End Effectors for Humanoid Robot

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Abstract

Professor Bhounsule's robotics laboratory at UIC possesses a humanoid robot for R&D purposes. He has assigned the task of designing, prototyping, manufacturing, and testing hand-like end effectors for this robot. The end effectors must be capable of identifying an object, securing it in some manner, holding onto the object, and letting go of it at any desired time. Several possible design solutions have been proposed and evaluated. The chief idea being a pneumatic powered gripper, i.e. a suction cup. The feasibility and forgiveness of such a method is appealing, as it allows for a higher margin of success. Further design considerations included the number of degrees of freedom desired, as well as possibly securing any object mechanically once it is pneumatically gripped via the suction cup method. In addition to design considerations and development, pneumatic components have been ordered by Professor Bhounsule for the purpose of experimentation. The components that have been ordered and acquired include two pneumatic pumps, four 20kg servos, several arduino UNOs, wires, multiple suction cups, pneumatic hoses, pneumatic fittings, joystick, and buttons. The goal of the project consists of creating an accurate demonstration of how Professor Bhounsule will utilize our design. Our design demonstration will have a 3D printed version of the humanoid robot's arm, mounted on a 2-axis swivel mount (driven by servos). At the end of the arm will be a mount for the wrist assembly, which consists of another 2-axis swivel mechanism, in order to replicate a humanoid's wrist movement. At the end of the wrist assembly will be a suction cup sub-assembly, driven by two pneumatic pumps attached to the wrist mount. For demonstration purposes, the end effector mechanism will be driven by user input, utilizing a custom open loop controller. This is due to the uncertainty of how future graduate students in Professor Bhounsule's lab will integrate our design, if at all. To accomplish all of this, standard engineering design steps were taken, including scheduling project deadlines via Gantt Chart, design criteria via Fishbone diagram, and design brainstorming via research and sketching. Looking forward, final design of our end effector should be complete by week 12, with Expo booth design subsequently following.

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Introduction

Problem Statement

This senior design project aims to equip a humanoid robot owned by the UIC Robotics and Motion Laboratory with two functional hands. Currently, the robot lacks any form of end effector, severely limiting its potential uses. The goal is to enable the robot to perform simple pick and place tasks involving small household objects of varying weights and sizes. The interface between the hands and the robot is not within the scope of this project. The main objective is to design and implement a pneumatic system that will allow the hands to suction items efficiently.

Sponsor Background

The sponsor for this project is UIC Assistant Professor Pranav Bhounsule, PhD. Professor Bhounsule leads the Robotics and Motion Laboratory, which works on developing algorithms and physical prototypes to push the limits of current robotic systems. His research interests include legged locomotion, robotics, and optimal control. The lab currently has a humanoid robot, but it lacks any sort of hand or end effector. This project will allow for a solution to be found that will fit the needs of the lab, and will allow for further testing and development of the robot.

Metrics & Product Specifications

The final deliverable will be pneumatic end effectors that can efficiently pick and place small household objects. The end effectors will need to be able to attach to the ends of the existing arms of the robot without modifications, and should be lightweight so it won't impede on the other functions of the robot. The hands also need the capacity to house extra accessories such as a microcontroller, battery, and air pump. Accessories may be mounted to the body of the robot when necessary if their placement on the hands would limit the capabilities of the hand. The hands should be able to detect and pick up a variety of household objects which are yet to be specified. Current objects being considered include cups, balls, and potentially more difficult objects such as eggs and pencils.

Codes and Standards

The robot hands are exclusively for research and will not be implemented in a system where they will be manufactured for a business. Because of this, codes and standards should not play an important role in our design process. However, considering code and standards for industries may help give insight into the design process. The following are some of the standard agencies relevant to us

- ISO: (International Organization for Standardization) develops standards to ensure the quality, safety, and efficiency of products, services, and systems
- ASME: professional organization focused on technical, educational, and research issues of the engineering and technology community.
- ANSI: American National Standards Institute, establishes engineering standards to ensure that products, services and processes are consistent and predictable for all.

Methods/Technical Content

Design Criteria

There are several design criteria that must be considered for the robot's hands. Our primary criteria are weight capacity, reliability, range of motion, workspace, control system, energy efficiency, safety, and scalability. One of the most important is weight capacity, which limits the robots ability to pick up certain objects. The type of control system used will also impact the robots effectiveness. Because of this the control system must be carefully selected as it will directly influence every other aspect of the design. Some current options include using an arduino or a raspberry pi. The sensors that are used are also tied into the system control as these will give input for detecting objects as well as ensuring the gripped object is secured firmly. Range of motion is another crucial factor because different types of objects will require the hands to be placed in different orientations depending on the objects geometry and weight. Understanding how many degrees of freedom that the hand needs is also important as this can make picking up objects in awkward positions. Energy Efficiency is important as pneumatic end effectors have the potential to use an abundance of energy so the design has to be efficient. Reliability is important so that it won't need to be serviced frequently. Workplace refers to the space that the hand will be used in. Picking up objects in weird or awkward places will require more sophisticated programming, so it is important to know what will be considered when designing. Safety is the most important criteria, and ensuring that manufacturing and using the hand will pose no safety risk is essential. Scalability refers to how easy it will be to manufacture as well as build on our design, which will require thought when designing.

The secondary design criteria are aesthetics, longevity, environmental impact, response time, and noise/vibration. The aesthetics of the end effector isn't crucial to its success, but given that the robot is humanoid it is important to create a design that is cohesive with the rest of the robot and doesn't impede on the existing design choices. The longevity ties in to the reliability, but more specifically deals with how long parts will last under normal use. The environmental impact is important to consider especially since 3D printing will play a large role in prototyping and manufacturing . Making sure that the filaments used have the least amount of impact is important, and will influence the design. Response time helps ensure that the robot is efficient with its movements and doesn't hinder its usefulness. The noise and vibrations produced by the robot shouldn't be distracting to others in the lab, and the vibration shouldn't impact the other functions of the robot.

Proposed Solutions

The initial designs began with claw and pincer end effectors as seen in the Appendix. This type of end effector is supposed to replicate picking up objects similarly to human hands. The key to this method would be two pincers that would act like a thumb and a finger to pinch an item between them in order to secure the item and then proceed to lift it and move it to its desired location. Upon reaching said location the fingers would separate and release the held item. There are several advantages and disadvantages to this method. Claw arm grippers are relatively simple in design and operation, making them easy to implement and maintain. They consist of two parallel fingers that can move towards each other to grasp an object, which simplifies the control system. They also operate quickly, making them suitable for high-speed applications like pick-and-place operations. These grippers are often cost-effective, making them a practical choice for applications where cost is a significant consideration. Due to their simple design, claw arm grippers tend to be reliable and have a lower risk of mechanical failures compared to more complex gripper types. However there are also many cons for this type of end effector. Claw arm grippers may struggle with irregularly shaped or non-rigid objects that do not fit between the two parallel fingers. They are less versatile than some other gripper types, such as multi-fingered or soft grippers. Claw arm grippers typically lack the ability to adapt to the shape of an object, which means they may not provide a secure grip on objects with complex geometries. While they are fast, claw arm grippers may lack the precision needed for delicate tasks, such as handling sensitive electronics or fragile objects. The two-finger design can limit the gripper's ability to handle multiple objects at once or to reorient objects during manipulation. If not controlled properly, claw arm grippers can exert excessive force on delicate objects, potentially causing damage. In summary, claw arm grippers offer simplicity, speed, and cost-efficiency, but they may have limitations in terms of versatility, adaptability, and precision. The choice of gripper type should be based on the specific requirements of the application and the types of objects that need to be handled.

