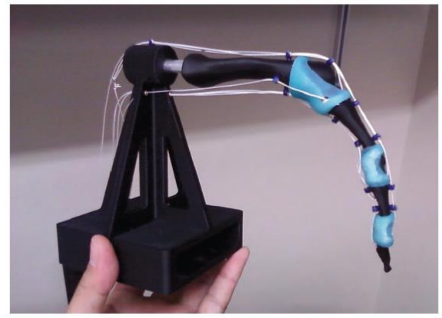

Figure 4 Cable Driven anthropomorphic finger

1.3 Objective of Anthropomorphic Grippers

The objective for anthropomorphic grippers is to closely imitate the biological function and performance of the human hand. Anthropomorphic grippers are designed to perform similar tasks to the human hand, and so they are also often design to meet similar specifications as the human hand. (Bhadugale, 2018) Some of the key requirements these grippers need to meet to be a viable option in use on humanoid robots include:

- Grasping: Perform a variety of grasp including pinching or lateral grasps
- Strength: ability to exert a high level of force onto an object.
- Compliancy: ability to deform or flex to external interactions.
- Weight: Low mass / weight
- Durability: ability to sustain frequent high load without breaking.
- Cost: the economic viability of the designed gripper
- Size: the overall volume of end effector

2 Anthropomorphic Gripper Design

2.1 Gripper Requirements

The objective of this project is to design and fabricate a custom anthropomorphic robotic gripper that could be used on humanoid robot. The gripper is designed to allow a robot to interact with a variety of objects using a cable driven actuation. To successfully perform the desired task the gripper needs to meet certain requirements. First it needs to meet the standard general requirements for anthropomorphic grippers mentioned before: Multiple grasping configuration, compliancy, small size and low cost. Our cable driven gripper also needs to meet application specific requirements on top of the general requirements. The application specific requirements include the following:

- Ability to lift a mass of 1 lb force.
- Ability to hold said mass for 8 seconds.
- Ability to grip objects with a maximum cross section of 4 inches.
- Able to interact with the desired object without damaging the object.
- Ability to drive each joint opening and closing motion using cables.

2.2 Hardware

After careful considerations we identified the key hardware required for the custom gripper. First most of the structure will be 3D printed, allowing for a custom lightweight frame. Second the gripper will utilize stainless steel cable as its control wire. These control wire will act like the human hand ligaments and tendons, transferring the force generated by the actuator to the desired joint. Third, servo motors were selected to be used as this gripper electric actuator. Lastly, an Arduino mega was selected to be the grippers microcontroller.

2.3 Servo Actuator

A servo motor is a stable of modern controllable actuators. Servos motors has an integrated gearbox and potentiometer that drives an output shaft precisely. Standard servos allow the shaft to be positioned at various angles, usually between 0 and 180 degrees and move from multiple position at a specified speed.

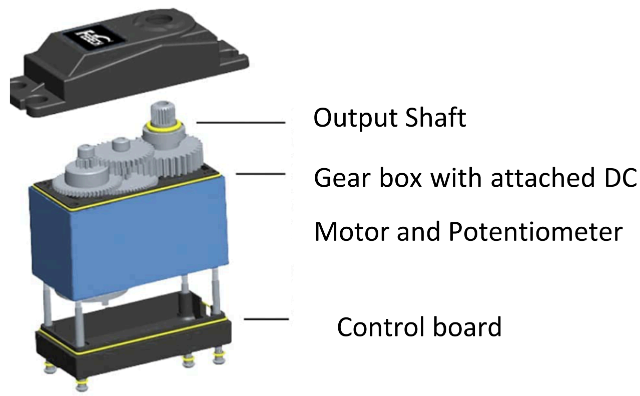

Figure 5 Servo Motor Design

The servo motor will allow for an easy-to-use actuator that can power the anthropomorphic gripper. However, servos are only rated for a certain load and so an estimated torque calculation is required in order to select an adequate servo motor.

