Soft Assistive Robotics for Helping Daily Tasks

Major Qualifying Project

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Abstract

This project focuses on creating a soft assistive robotic arm with a user-friendly interface to help people who use wheelchairs with daily tasks. This year the team created a model of this system by modifying existing origami modules, designing a soft robotic gripper, and creating a control system which integrates user inputs with sensor data to easily manipulate common household items. Soft robotics is a growing field of research. These robots offer the flexibility and adaptability that traditional rigid robotics lack, making them safer for interacting with humans and other delicate environments. This project looks at how soft robots are applicable for assistive technologies. Wheelchairs, which are used by over 3.3 million Americans, are typically used for mobility related disabilities, which often affects overall motor skills making daily tasks significantly more difficult. This design would provide greater independence to people who use wheelchairs worldwide.

Acknowledgements

We would like to extend our gratitude to our advisor, Professor Berk Calli, for his guidance in completing our project. We also would like to thank Professor Cagdas Onal for his feedback on our work. Lastly, we would like to thank Abhinav Gandhi, Jennifer Shaughnessy, Tim Jones, and Shou-Shan Chiang for all of their support throughout the term. They were influential in helping our team understand the existing technology and processes, accessing lab equipment, and helping our team to troubleshoot issues.

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Introduction

The United States is currently facing an unprecedented nursing shortage. As of 2022, "Federal data shows that we are expecting to lose 500,000 nurses by the end of this year, many through retirement, bringing the overall shortage of nurses to 1.1 million." [1] This shortage has effects on every area of the health care field, from the quality of care patients receive in hospitals to access to health care support at home. Simultaneously, the United States has a growing aging population that will need increasingly more support. As the supply of health care workers in decreasing, the demand for health care workers will continue to grow. This ultimately will lead to a decreased quality of care unless the United States is able to find other solutions.

In the United States there are also currently 3.3 million wheelchair users. According to ScienceDirect, "Mobility disability is a primary cause of wheelchair use. A wheelchair can be the primary means of mobility for someone with a permanent or progressive disability such as cerebral palsy, spinal cord injury, or multiple sclerosis." [2] Such disabilities impact all motor control. This makes independent living extremely difficult, if not impossible. People with these disabilities may struggle to complete daily tasks like opening door, cooking, cleaning, etc. due to limited motor control and limited strength. In addition to mobility aids such as wheelchairs, these individuals may also require assistance from a caretaker, nurse, or loved ones to help them day to day. This dependence on others limits their personal autonomy. This is not only frustrating, but extremely expensive. Having full-time help may be unaffordable for many people. The nursing shortage in the United States has only exaggerated this problem. The more demand for health care workers that there is, the more expensive they have become. Ultimately, this has created a greater need to find alternative ways for people with mobility disabilities to complete daily tasks independently.

Assistive technologies have played a huge part in helping individuals to maintain their personal autonomy for decades. Assistive technology is an umbrella term which describes technologies which help individuals be more independent. There is a wide range of inventions that fall into this category. Common assistive technologies include wheelchairs, prostheses, glasses, hearing aids, and braille. However, not all assistive technologies are physical aids. Voice command devices or text-to-speech could also be included in this category as they also may help individuals with mobility or vision impairments.

As we move toward the future, the next horizon for assistive technologies is robotics, specifically soft robotics. Robotics can be programmed and designed to complete complex tasks and adapt to their environment using sensor feedback. They can be integrated in user-friendly systems to allow individuals to have more independence than ever before. Instead of needing multiple assistive devices or human assistance, a robotic arm could allow individuals to complete a variety of tasks on their own. These devices can be designed with the physical capabilities to complete daily tasks that would otherwise not be possible, as well as the feedback controls to properly assist the user. Soft robotics specifically are perfect for this application. Safety is a top priority in any device that interact directly with humans. While robotic devices can be very precise, humans can be unpredictable. Accidentally interfering with a robotic system can be dangerous depending on the design of the system. Soft robotics are designed from compliant and flexible materials. This allows them to be safer for human interactions.

This project specifically focuses on applying soft robotic technologies to create an assistive arm that people who use wheelchairs can use to complete daily tasks. Ultimately, such a device would decrease the need for full time support, providing personal autonomy back to people with mobility disabilities.

Over the course of this year, our team created a functional model and initial control system for a soft assistive robotic arm. We worked to adapt robotic origami modules, developed in the WPI Soft Robotics Lab, for this purpose. We also designed a soft robotic gripper to lift common household objects. This mechanical system was able to manipulate objects up to 1 lb of varying shapes and sizes. Our team worked to integrate a joystick, camera vision, and encoder feedback using a ROS2 interface to create a user-friendly control system. This system was then tested to gather user feedback that will be used to inform the next steps of the project.