A pneumatic gripper was another proposed solution for this project. A pneumatic gripper would use an air compressor to create suction between the end effector and the object being picked up. This type of design will allow the robot to pick up a greater variety of objects because the geometry of the object will be irrelevant. Also it is less sensitive to the position of the object being moved. This allows for more flexibility and forgiveness in terms of picking up the object. There are several advantages and disadvantages to this method. Pneumatic end effectors can operate with high speed and force, making them suitable for applications that require rapid gripping, lifting, and holding of objects. They are often more cost-effective than electric or hydraulic alternatives, making them a better economical choice. Compressed air is generally safer than some other power sources, such as electricity or hydraulics, as there is no risk of electrical shock or fluid leakage in hydraulic systems. Pneumatic systems are clean and do not require hydraulic fluids, which can be messy and pose environmental concerns. Pneumatic systems are relatively easy to control and can be quickly adjusted to accommodate various tasks. They are durable making them suitable for several applications. Pneumatic end effectors are typically light weight making them easier to integrate into robotic systems or other machinery. However there are multiple cons that need to be considered. Pneumatic systems may lack the precision required for some applications. They can have limited control over force and positioning, which can be a disadvantage in tasks that demand high accuracy. While they are more energy-efficient than some alternatives, pneumatic systems can still consume a significant amount of compressed air, which can be costly in the long run. Pneumatic systems can be noisy, which can be a concern in environments where low noise levels are essential. Compressed air storage has limited capacity, which may limit the duration of operations compared to hydraulic systems. Although pneumatic systems are cleaner than hydraulic systems, they still consume energy, and the production of compressed air can have environmental impacts. Pneumatic systems may require regular maintenance, including checking for leaks and ensuring the integrity of the pneumatic lines and components. Pneumatic end effectors may not be suitable for all applications, especially those requiring fine control, high precision, or very low force. In summary, pneumatic end effectors offer advantages in terms of speed, cost-effectiveness, and safety but may have limitations in precision, energy consumption, and noise levels. The choice of a pneumatic system should be based on the specific requirements of the application and a careful evaluation of the pros and cons in relation to those needs.

The gripper design will also need to be fastened to the robot via some sort of mounting mechanism, as well as have articulation in order to position the suction cups. The articulation would come in the form of a wrist, and would comprise two servo motors that rotate across different axes. This allows for a minimum of two degrees of freedom, and should allow for the gripper to be oriented in any way necessary. This design would give lots of flexibility in terms of movement, but may pose some difficulty in programming. This hurdle will be subverted by being remote controlled for expo since the implementation of autonomous coding falls outside the scope of the project. The wrist will be mounted to a brace on the arm, which has several possible ways of being implemented. One key idea is to have two straps or clamps around the arm at different spots, that will conform to the shape of the arm. This will allow for the design to not require as precise of fabrication as irregularities could be accounted for easily. A brace would also allow for a spot for controls and wires to be mounted without being too unsightly.

A fishbone diagram for a pneumatic end effector can be seen below in Figure 1. This diagram helps sort out the different aspects of the pneumatic into a single spot, and can help with troubleshooting when prototyping begins.

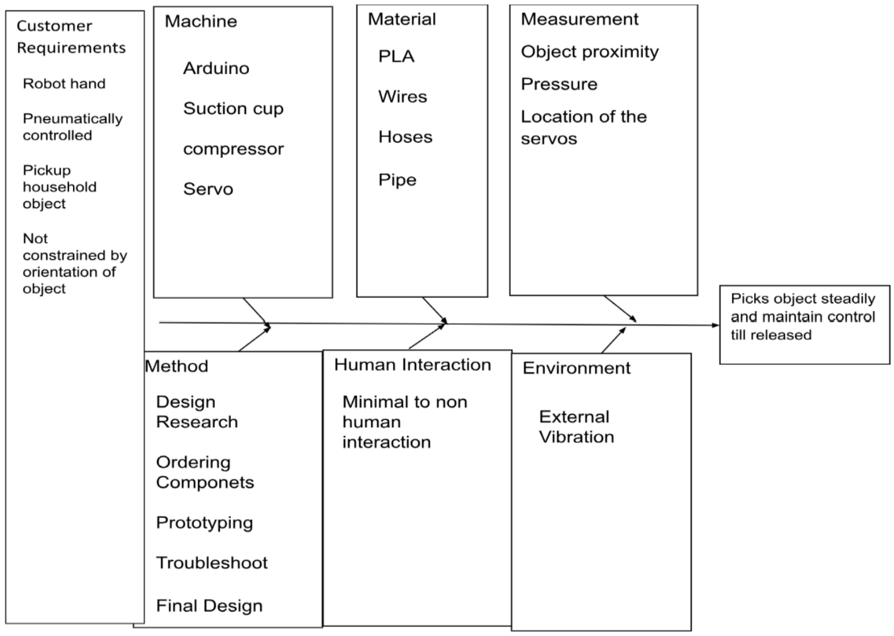


Figure 1: Fishbone Diagram

A Quality Function Deployment diagram for a pneumatic end effector can be seen below in Figure 2. This diagram helps to transform qualitative user demands into quantitative parameters, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process.

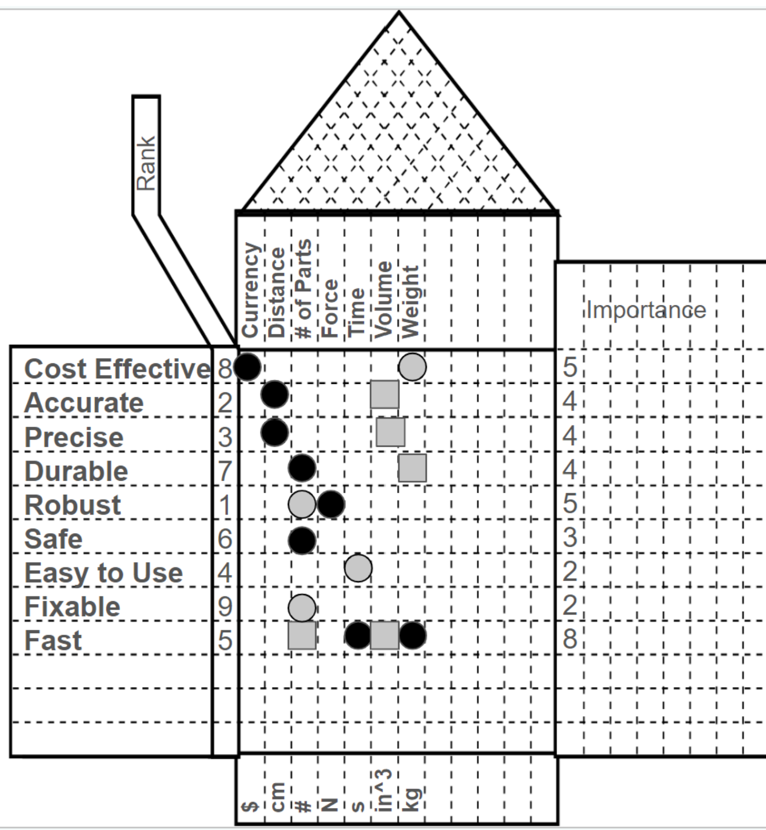


Figure 2: QFD

Decision Matrix

		Decision Matrix				
	Strength	Speed	Durability	Accuracy	Cost	Rating
Weighted Value	0.2	0.2	0.2	0.2	0.2	10
Fractal Vice	9	2	8	3	3	
	1.8	0.4	1.6	0.6	0.6	5
Two Pronged Vice	5	6	3	7	8	
	1	1.2	0.6	1.4	1.6	5.8
Single Pneumatic	3	9	2	8	9	
	0.6	1.8	0.4	1.6	1.8	6.2
Multi Pneumatic	7	6	9	5	6	
	1.4	1.2	1.8	1	1.2	6.6

The group collaborated in making a decision matrix, as seen above, to see which design would be the most viable option. This was performed in order to create a better picture of how well each design would match up with one another when looking at its cost, accuracy, durability, speed, and strength. Each aspect is equally important because every single aspect is important in the overall function of the robot arm. As to how the criteria was evaluated was based on how well each design would perform under the given category. After analysis it is clear that the multi pneumatic arm is the most practical option for our purposes.

System Design

Three main components need to be designed for an effective robotic hand that simulates the function of a real human hand. The first would be pneumatic grippers that can easily grab and pick up an object regardless of that object's geometry or material. In order to achieve this the grippers shape and size as well as the brackets layout need to be optimized. This is to ensure that the grippers meet the design criteria of being able to pick and place a variety of household objects. Several design sketches were created by hand and in solidworks in order to visualize the different potential designs that could be used. Through consideration, research, and testing it was determined that two grippers both twenty millimeters in diameter positioned on the same axis will produce the optimal results. Smaller grippers will allow for smaller objects to be lifted while the use of both grippers will allow for heavier objects to be lifted. Smaller grippers also reduce the chance for gripping error or any air leakage to occur. The two grippers are aligned on the same axis because they can be oriented in different positions such that it will grip and lift most if not all objects. No more than two grippers are required because the use of more than two would be impractical for the design requirements.