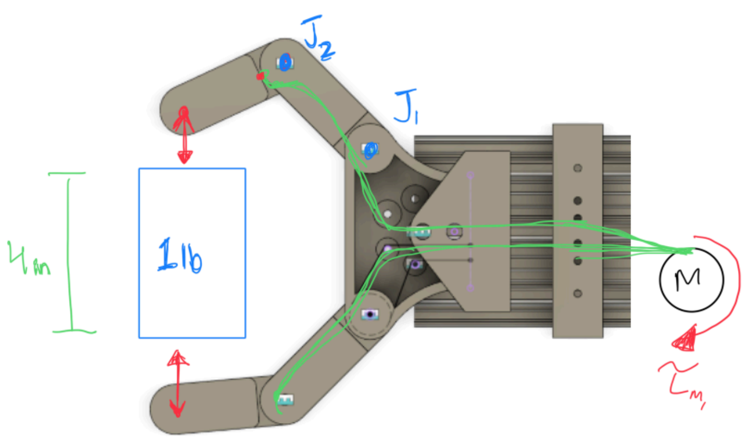

Figure 6 Force Diagram

2.3 Servo Actuator Foce Calculation

To determine the required size of the servo motor a simple force calculation was conduction. In order to pick up an object the gripper needs to generate a reaction force from the finger equal to the weight of the part. Let us consider the following situation in which the finger is partially extended, and a force is applied near the tip of the finger, as shown in figure 6. Joint 2 will be experiencing the moment created by the reaction force from the object and the moment created by the control wire. The net moment on joint 2 would need to be balanced in order to have equilibrium. To calculate the moment on joint two a simplified force diagram was created.

Moment = (Force) x (Perpendicular Distance)

M = F·d

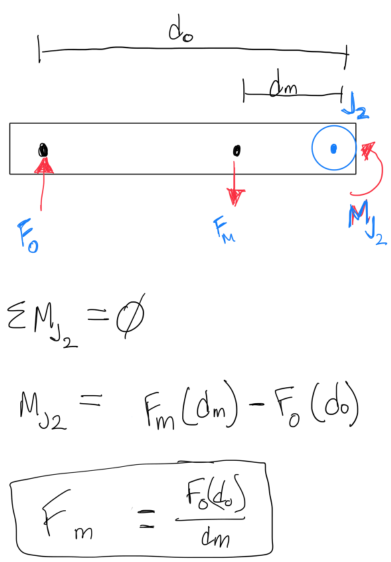

Figure 7 Simplified Force Diagram of Finger

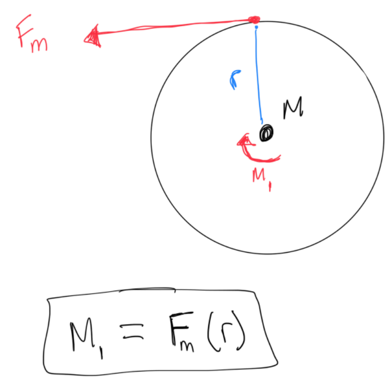

Figure 8 Simplified Force Diagram of Servo

Figure 7 shows the simplified force diagram of the isolated finger link, A force exerted on fingertip and the force exerted by the control wire acting on joint 2. The reaction force (Fo) is located a set distance (do) from joint 2. While the force exerted by the control cable (Fm) is located a closer distance (dm) to joint 2. Knowing that the sum of moment will need to balance the force required from the control wire can be calculated. Once the required force is determined then the torque of the servo motor can be calculated using the same moment equation. As shown in figure 8 the moment or torque required for the motor will be determine by the force required by the control wire and the size of pully used. After conducting the necessary calculations, the required torque needed is 2.1 kg force. A larger servo will be selected to allow for losses due to inefficiently and friction.

Known Variables

Force Object	Fo = 1 lb = 0.45 Kg
Fo Distance from J2	Do = 4.4 cm
Fm Distance from J2	Dm = 2.4 cm
Radius of Pulley	R = 2.5 cm

Calculation

Force wire	Fm = 0.825 kg
Torque Motor	M = 2.0625 Kg * cm

2.5 CAD Design

Once the hardware was selected the next phase was to design the Anthropomorphic Gripper in CAD as shown in figure 11. The gripper system is divided into two elements. The mechanical fingers and the control wire actuators.