Chapter 2

Background

2.1 Overview of Soft Robotics

Soft robotics is a subset of robotics that focuses on using compliant and flexible materials. They are designed to perform human-like motions and are capable of handling delicate objects better than rigid body robots. Soft robots are often inspired by biology and often mimic characteristics found in nature. They are able to bend, twist, and stretch to adapt and interact with their surroundings in unique ways. Due to their versatility, these robots are used in many different applications including, but not limited to: instruments for minimally invasive surgeries, assembly line pieces for producing delicate objects, and agricultural tools designed to limit damage to crops. One area that has great potential for soft robots is the assistive robotic/prosthetic field.

The origin of soft robotics dates all the way back to the 1950's when a scientist named Joseph Laws McKibben created the first Pneumatic Artificial Muscle (PAM) [3]. The origin of PAM's started with the idea to help polio patients. The idea being that PAM's were lighter and more flexible than most actuators at the time, however this idea never fully took off. The original PAM design can be seen in Figure 2.1. The concept of soft robots did not gain traction again until recently in 1990, but still did not receive much scientific attention. They finally began to gain recognition in the 2000s, as "The words 'soft robotics' were first widely recognised and used around the year 2010" [4].

One concept that has played a large role in the development of soft robotics is the concept of bio-mimicry. Bio-mimicry is the study of using concepts or ideas found in nature to inspire robots. In other words, basing technological design after living organisms in an attempt to increase the efficiency of modern technology. There are many examples of bio-mimetic robots in recent years. MIT used a fish as inspiration to create a bio-mimetic robot. Other examples inspired from octopus, such as robots using many long tentacle-like arms as a gripper system [4]. Bio-mimicry

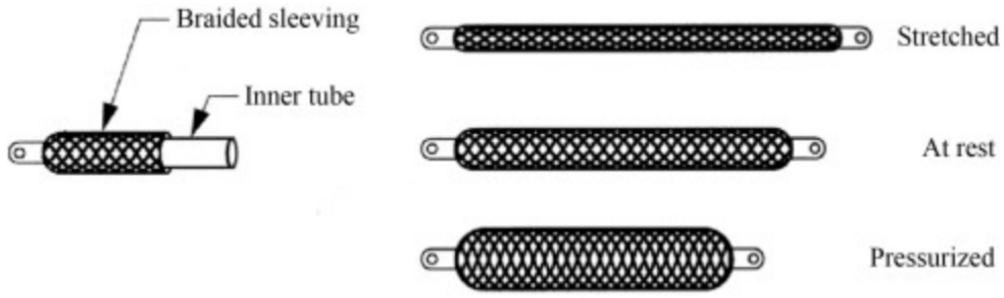

Figure 2.1: *First Pneumatic Artificial Muscle*
[3]

is a great tool when designing soft robotics. It can provide inspiration to an otherwise difficult problem with an existing solution. A solution which has passed the test of survival through many years of evolution.

2.1.1 Applications of Soft Robotics

These unique designs open up a new world of possibilities for robotics. Their compliant structure offers the ability to pick up delicate or oddly shaped objects using flexible materials. Bio-mimicry has been used to create grippers that mimic octopus tentacles, camouflaging, a cheetah's gait, insects, etc [4]. These ideas are fascinating, but also offer very practical applications. One example of this is surgical robotics. Soft robotics are being used to remove kidney stones [5]. Hard robots can be abrasive on human skin, which could cause harm. However, soft robotics are smooth and soft, and can enter through small incisions and then expand once inside a person. This allows them to complete tasks that would be impossible with a rigid body system. Additionally, researchers at Carnegie Mellon are creating soft robotics out of algae to safely study slugs in their natural environment as shown in Figure 2.2 [6]. This alternative is safe for the animals and reduces stress as they are not harmed by the equipment. Soft robotics provides an eco-friendly alternative. Within a week the soft robotic hand used can bio-degrade into materials native to the environment.

Moreover, Soft robots can also be designed to move like snakes. These designs can be used for search and rescue efforts. Their unique style of movement and compliant design allows them to maneuver hard to reach locations to save human lives [7].