The second main component is a wrist for the hand so that regardless of the object's orientation the pneumatic grippers can align in such a way to properly lift the object. The wrist itself needs to simulate the function of a human hand which is why it will require two degrees of freedom. One to simulate the hand moving up and down or left to right and the other to simulate the rotation of a wrist. A three dimensional model was created to assist in visualizing and simulating how this wrist will appear and function.

The last main component is an arm mount to attach the wrist and pneumatic grippers to the robot as well as any other mechanical or electrical subsystems that may be implemented. The design will have to be robust and durable in order to support the weight of all subsystems and the weight of the object being moved. It will also have to be modeled after the robot itself as it will need to be securely attached to the robot arm. Ideally the design shape will be modeled in such a way that the subsystems can be attached with ease and the size of the mount will not hinder the robots movements\ due to the weight. A three dimensional mount was designed in solidworks to aid in the visualization of the product.

Implementation and Integration

In order to implement and integrate the three main components for the robot hand, both purchased components and three dimensional printed parts are used in the fabrication process. The pneumatic grippers are going to be attached to the wrist via a printed bracket that will also allow attachment of pneumatic pumps and hosing. Both the pumps and hosing are going to be purchased components.

The wrist will be composed of servos and brackets that allow for the desired degrees of freedom. These will also be purchased components as there are many previously designed servo bracket kits that fulfill the design requirements necessary. Ordering these components ensures that they will be strong enough to support the weight of any object being lifted.

The arm mount will be a printed part as it has custom specifications and is large enough such that even being printed it will remain strong.

In order for these parts to function an electrical system must be included to power and control the wrist and pneumatic hosing. Arduino Uno is implemented and integrated in order to fulfill these requirements. Programming using C++ is utilized in order to control the wrist movement using a joystick while on and off buttons are used to activate the pneumatics. For secure wiring all connections to the robot arm and its controls are soldered to a prototype shield. The prototype shield is useful in the event the arduino uno board needs to be replaced.

Testing

Testing was conducted for the wrist and grippers both separately and combined. The pneumatics were tested by linearly increasing the amount of weight a single gripper could hold. The purpose of this was to determine the strongest gripper type and to determine the range of objects that could be lifted. Also objects with different material types were tested in order to find out if the grippers had any issues gripping onto certain objects. Other factors such as shape and size were also considered in finding the most optimal gripper type for the robot hands.

The wrist was tested by setting up the proper controls to ensure the wrist functioned as intended for the design criteria. For instance any limitations or restrictions needed to be included in the code for proper control. The controls also need to be user friendly so that most people could easily figure out the mechanics. The most important function is that the wrist can provide the necessary degrees of freedom to pick up objects that are in different orientations. Through trial and error the optimal settings for controls were determined.

Lastly both systems were combined and tested together to ensure that the final prototype worked harmoniously. It needed to be assured that the wrist wouldn't have any trouble moving when a heavier object was lifted. If the wrist couldn't handle the load it could cause the servo to break and fail. Similarly, it was important to find out if the hosing or wiring created any new limitations in the movement of the wrist. With the grippers and pneumatics now connected to the wrist certain movements may damage the wiring or tube causing the pneumatics to fail. Additionally it needed to be determined which system would fail first, the wrist or the gripper. Through testing new limitations were set on wrist movement and the range of objects that could be picked up. Also, it was determined that the wrist failed before the pneumatic grippers would. The grippers could handle a larger load than the wrist would be able to move.

Calculation for Pneumatic Testing

The formula F = p x A is used to calculate the force of the suction cup. Where:
- F is the vacuum force
- p is pressure
- A is is the area of contact

In order to calculate force three different loading conditions need to be considered
- horizontal orientation, vertical direction of force
  $F = m \times (g + a) \times S$
- horizontal orientation, horizontal direction of force
  $F = m \times (g + a / \mu) \times S$
- vertical orientation, vertical direction of force
  $F = (m / \mu) \times (g + a) \times S$

The following variables are used in the above equation:
- m is the mass of the workpiece
- μ is the friction coefficient
- g is the gravity (9.81 m/s^2)
- a is the acceleration of the system (m/s^2)
- s is the safety factor

Updated Cost Analysis

Project Budget: $1000 from Pranav's Lab, $350	
Purchased	*To be purchased*
Wrist Bracket- $12.99 Servo Kit - $19.99 Suction Cup(s)-$96 Wires/Hoses:$25 Pump:$9.69 Buttons:$9.99 Joystick:$11.99 Arduino:Provided by Prof.Brown Total:$185.65	Better Joystick-TBD 3D Printed Parts - TBD Battery Pack-TBD

Cost Analysis from parts ordered

A	B	C	D	E	F
		Robot Hands Budget			
Item Description	Quantity	Link	ASIN Code	Status	Price Per Unit
Wrist Bracket	1	csd=d2lkZ2V0TmFtZT1zcF	B07PQ12TXS	Purchased	12.99
Servo 4 Pack	1	43d2-b75f-28935d70f100&	B07NQJ1VZ2	Purchased	19.99
Solid Core Wire	1	IBFVWMO&keywords=brea	B07V1D82HM	Pending	13.99
Hose Kit	1	hvnetw=g&hvqmt=e&hvran	B07RK4MCKP	Pending	11.99
Stronger Pump	1	&hvnetw=g&hvrand=18679	B089ZRYZV8	Pending	9.69
Battery Pack	1	DZ&keywords=BATT+HOLD	B07T7MTRZX	Not Ordered	6.48
Rechargeable Battery	1	vpos=&hvnetw=g&hvrand=	B07TW9T8JW	Not Ordered	28.99
Joystick	1	61-a7b4-41dc-9467-a85a2	B01N0DO631	Pending	11.99
Buttons	1	7c1ac5-7c51-4df5-ba34-ca	B08R9P9DFC	Pending	9.99
Suction Cups	5			Pending	96
			Total		222.1

Conclusions

The goal of designing and manufacturing an end effector prototype capable of maneuvering and capturing an object at will that attaches to the humanoid robot in Professor Bhounsule's lab was properly achieved. A custom designed system consisting of an Arduino Uno, 3D printed brackets, servos, pneumatic pumps, and suction cups was used to accomplish this. For demonstration purposes, a stand and replica arm were designed and manufactured to simulate the future applications.

Future Iterations

There are several recommendations that should be considered by Professor Bhounsule's lab for future iterations of the robotic hands. The first would be obtaining higher quality produced components for the wrist assembly. This would reduce the limitations and failure of the hands. It would also enable the robot to pick up a larger range of objects. It would also be beneficial to integrate a sensor such as a laser proximity sensor or an ultrasonic proximity sensor as a feedback mechanism in lieu of user input. Obviously the robot should be able to function independently without being controlled by a third party. Driving each pneumatic pump independently, only using whichever pump is in contact with the object being maneuvered. Also running pumps in series or in parallel in order to increase pressure or air flow depending on needs. Potentially adding more suction cups for a more robust system.

Appendix

Pranav's Robot

Gantt Chart

Task	Task Type	Start Date	End Date	Status	10/5	10/12	10/19	10/26	11/2	11/9	11/16	11/23	11/30
Sketch & Brainstorm Ideas	Individual	10/5	10/12	Complete									
Gantt Chart Planning, Task Layout	Group	10/5	10/19	Complete									
Fishbone Diagram	Group	10/12	10/26	Complete									
Preliminary design research	Group/Individual	10/12	10/26	Complete									
Suction prototype design discussion	Group	10/26	11/9	Complete									
Wrist prototype design discussion	Group	10/26	11/9	Complete									
Order suction prototyping components	Group	10/26	11/2	Complete									
Wrist design research and development	Group/Individual	11/2	11/23	Complete									
Arm Mount R&D	Group/Individual	11/2	11/23	Complete									
Suction/Pressure Research	Individual	11/2	11/23	Complete									
Begin 3D printing Arm	Group	11/16	11/23	Not Started									
Order Wrist Components (if necessary)	Group/Individual	11/23	11/30	Complete									
3D Print Arm Mount Concepts	Group	11/23	11/30	Not Started									
3D Print Wrist Mechanism	Group/Individual	11/23	12/7	Not Started									
Test Wrist tolerances	Group/Individual	11/23	12/7	Not Started									
Test/Arm Mount to fit snug (if necessary 3D print more)	Individual	11/30	12/7	Not Started									
Manufacture suction prototype	Group/Individual	11/23	12/7	Not started									
Troubleshooting suction prototype	Group	11/23	12/7	Not started									

Figure 2: Gantt Chart

Preliminary Sketches

Attached below are some of the initial ideas of the different designs. As seen in Figure 3, this design is supposed to be operated using a vertically mounted servo or stepper motors which will rotate the gears and create the movement. The design also has two bars that move per claw which allows for a parallel movement.