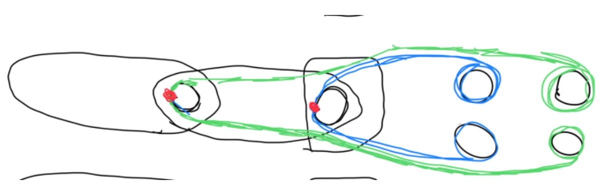

Figure 9 Sketch of Design

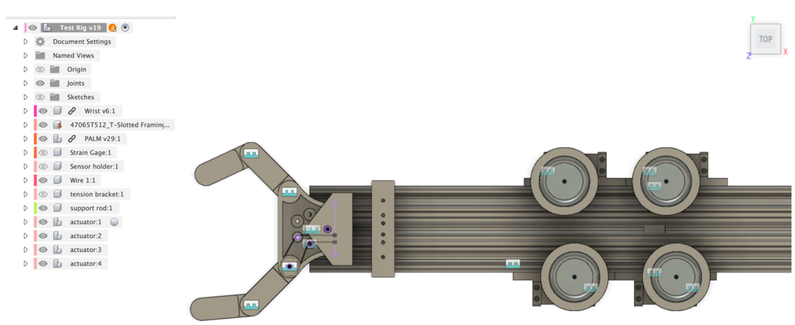

Figure 10 CAD Model of Design

The mechanical finger consists of two identical finger assemblies each with two joints allowing for 2 DOF. The fingers are actuated by control cables that runs internally to the servo actuators. Each joint will utilize two control cables, one to pull the joint clockwise the other to pull the joint counterclockwise. Each control wire is anchored to its assign joint using set screws. A rubber membrane was used on the surface of the gripper to allow for a larger surface friction between the object and gripper.

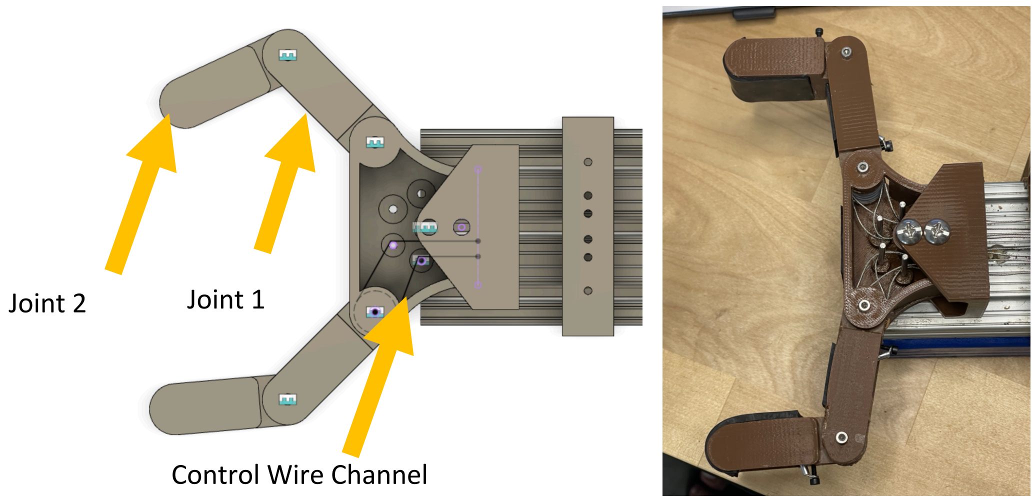

Figure 11 Finger Diagram

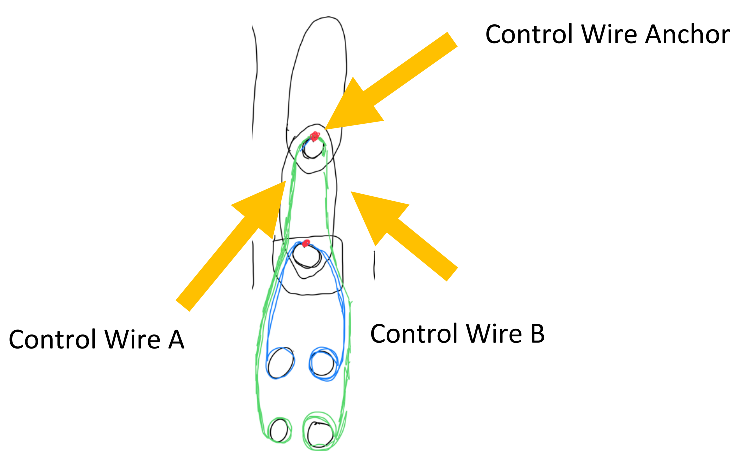

Figure 12 Control Wire Internal Diagram

The control wire actuator unit includes all the servo motors used to power the gripper. The Stainless-steel cables that are anchor to each join are connected to a specific motor that will control the wire motion. These control cables are tied to the custom 3D-printed servo pulleys as shown in figure 13 and figure 14. The servo motor rotates in one direction to achieve flexion movement (closing of the finger), while it rotates in the opposite direction to achieve extension movement (opening of the finger).