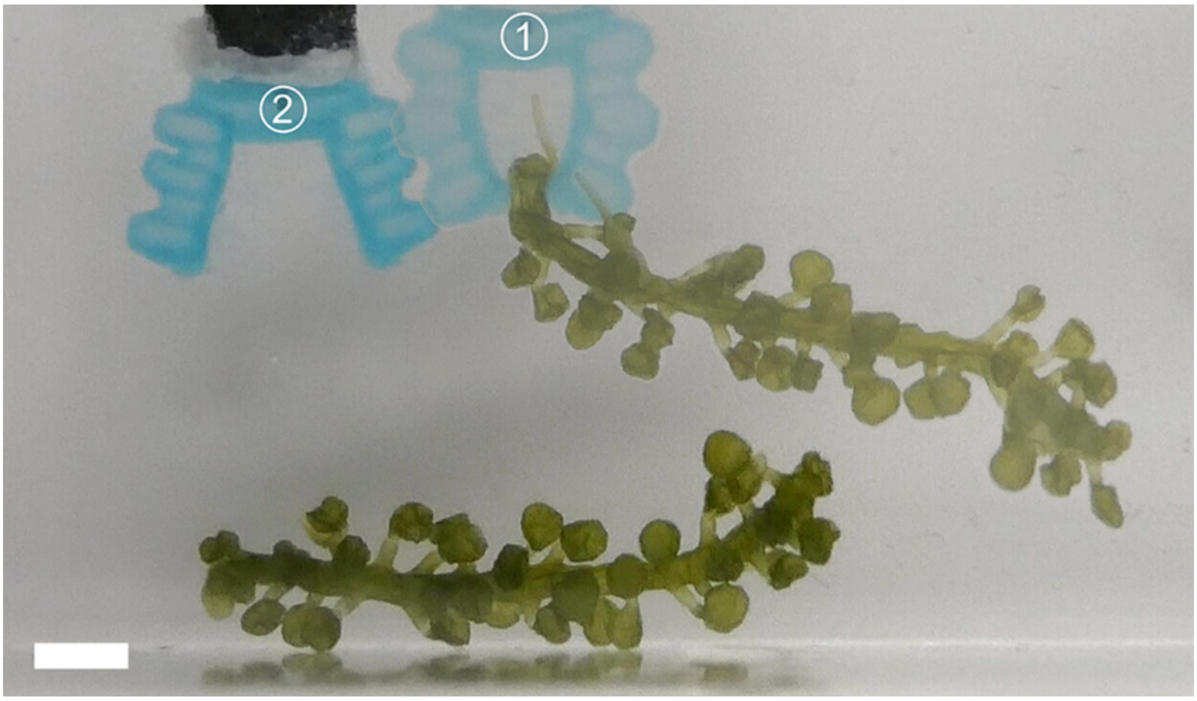

Figure 2.2: *Biodegradable Soft Robotic Arm for Researching Slugs*
[6]

2.2 Assistive Robotics

2.2.1 Drawbacks of Hard Robotic Arms

People with mobility disabilities may struggle with everyday tasks due to their condition. Those who are in wheelchairs, missing limbs, or paralyzed may require assistance for jobs everyday tasks. However, there are current solutions on the market to help this issue. There is a growing market for robotic arms/prosthetheses. However, the rigid body systems that are currently on the market have a number of areas where they could be improved. To start, these designs are not very affordable. They range from 20,000 USD all the way up to 35,000 USD [8]. Due to this large price tag, it is estimated that around 80 percent of people in need around the world will not have access to these prosthetic services [9]. This is a major problem because there are around 100 million people worldwide in need of prosthetic assistance. Without an affordable solution, the vast majority will not get the help they need [9].

Two examples of rigid body systems that are currently on the market are the Obi Robotic Feeder shown in Figure 2.3 and the Assistive Innovations iArm shown in Figure 2.4. The Obi Robotic Feeder retails for 11,715 USD and is strictly designed to help with eating [10].

The Assistive Innovations iArm offers more versatile applications, but retails for 16,000 USD [11]. While this solutions may still be cheaper than full time help, they are still extraordinarily expensive for systems with limited capabilities.

Figure 2.3: *Obi Robotic Feeder*
[10]

Another concern with rigid body robots is their ability to handle objects delicately. By only using hard metal materials, there is a limit to how gentle they can be. This creates difficulties for handling foods and other delicate items.

Furthermore, safety is a top priority when creating a design that interacts with humans. The hard metal surfaces and rigid, forceful movements of the rigid body machines run a greater risk of injuring the user or people around them. While these machines may move precisely, people can be unpredictable. If a person were to accidentally interfere with a hard metal arm, they could potential seriously injure themselves. It is imperative that assistive robots do not run this risk.

2.2.2 Benefits of Soft Robotics for Assistive Applications

The alternative to rigid body robotics is soft robotics. These robots are designed from compliant and flexible materials. Soft robotics offers a more affordable solution as the material and production costs are much cheaper. The plastics and polymers used to build soft robots are consistently lower costing than the metals used in rigid bodies. Their affordability allows them to become more widely available to all who are in need.

Another benefit of soft robots is their ability to provide a gentle touch. Primarily this is important because it ensures a greater level of safety for the humans involved. These complaint

Figure 2.4: *Assistive Innovations iArm*
[11]

designs will not forcefully push against a person, instead it will bend with their movement. Additionally, this gentle touch is especially crucial for tasks that involve delicate objects. For example, tasks such as closing a soft bag or holding/transferring a fragile object a soft robot's compliance and flexibility become highly advantageous. The ability to slowly apply force as needed reduces the risk of discomfort or damage to sensitive items. When performing everyday routines like brushing teeth and combing hair, a soft arm's gentle and adaptable nature ensures that the assistance is comfortable and minimally obstructive. The risk of damaging the surrounding also becomes a lot smaller because of the forgiving materials and design.