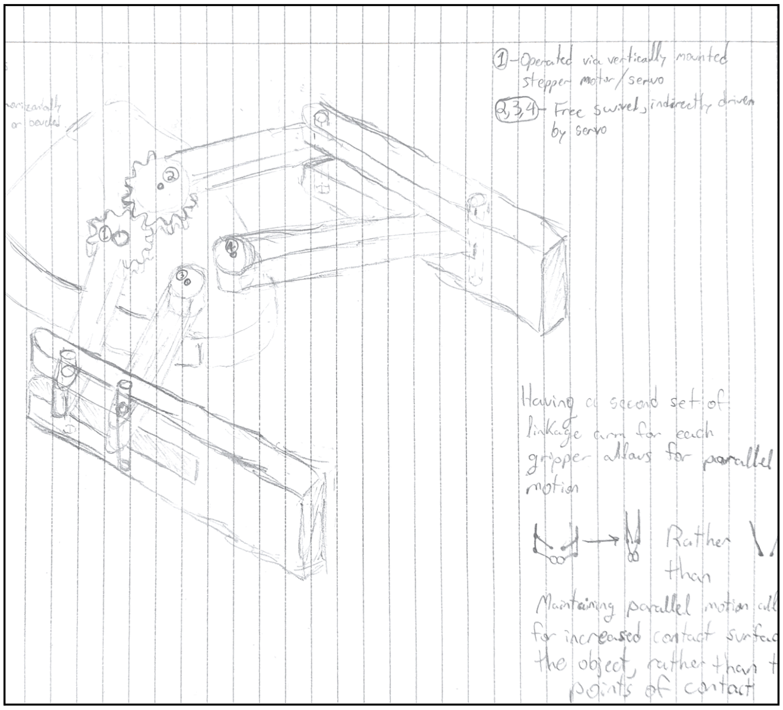


Figure 3:Claw/Gripper End Effector

The design in Figure 4 includes a pneumatic system combined with mechanical pincers. The suction cup attached between the claws will suck on the object and the moving clamp will add more support.

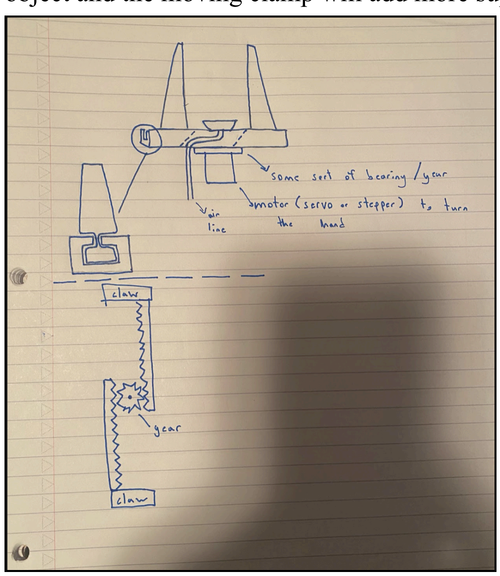


Figure 4: Pincer Design Sketch

This design is purely driven pneumatically. Components of the system are the pouch which inflates and deflates, which surrounds the support ring inside it creating a gap in the middle so when the balloon inflates it grab on to the object and when it deflates it releases it ,Compressors and battery are being used to create air pressure inside balloon.

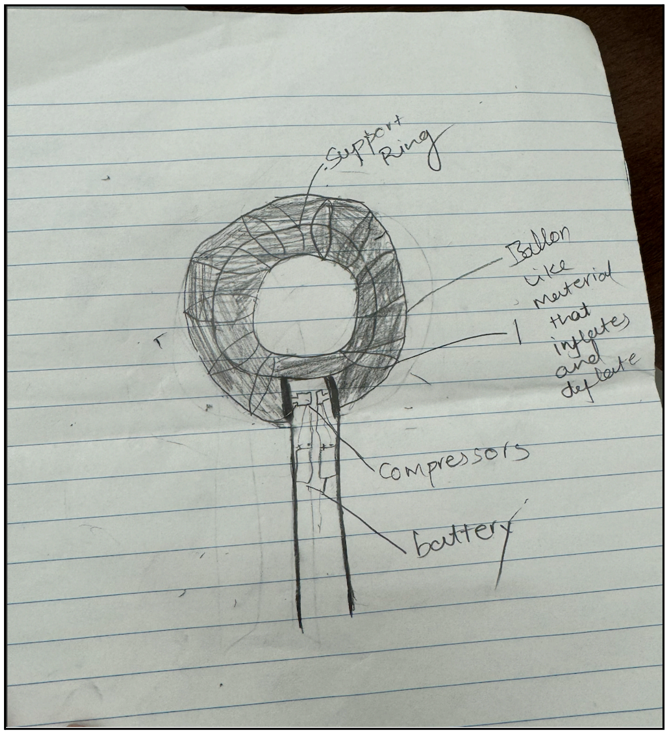
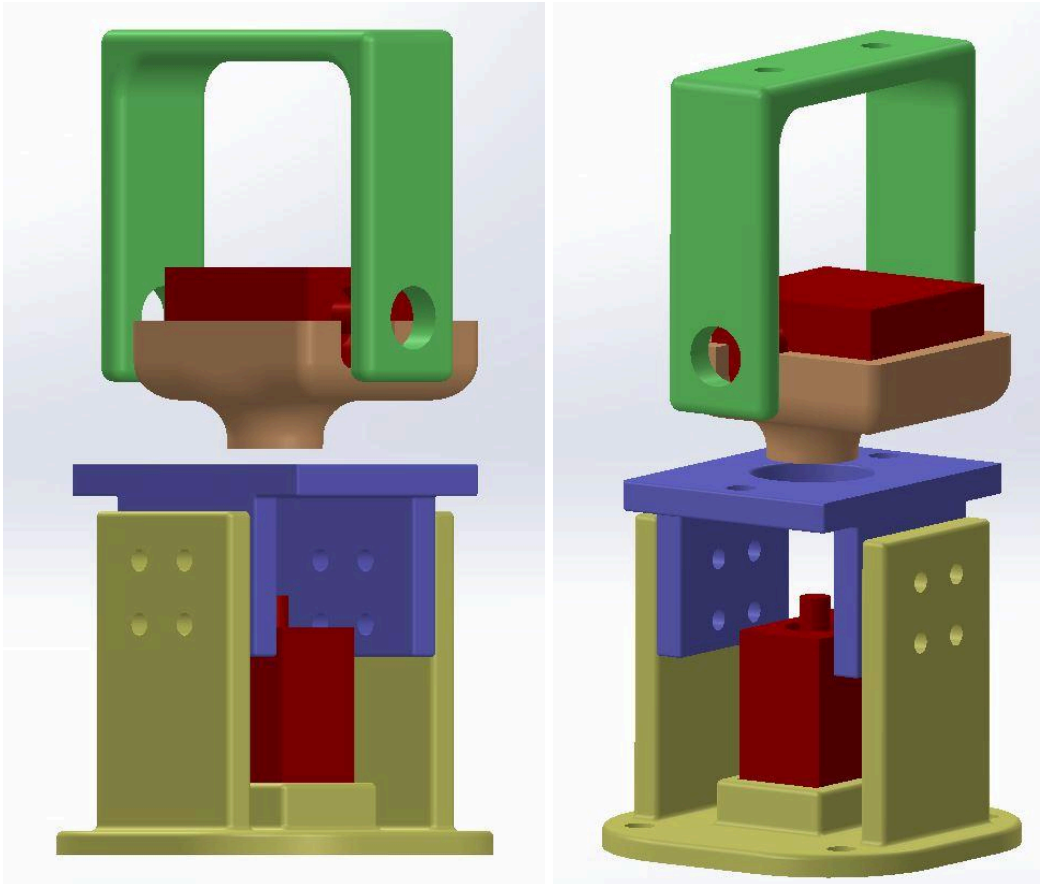
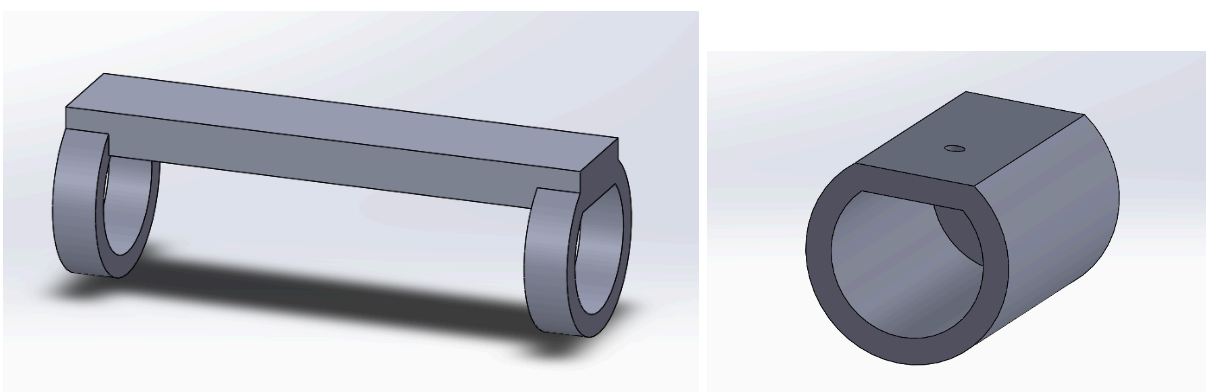