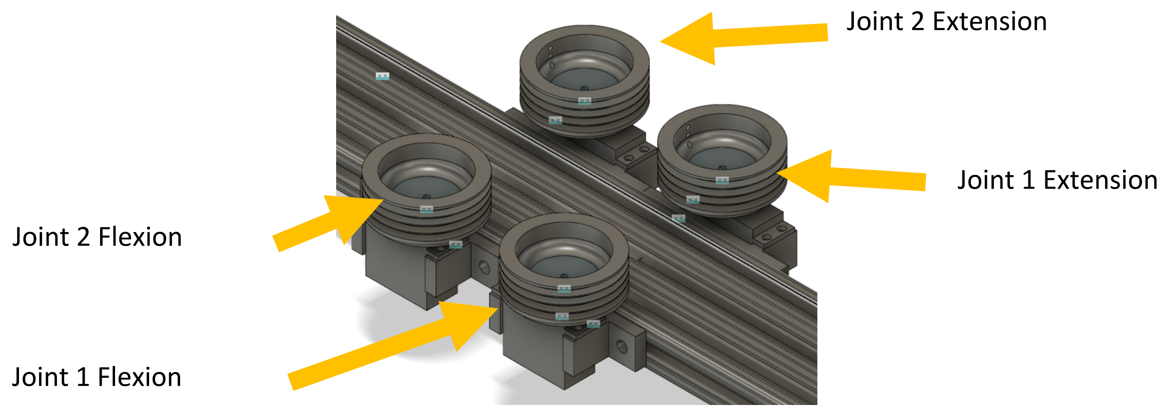

Figure 13 Actuator Diagram

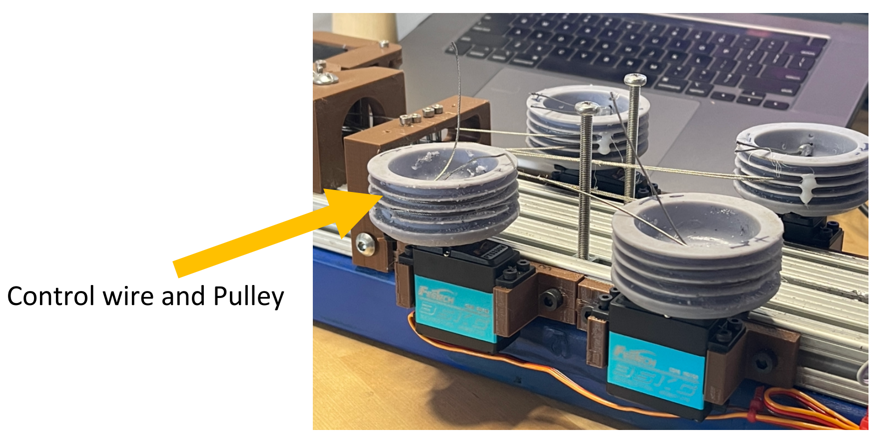

Figure 14 Actuators

3 Materials & Manufacturing

3.1 Materials

Majority of the physical components used in this custom gripper are off the shelf units. This made acquisition simple and affordable. Listed below is the list of components used, their specific function in the gripper, and the cost per unit. The final cost of the sensors used in the tactile unit is around $300.

Component ID	Description	Brand	Function	Cost
FT5330M	Digital Servo Motor	Feetech	Actuator	$48 x4
Mega	Microcontroller	Arduino	Microcontroller	$36
Steel Cable	Stainless steel wire cable. 1/32	AHANDMAKER	Control Wire	$21
PLA	PLA Filament for 3D Printing	Overture	Raw Material	$25

3.2 Manufacturing

Once the design of the gripper was completed, the manufacturing of the system began. Off the shelf items were ordered using online services and custom hardware was fabricated using 3d printing.

All components created in Fusion 360 was fabricated using my personal 3D Printers. I used two typed of 3D printing in this project, SLA and FDM printing. SLA or Stereolithography 3D printing was used for more accurate components, this included the pullies that mounts to the actuators.

Figure 15 SLA & FDM Printers

Figure 16 Post Process Cleaning

All the 3D printed components required a level of post processing to remove supports, clean surface, and sand interactive surfaces to lower friction of the joints. After preparing the gripper the control cables where then anchored to each joint and the rubber liner was glued to the surface completing the gripper assembly as shown in figure 17, figure 18, and Figure 19.