The compliant design also can allow them to be more adaptable to the objects they are manipulating. A soft gripper for example can bend to fit objects of different shapes and sizes. Soft robotics is therefore more versatile for assistive applications.

Lastly, soft robots are also lightweight. There materials tend to weigh less than the heavy metals and actuators on a rigid body design. This is an extremely helpful quality for assistive applications. Users will not want to or may not be able to move around a heavy system all day. A lightweight design removes this burden from the user.

2.3 Origami Modules

Over the last few years, the WPI Soft Robotics Lab has developed a modular origami soft robot design. This design has been used in a variety of applications from robots that simulate lizard movement to robots that can path plan using camera vision and April tags. Several projects have worked on improving various areas of their control system and mechanical design. Our team worked to adapt these modules to be the base of our soft assistive robotic arm [12].

These modules consist of three PET sheets that are laser cut to perforate fold lines. They are then each folded and connected together to create one large origami prism. This structure acts as a large spring. Fishing line attached to a small actuator is then threaded through each of the PET sheets. As the motors wind and unwind the string, the triangular prism can be curved in any direction. Each of the motors is controlled by an Arduino, motor driver, and I2C communication. Each module also has acrylic end plates, which supports all of the motors and electronic components. Multiple modules are then stacked together to create a modular soft robotic arm. When more modules are added to the arm, the robot can achieve a greater range of motion.

This design has many strengths. It provides high torsional resistance, which is extremely important when manipulating objects to ensure the arm does not twist under pressure. Additionally, this design is extremely strong for its weight. These origami modules are 73 times stronger and 50 lighter than their silicon counterparts [13]. In previous experiments in this lab, this robot has been able to lift 0.5 kg when it is hanging upside down, navigate moving through a series of obstacles, and move precisely enough to spell out words [13].

The WPI soft Robotics Lab has also implemented various control systems for this robot. One of the challenges in soft robotics is that they do not move as precisely as rigid body robots. To generally predict the motion of this design, we assume each module's motion can be represented as a circular arc in 3D space. The equations below represent the cable lengths based on different parameters of forward kinematics [13].

$$l_1 = 2n\sin\left(\frac{ks}{2n}\right)\left(\frac{1}{k} - d\sin(\phi)\right), \tag{2.1}$$

$$l_2 = 2n\sin\left(\frac{ks}{2n}\right)\left(\frac{1}{k} + d\sin\left(\frac{\pi}{3} + \phi\right)\right) \tag{2.2}$$

$$l_3 = 2n\sin\left(\frac{ks}{2n}\right)\left(\frac{1}{k} + d\cos\left(\frac{\pi}{6} + \phi\right)\right) \tag{2.3}$$

There is currently a grow to shape heuristic used to define the inverse kinematic functions. This control system is also enabled by multiple feedback loops. Each motor controller has an encoder to determine how much string has been released/wound. They also have used a camera tracking system to determine the robots position in 3D space. Using sensor feedback the control algorithm is able to adjust accordingly to ensure the robot reaches the proper position. All code is currently run in MATLAB and using ROS1 [14].

This design successfully demonstrates that soft robotic arms can have effective and compliant structures. As discussed previously our goal is to adapt this technology to assistive applications. Previous groups have provided a proof of concept for this origami technology. It will be our role to adapt this technology into a real world application. A current limitation of the modules are that they struggle to support their own weight when they are not mounted upside down. It will be our role to improve the structural integrity of this design. Additionally, the current interfaces are designed to be used by engineering students with extensive knowledge of how the system operates. Another part of our project will be to add additional control systems that are intuitive for people who need this technology with minimal instruction. Lastly, this system currently does not have an end effector for this application. We will be working to create a soft robotic gripper that seamlessly integrates with the existing design.

Chapter 3

Methodology

To create our design, our team began with extensive research of the existing system and research about other soft robotic designs. This provided important context for the systems we were working with as well as inspiration for how to improve the system. We then developed our initial criteria for the system and a timeline for the project. To accomplish our goals, our team split into two sub-groups: Mechanical and Controls. These sub-groups worked closely with one another to develop our final design. Our team frequently tested the system to ensure the progress aligned with our design goals and find areas of weakness to improve upon. We also completed some basic user testing to get feedback on how intuitive our system would be for new users. Our overarching goal was to create a soft robotic arm to assist people with mobile disabilities with daily tasks.