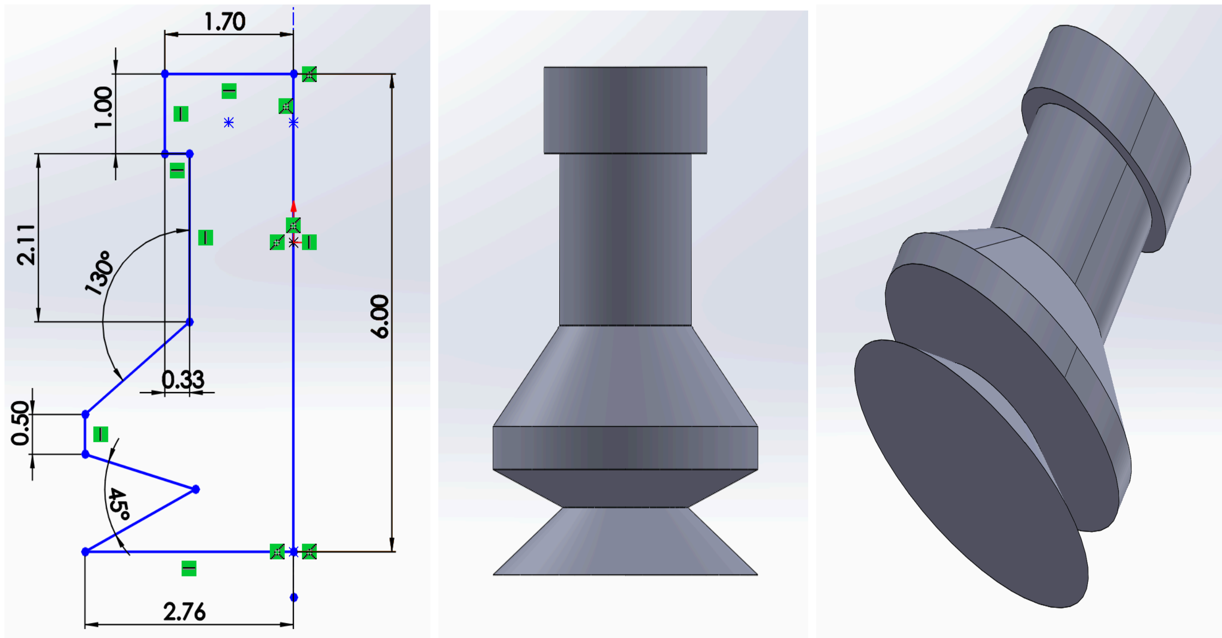
Figure 5: Pneumatic Design



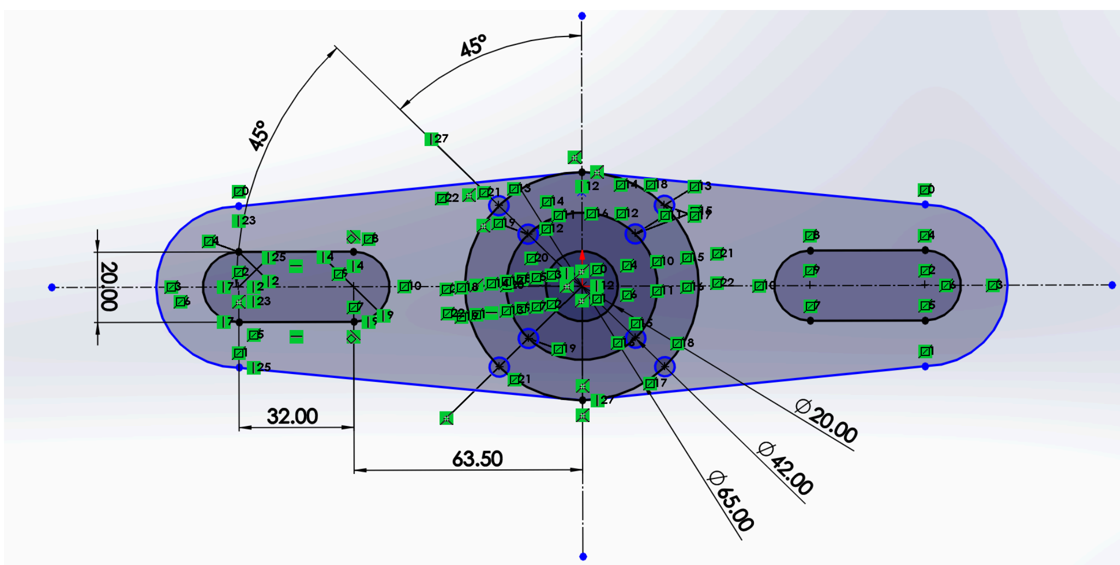
Figures 6 & 7: Robotic Wrist Design

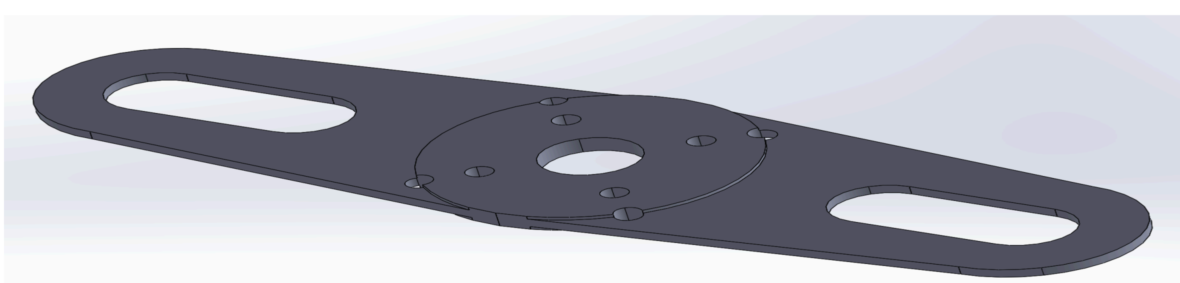


Figures 8 & 9: Wrist Mount Design



Figures 10, 11 & 12: Pneumatic Gripper Design





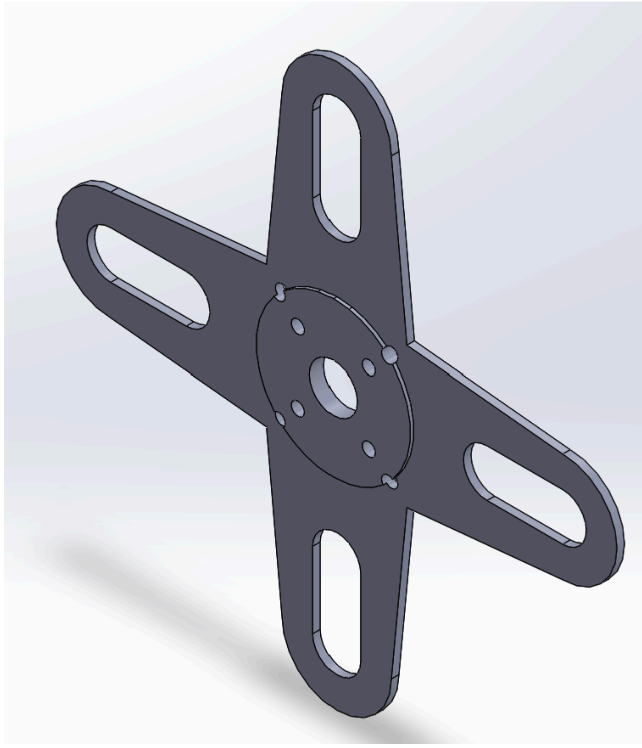


Figure 13, 14 & 15: Pneumatic Bracket Design

Figure 16: Wrist Kit

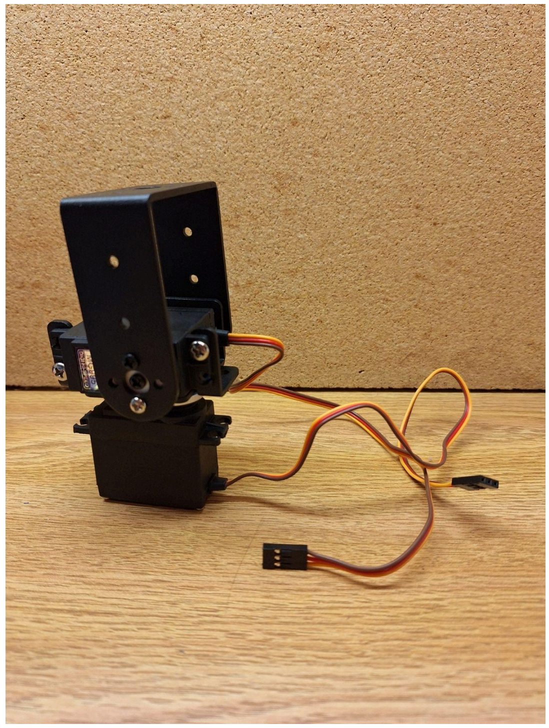


Figure 17: Assembled Wrist/Elbow

```
#include <Servo.h>
Servo servo1;
Servo servo2;
int x_key = A1;
int y_key = A0;
int x_pos;
int y_pos;
int servo1_pin = 10;
int servo2_pin = 9;
int initial_position = 90;
int initial_position1 = 90;

void setup ( ) {
Serial.begin (9600) ;
servo1.attach (servo1_pin ) ;
servo2.attach (servo2_pin ) ;
servo1.write (initial_position);
servo2.write (initial_position1);
pinMode (x_key, INPUT) ;
pinMode (y_key, INPUT) ;
}

void loop ( ) {
x_pos = analogRead (x_key) ;
y_pos = analogRead (y_key) ;

if (x_pos < 300){
if (initial_position < 10) { } else{ initial_position = initial_position -
20; servo1.write ( initial_position ) ; delay (100) ; } } if (x_pos >
700){
if (initial_position > 180)
{
}
else{
initial_position = initial_position + 20;
servo1.write ( initial_position ) ;
delay (100) ;
}
}
```

```
if (y_pos < 300){
if (initial_position1 < 10) { } else{ initial_position1 =
initial_position1 - 20; servo2.write ( initial_position1 ) ; delay (100) ;
} } if (y_pos > 700){
if (initial_position1 > 180)
{
}
else{
initial_position1 = initial_position1 + 20;
servo2.write ( initial_position1 ) ;
delay (100) ;
}
}
}
```