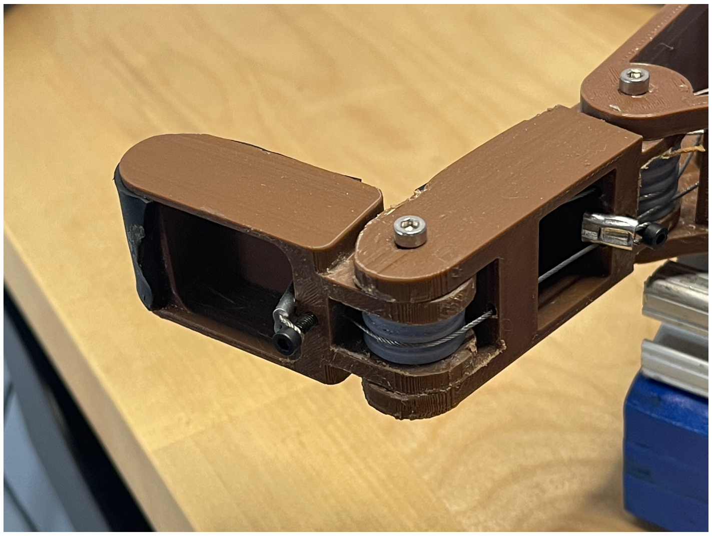

Figure 17 Anchoring Control Wire to Joints

Figure 18 Control Wire Through Gripper

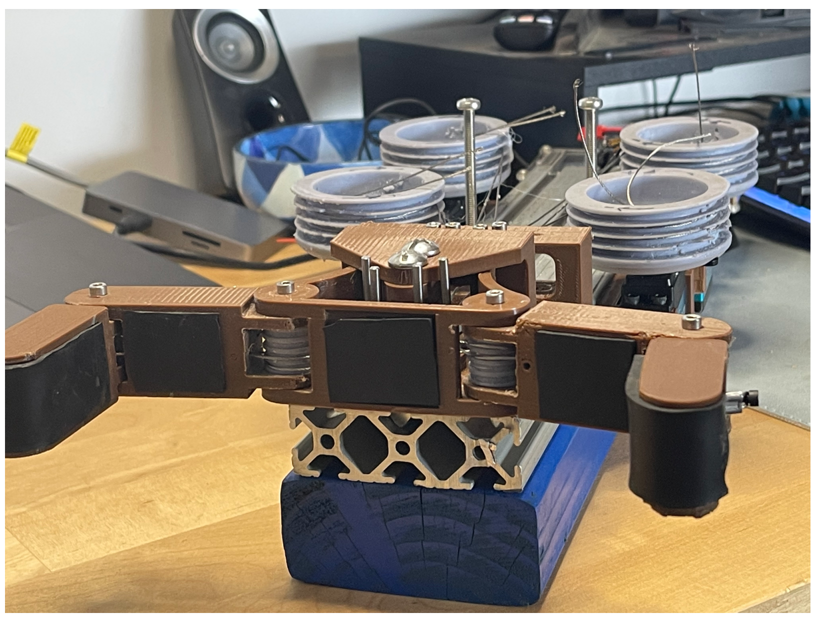

Figure 19 Rubber Pads for Gripper

3.3 Electrical System & Wiring

Upon completing the hardware assembly of the gripper, the next phase was to assembly the electronic bay that will control the system. The electrical system consists of 4 key elements, the microcontroller, power supply, LCD Shield and servos. An Arduino Mega was used as the microcontroller for this project. This unit would run the code that will control the servo and LCD screen. The LCD screen will be the primary interface between the user and the gripper. The LCD will allow the user to select the desired grip mode for the gripper to perform. The power system for this gripper is a simple 5V usb power supply. Lastly the servo motors were connected to PWM pins on top of the LCD shield that connects directly to the Arduino PWM output pins. Below are the wiring diagrams used for the gripper.