3.1 Mechanical Design

3.1.1 Design Criteria and Goals

Our first step was to outline our goals and criteria for the final product. Mechanically, the two of the top priorities of this project were the cost and the weight of the final design. Based on our MQP budget, we decided our final design needed to be less than 1000 USD. We also decided that we wanted the entire system to have a maximum weight of 10 lbs. In the end our design was well below both of these criteria. In order to be classified as a soft robot the arm also had to be made up of compliant material. To be helpful for daily tasks, we decided to mount the origami modules horizontally to provide the greatest range of motion for most tasks. In this new orientation, we wanted the arm to be able to lift household items up to 1 lb. This would allow the arm to be able to help with most daily tasks and object manipulation. Lastly, this design needed to be able to pick up a variety of household objects. Daily tasks may require objects that are different weights,

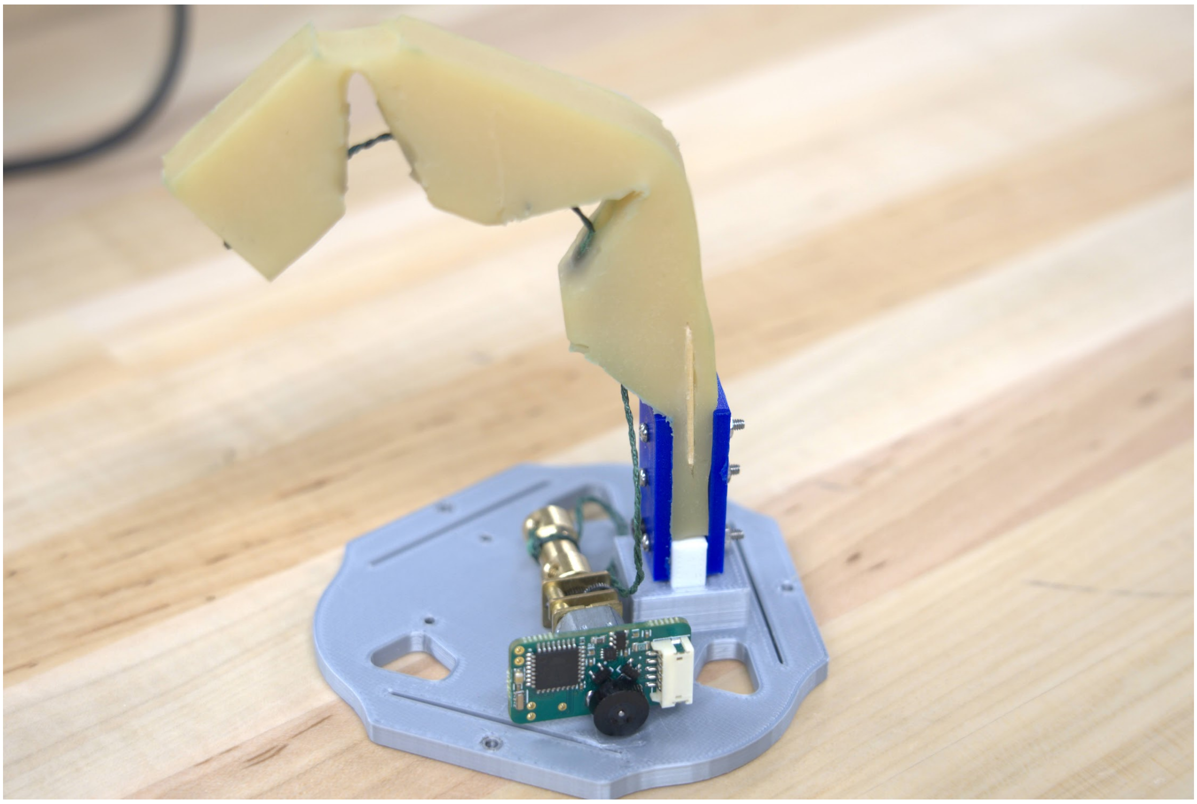

Figure 3.1: *Finger and Palm Gripper*

shapes, and sizes. It was important that our mechanical design would be able to accommodate this.

3.1.2 Gripper

To achieve this functionality a key part of our design was creating a soft robotic gripper. This design went through multiple iterations and testing to ensure that it met our criteria. When we began our design process it was recommended that we looked at the Finger and Palm design created by another group in the WPI Soft Robotics Lab. This design consisted of a silicon based with fishing line that ran through it like a tendon. It was actuated by a micro metal gear box at the base. the design attached directly to the end of the origami module. The finger would curl and uncurl to wrap around and release objects. The Finger and Palm design is shown in Figure 3.1.

This design was effective for lifting objects it could easily hook on to. However it struggled to grasp objects that were greater than 0.5 inches wide. It was unable to adapt to many of the household objects that we tested with. We were also concerned with the durability of the design as we started to notice wear and tear after basic testing.