Figure 18: Code for wrist control with joystick

Figure 19: Servo Motor

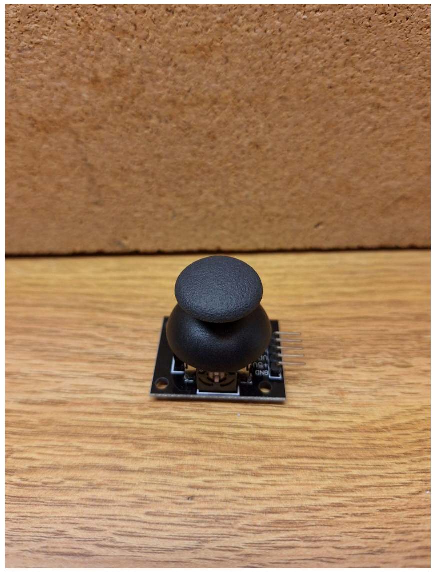


Figure 20: Joystick

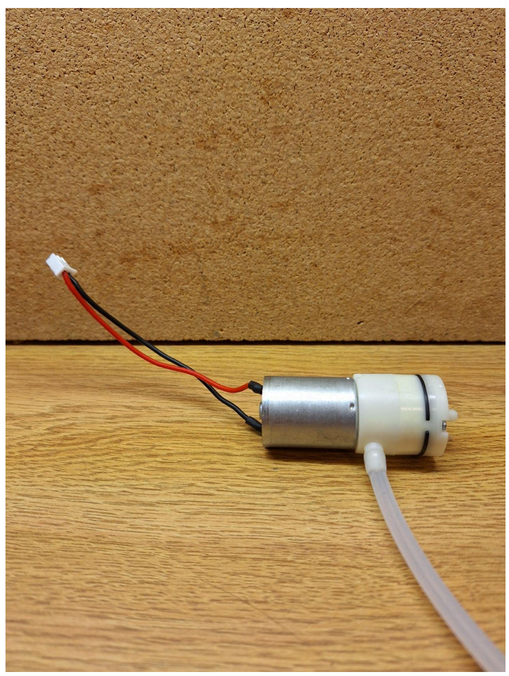


Figure 21: Pneumatic Pump

Figure 22: 30 mm Suction Cup

Figure 23: 20 mm Suction Cup

Figure 24: 50 mm Suction Cup

Figure 25: 50 mm Suction Cup

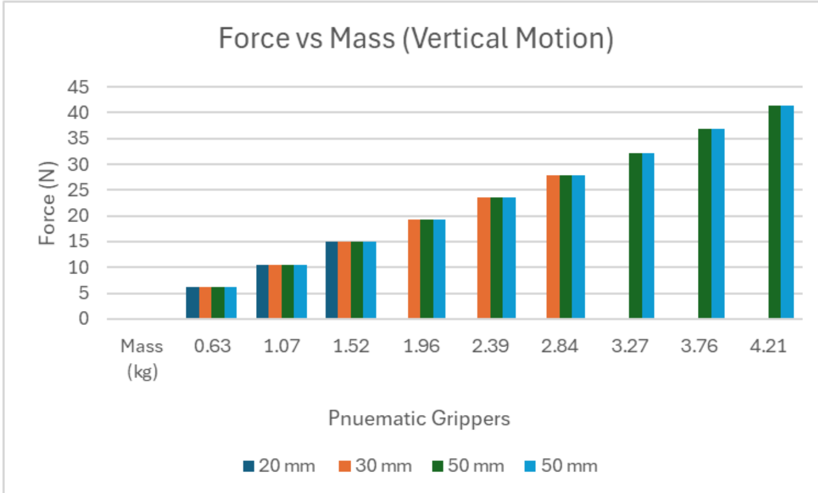


Figure 26: Testing of pneumatic grippers picking up objects from the top