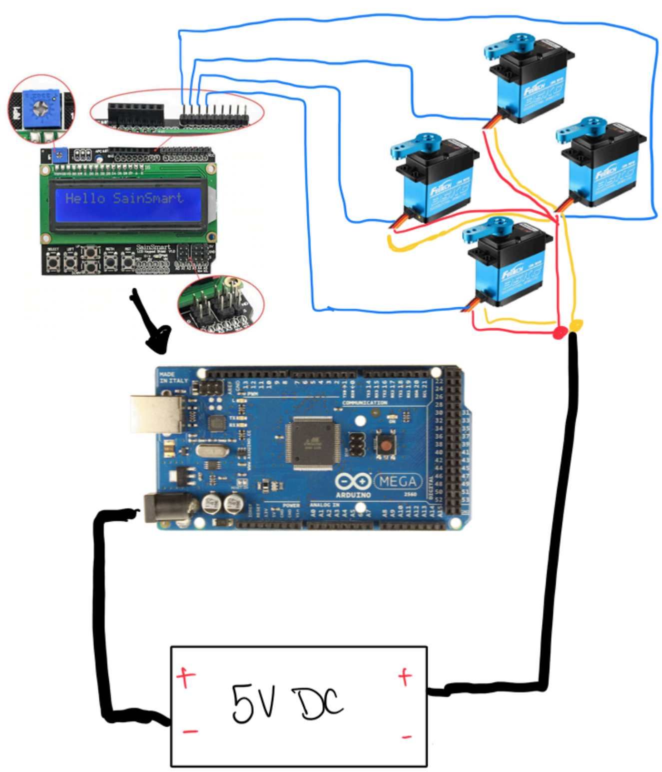

Figure 20 Full Tactile System Wire Diagram

3.4 Programing

After the successful wiring of electrical system, the next phase was to create the custom code that the Arduino nano will use to control the gripper. The microcontroller was programed on the Arduino IDE and uses C as the programing language. The microcontroller and LCD Screen and servos communicate using the analog and digital pins of the Arduino mega.

Figure 21 Custom Code For Gripper

To control the gripper, we first began by moving the servo, and intern each joint, to multiple positions and record the angle of each servo at each position. To determine the desired positions, we used reference objects as shown in figure 22 and figure 23. We record over 10 different positions using 10 different objects, ranging from small water containers to large boxes. Each object required a slightly different gripping position and load. Once all these reference positions were saved then can later be called again allowing the gripper to quickly change gripping styles.

Figure 22 Gripper and Large Box

Figure 23 Gripper and Bag of Chips

The list of gripping positions saved is listed below:

Grip Modes	Function	Example
Fingertip	Increase Load at the fingertips for small objects	Chips
Medium Wide	Wide gripper for use on boxes 2-3 inches wide	Small Box
Large Wide	Extra Wide gripper position for boxes 3-4 Inches wide	Large Box
Loose Grip	Moderate force evenly distributes on all 4 joints for larger objects 3 inch +	Mug
Tight Grip	As high of force servo can exert on the smallest size allowed by the finger inner perimeter.	Water Cup
Large Diameter	Used for Large water bottle/jug	Large Water Bottle
Small Diameter	Used for standard water bottle/jug	Water Bottle

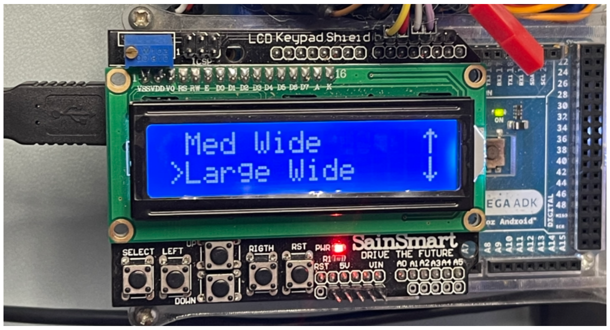

Figure 24 LCD Menu 1

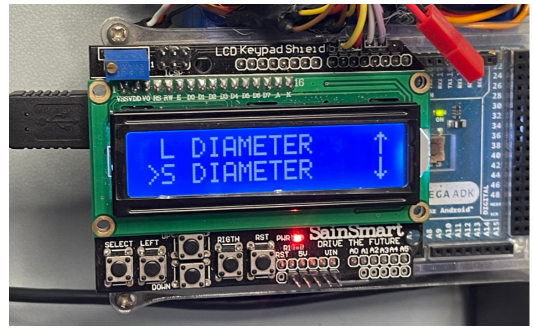

Figure 25 LCD Menu 2

Now that the different gripping positions are saved and can be called upon, we developed a simple user interface that allows an operator to select the desired grip mode. As shown in figure 24 and figure 25 an operator can scroll through a list of gripping modes. Once selected the gripper will first loosen all joints, then set the Flexion control cables first followed by the Extension control cables.