Our next step was to create our own design. We did so using SolidWorks and the 3D printers in WPI's prototyping lab. 3D printing allowed for quick manufacturing time, but also helped to keep our design lightweight. Our mechanical team decided that a gripper system that applied pressure to both ends of the object would be more effective at grabbing and holding objects. We took inspiration from the finger and palm design and created a gripper that attached directly to the origami module. Our design was also powered by a micro metal gear box which wound and unwound to open and close the system. This gripper was designed to have both a naturally opening and naturally closing configuration to allow our team to test both to find which one is more effective. It also has interchangeable pinchers so that we could assess and easily modify the pincher design. The CAD for this gripper is shown in Figure 3.2.

Through testing, our pincher design improved over time. Initially, our design consisted of a hard PLA surface that has 0.2 inch thick walls and was curved to fit the objects. We quickly found that this was not effectively able to adapt to different sizes and shapes. To improve upon this design, we printed out of TPU. TPU is a far more flexible material than PLA. This design was more effective, but the smooth surface often caused objects to fall. Additionally, the curve of the surface was too large for some of the smaller objects. In the next iteration, we decreased the curve and the wall thickness to allow the pinchers to better bend to the object it is manipulating. We also added a textured surface in both the horizontal and vertical directions. Then tested both of the new pinchers to find the most effective one. The evolution of the pincher design is shown in Figure 3.3.

Lastly, once we had determine the best pincher design, we still felt that the mechanics of this gripper could be improved. We replaced our current motor with a 1000:1 Pololu micro metal gear box. For roughly the same current draw, this motor would provide about double the torque of the previous motor. This would decrease the max speed, however the gripper was operating far from the max speed making this trade-off effective.

3.1.3 Adjustments Made to Module Design

Throughout the manufacturing and testing process the origami module also underwent many adjustments and improvements before reaching the final design. The first iteration of the robotic arm ran into complications with repairs and tweaks due to the motors being enclosed within the PET sheets. The motors and motor mounts also interfered with the bottom of the PET sheets causing a more limited range of motion and friction wear on the plastic. To mitigate these problems, a buffer zone was created in between the bottom of each module so that the motors could be placed underneath the acrylic plate and outside of the PET sheet. The buffer zone was accomplished by placing 1 inch spacer screws in between the acrylic plates, and screwing the motor mounts to the bottom of the plate. This change allowed for easier mechanical repairs. It also allowed the PET sheets to fully compress without interfering with the motors or motor drivers. The buffer zone is shown in Figure 3.4.

Another adjustment that was made was replacing the 0.005 inch thick PET sheet with a 0.01 inch thick PET sheet. This changed the spring constant and overall strength of the modules.