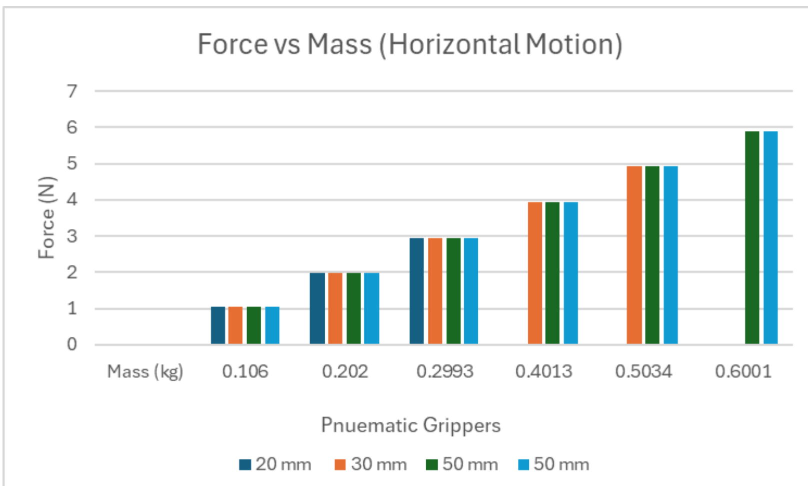


Figure 27: Testing of pneumatic grippers picking up objects from their side

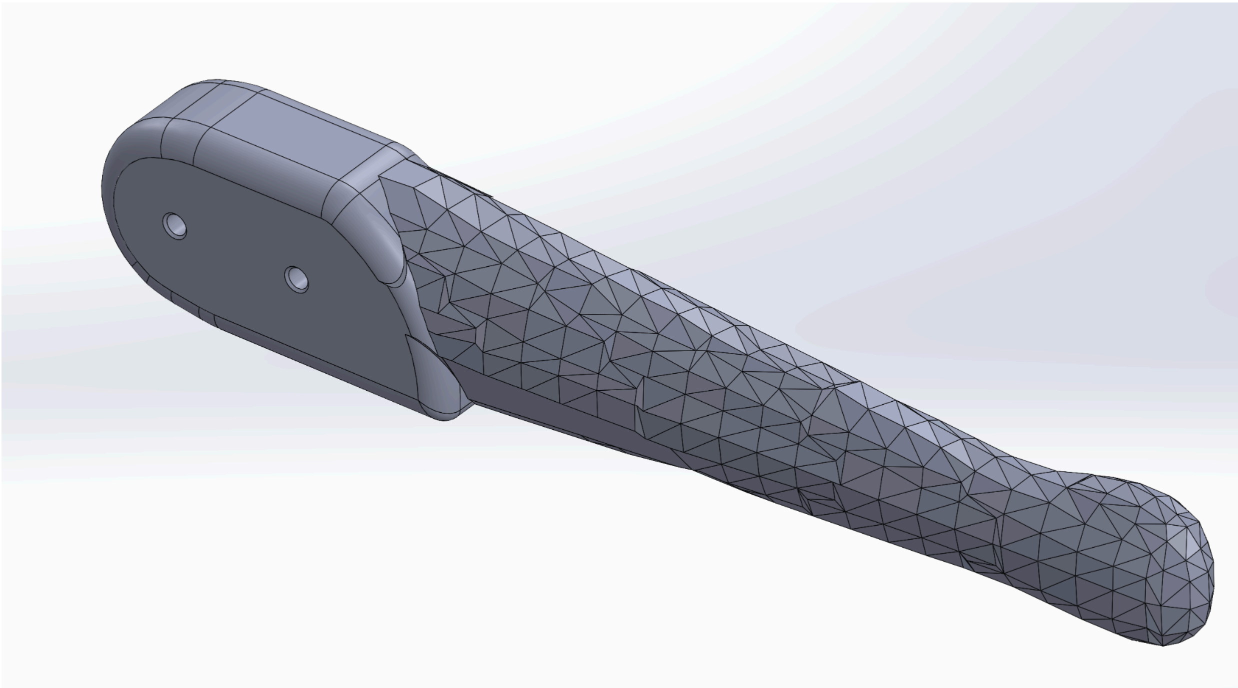


Figure 28: Solidworks rendering of robot arm

Figure 29: 3D printed arm

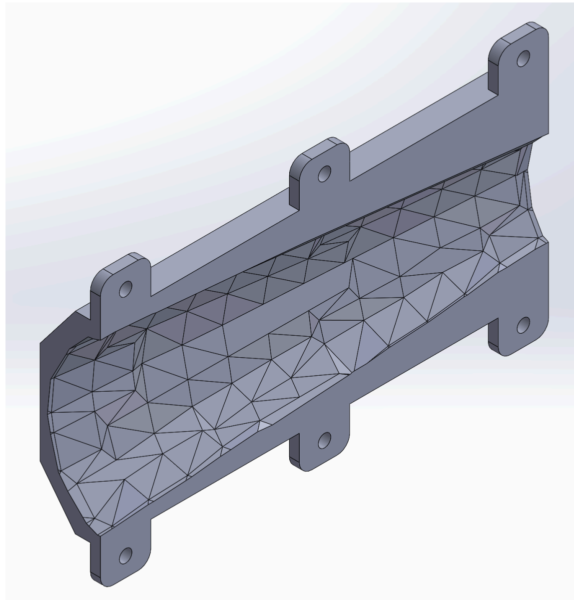


Figure 30: Solidworks rendering of mount

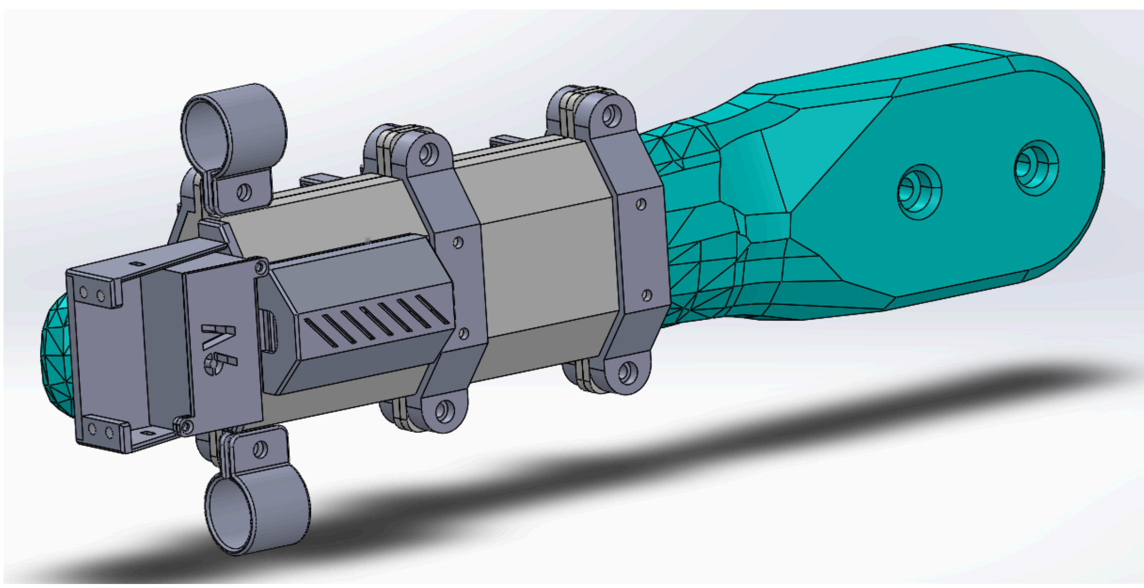