4 Analysis & Results

4.1 Gripper Evaluation

Once completing the gripper system, it was then time to evaluate the effectiveness of the system. The gripper was designed to meet general requirements for anthropomorphic grippers including Multiple grasping configuration, compliancy, small size and low cost. Our gripper also was designed to meet the following application specific requirements:

- Ability to lift a mass of 1 lb force.
- Ability to hold said mass for 8 seconds.
- Ability to grip objects with a maximum cross section of 4 inches.
- Able to interact with the desired object without damaging the object.
- Ability to drive each joint opening and closing motion using cables.

The final size of the gripper was slightly larger than a typical human hand. The gripper had a base width of 4 inches wide and 3.5 inches long. Each finger measured 4.5 inches long and 1.5 inches thick. Overall, the size of the unit was relatively compact and weighing 1.5 lbs. (without including the wooden forearm) can easily be places on a robot arm. Overall passing the size and weight requirement.

The final cost of this gripper was $300 making it a moderately expansive unit. Half of the overall cost was due to the type of servos used and this could be changed in future design to allow for a stronger but cheaper future version of the gripper.

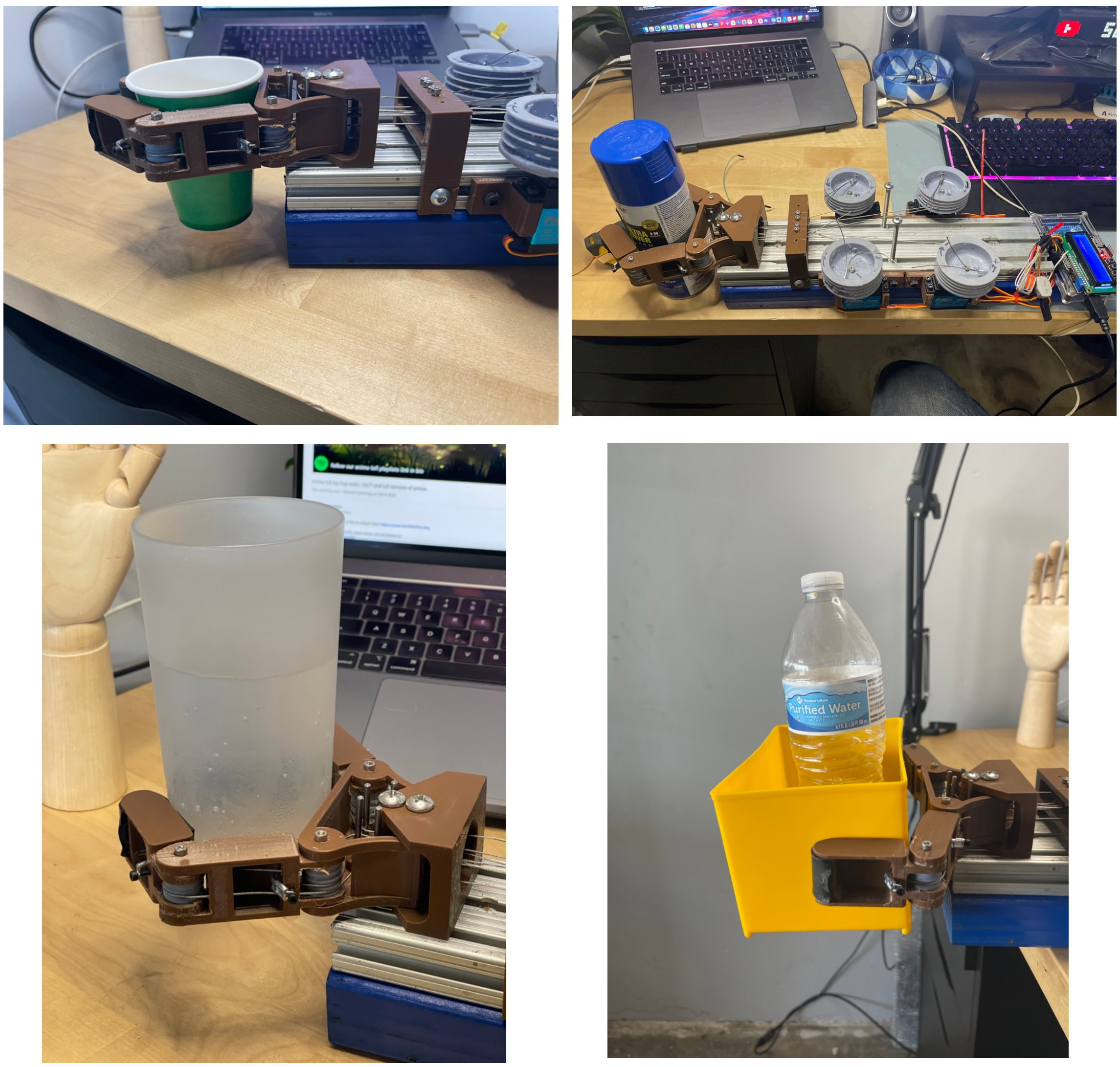

Figure 26 Assembled Gripper Testing Different Objects

The primary goal of the gripper was to have multiple gripping methods using a cable driven mechanism and being able to lift a mass of 1lb for more than 8 seconds. The gripper successfully passed this requirement as well. As shown in Figure 26 the gripper contains a variety of gripping position, each allowing it to interact with a variety of object. The powerful 35Kg servos that we used allowed plenty of torque to be generated to carry the 1lb payload for an indefinite amount of time and allow for the gripper to dynamically move the 1lb payload at the same time.

3.4 Improvments

After the successful testing of the gripper a few design flaws were highlighted. The actuation method used pullies to control the tension of each control wire. Each pully controlled the left and right finger joint concurrently. Ideally each joint will be individually controlled. Because of the anchoring method used it was quite difficult to ensure even tension of the cables. A different tensioning system/ anchoring method would be recommended to solve this problem. Another issue with the