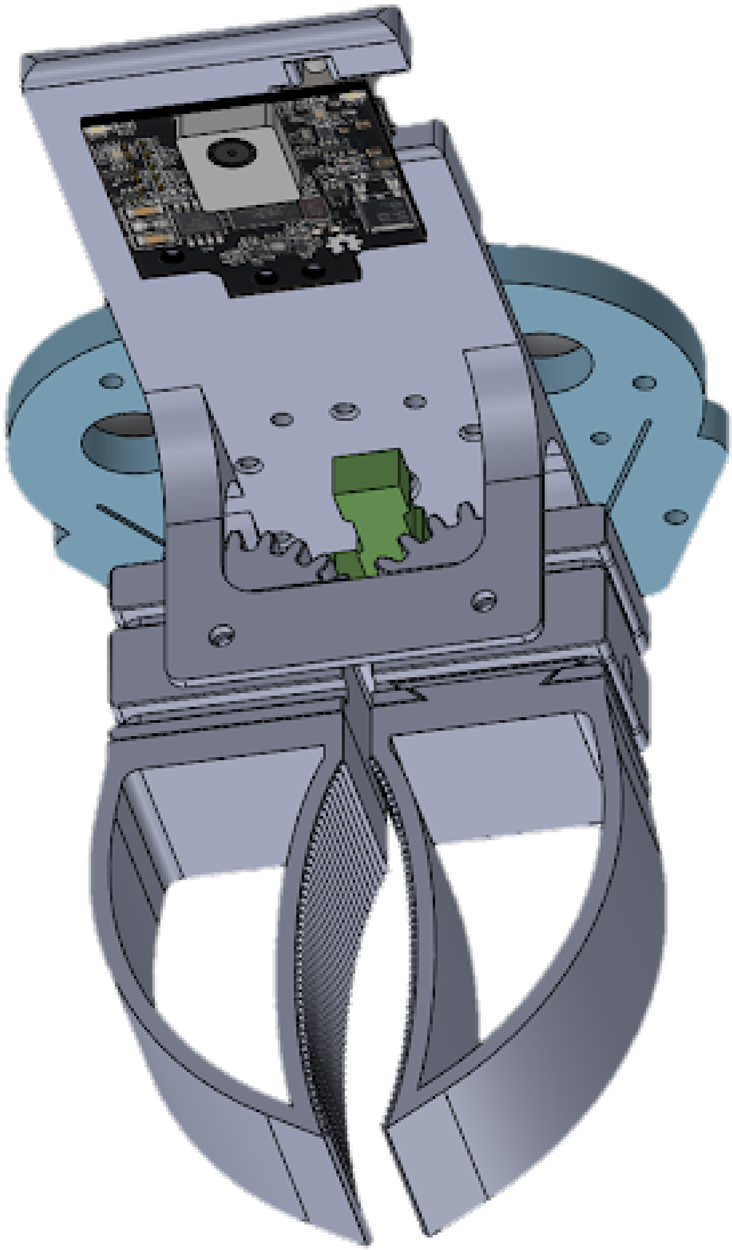

Figure 3.2: *Gripper in SOLIDWORKS*

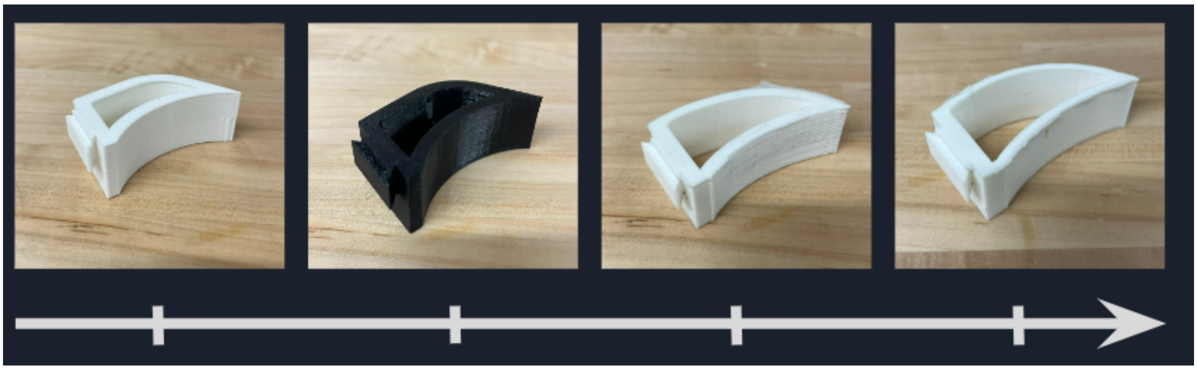

Figure 3.3: *Design Evolution of Pinchers*

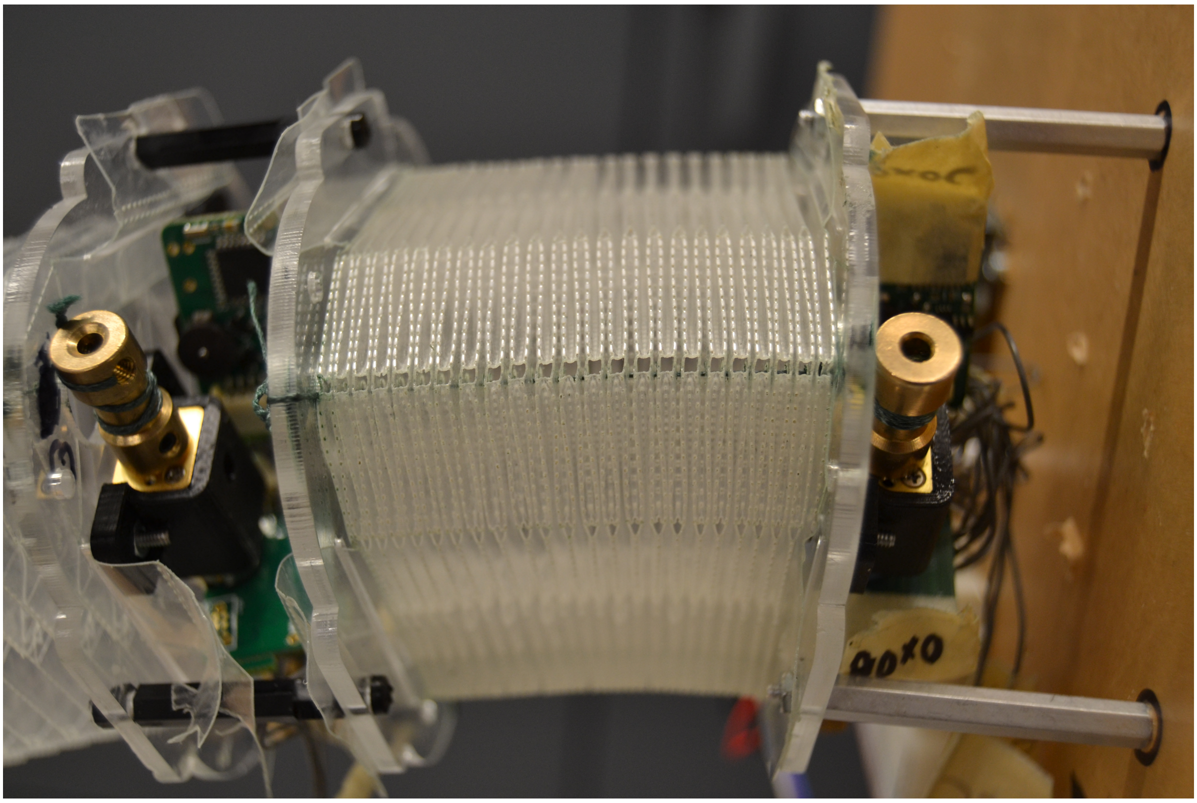

Figure 3.4: *Buffer Zone in Between Modules*

Ideally, our team predicted that the module with the high spring constant would be able to lift more weight. However, this change was eventually reverted because the motors were not strong enough to fully compress the thicker module, resulting in a limited range of motion. The group ultimately decided to go with the 0.005 inch PET sheet to prevent the motors from burning out and because the range of motion was valued more than the strength of the robot arm. It is worth noting that with higher torque motors we believe that the range of motion would not be sacrificed and strength would be improved.

Ultimately, the assembly of the module was fairly seamless, however some issues included improper folding techniques, motor location and interference with the plastic sheet. In order to reach full strength and flexibility the PET sheet must be folded perfectly along the perforated lines, and any sheets that did not meet that standard could not be used.

3.2 Controls

3.2.1 Design Criteria

Similarly to the mechanical design, it was first important to outline the criteria for the final control system. Primarily, this system had to be intuitive to use. We wanted to ensure that users needed minimal prior training to understand and implement to complete daily tasks. A complicated system with lots of training required would discourage users from integrating this system into their lives, it may also make these tasks even harder than they already are. Our team wanted to focus on creating an intuitive design to ensure the transition to using this system would be seamless.

Additionally, it was important that our control system reacted in real time to human in the loop control. Nothing is more frustrating than when a system is lagging or moving unpredictably. With the soft robotic design, there is already a significant amount of room for unpredictability with how the arm will move. It was imperative that our user was able to correct for this in real-time using the control system.

Similarly, we knew we wanted the system to act accurately to user inputs. However, it was important that the system was also forgiving to error. If the system was too precise a user may get frustrated that the system is too sensitive to their every move, requiring a high level of precision on their end. For people with mobility disabilities, precise motor control may be difficult. Therefore, our goal was to create a system that responded accurately, but was also forgiving to user error.