Figure 31: Solidworks assembly of robot arm and mount

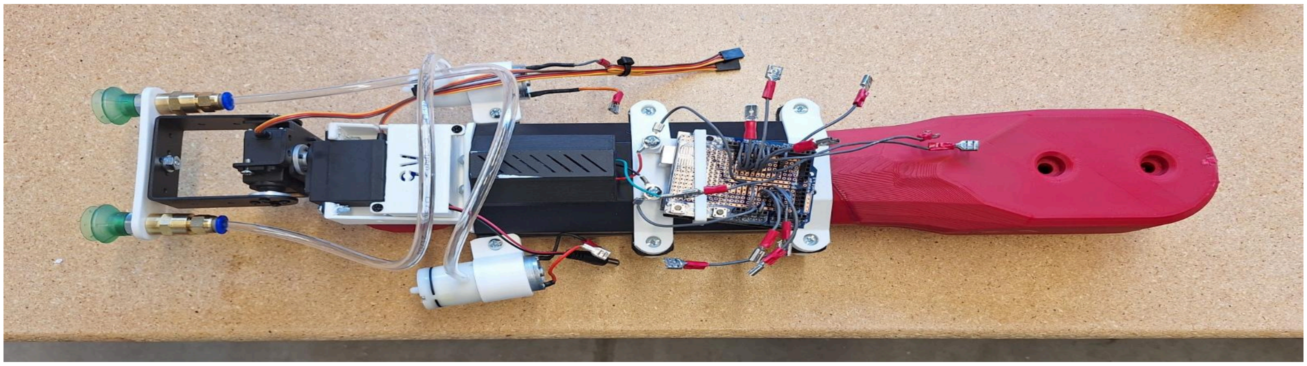


Figure 32: Partially Completed robot arm

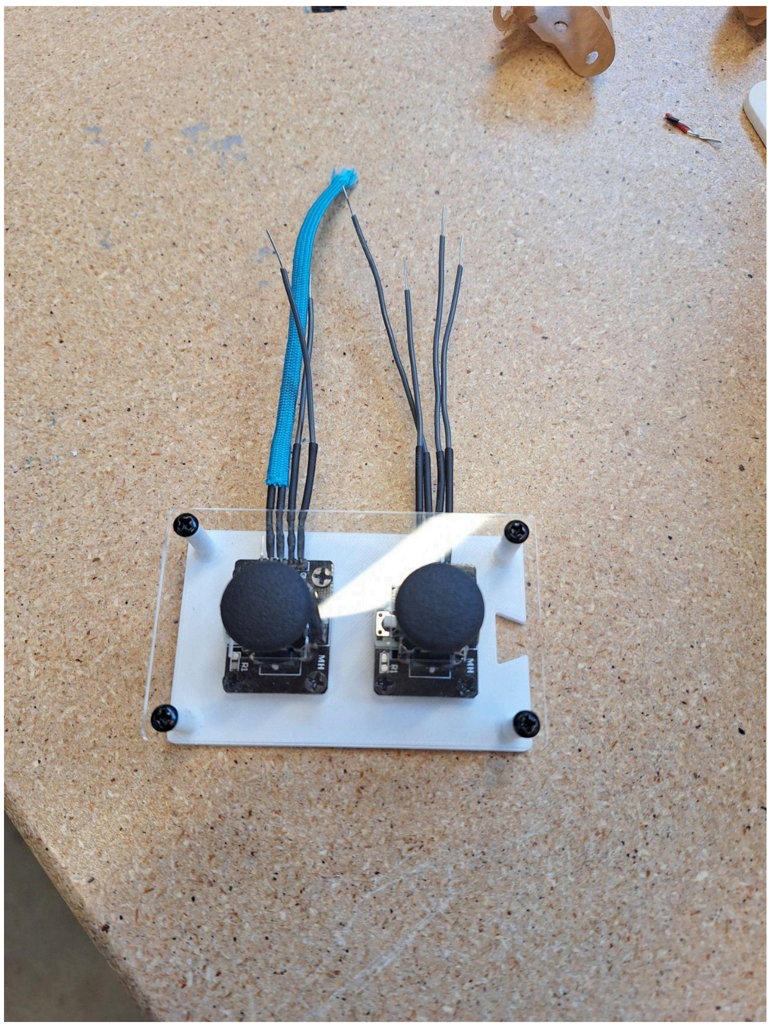


Figure 33: Joystick control for servos

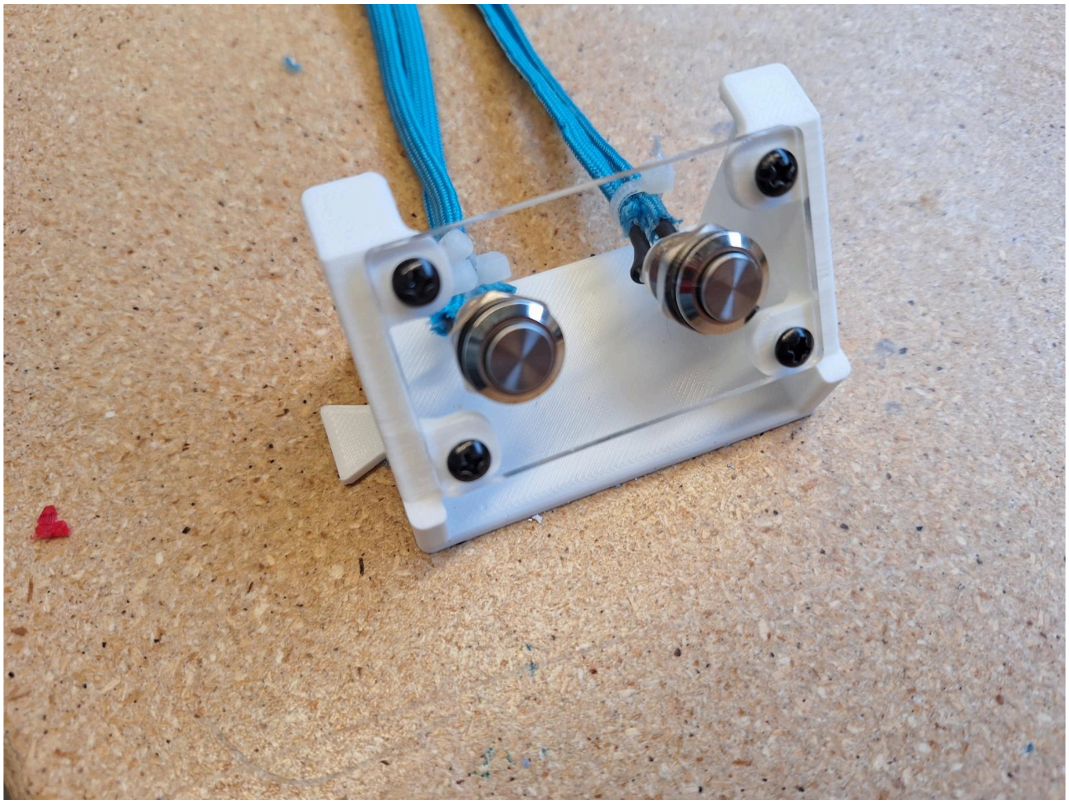


Figure 34: Button Control for activating and shutting down pneumatics

Figure 35: Stand for robot arm

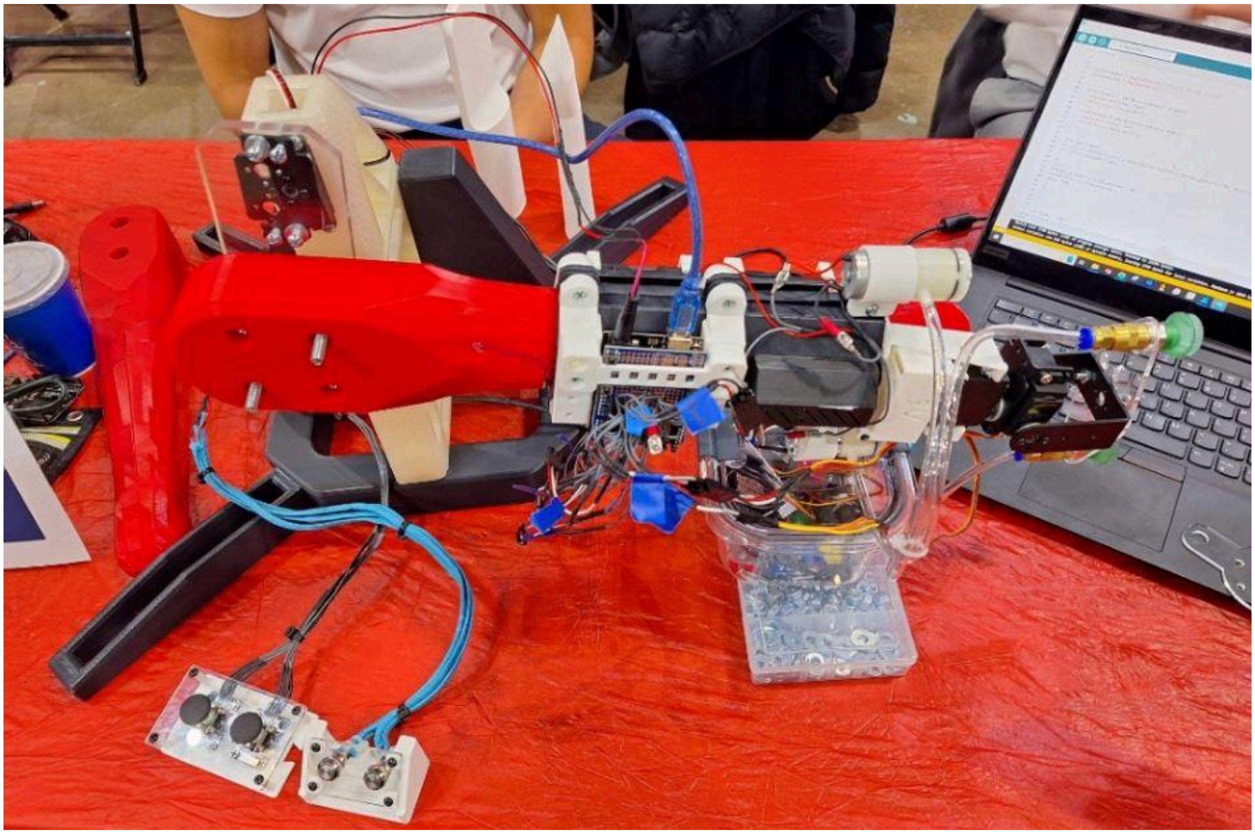


Figure 36: Finished Prototype