pully was the lack of support on the axil. As higher loads the pulley would begin to pivot and would eventually fail. Lastly, we believe it would be far better to measure the angle of each joint at the joint location rather than the angle moved at the servo. It was not uncommon for the joint angle to be a few degrees off from the desired position due to external forces or friction. Moving the potentiometer to each joint will likely make a far more accurate and consistent gripper.

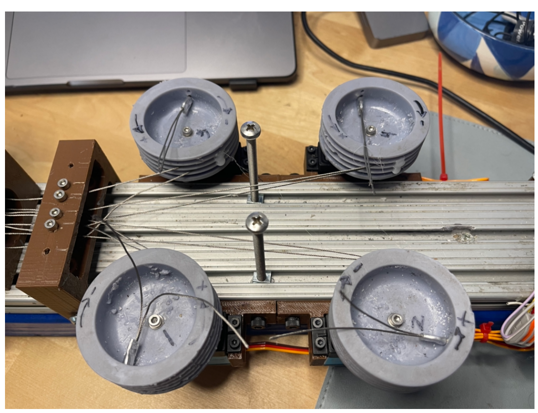

Figure 27 Future Improvements

5 Conclusion

End effects allows robots to interact with their environments much like how human hand allows do. End effects that attempt to mimic the biological design and function of the human hand are called Anthropomorphic Gripper. Our goal was to take inspiration from the human biology and design a cable driven anthropomorphic robotic gripper. Our gripper was design to lift a variety of objects ranging from 1 inch to 4 inches and weighing up to 1 lb. Our gripper consists of a two double hinged finger, servo actuators, and a LCD user interface.

The double hinged fingers allow for an adjustable, configurable gripping interface between the gripper and desired object. The adjustable fingers allow gripping of objects varying from 1-4 inches wide. To increase surface friction between the object and gripper a rubber pad was used like skin for the fingertips.

The servo actuator powers the control cables that are connected to each finger joint. The servos are separated into pairs where each power either the closing or opening of a finger joint. The gripper will be able to dynamically change the gripping configuration and the amount of force applied at the fingertips depending on the tension of the control cable.

Using a microcontroller, we were able to configure the gripper to have multiple gripping methods allowing the system to select the optimal gripping pattern for a desired object. A LCD screen gave the human operator the ability to select the desired grip pattern when interacting with the desired object.

Overall, the system works as designed. The gripper successfully interacted with objects in the desired size range and at weights exceeding 1 lb. However, the system is far from perfect. Many improvements can be made to improve the durability, accuracy, and the strength of the design.

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6 Appendix

7.1 Arduino Code

Attached is a PDF of the Arduino created for the tactile sensor