Lastly, our controls team also set out the technical goal to implement all of this functionality in ROS2. Previously ROS1 had been used to control this system. By updating this software we were able to create a more effective system that will last longer as it uses updated technology. This could implementation could also be used by other groups in the lab working with the origami modules.

3.2.2 Design Process

To create a control system that met each of these needs, we began by understanding the existing systems and transferring those controls into ROS2. Once we were able to effectively move our module, we decided to implement joystick control. The movement of the joystick is similar to directly moving the module. When the joystick goes left, the robot goes left and so on. The joystick also had multiple buttons that we could use to add other functionality. In this case, we added buttons to expand, contract, and reset origami modules. We also added buttons to open and close the gripper. Using forward kinematics, we were able to translate the messages from the joystick to the module motors. From here, we implemented the encoders. These helped the robot to automatically stop at maximum/minimum length as well as to automatically switch between modules. This functionality took the burden of these tasks off of the user. Lastly, we planned to implement camera vision. This would help to auto center on an object. Users could point the gripper in the direction of the object they are trying to pick up and the camera would help them to properly align. This allows the robot to accurately respond to the users inputs while being accommodating of potential error on the user end.

3.3 Testing Set Up

To properly evaluate these systems, we set up two tests. First, we created a basic testing set up for the gripper. This allowed us to test which objects the gripper was effectively able to manipulate. The second form of testing was user feedback. We worked with the Escape Room MQP to perform a think aloud test that helped us evaluate how intuitive our system is.

3.3.1 Gripper Testing

A key part of the soft robot is how it interacts with objects via the soft gripper. The gripper needs to be strong enough to lift necessary items while also handling them delicately. There are many qualities the gripper must possess, such as being lightweight so that it does not use up the limited amount of weight that the arm can lift, as well as being able to pick up a variety of objects with different sizes and shapes. The following objects listed in Table 3.1 were used for testing each gripper configuration.

The arm itself was mounted to an acrylic plate held up by a computer monitor stand as shown in Figure 3.5. This stand allowed us to easily adjust the height, angle, and location of the arm in the lab. For testing, the arm was vertically mounted 1 foot off of the table. We then used the arm to pick up each of the objects and recorded the success and failure rate of each design. Through this process we modified the design to be naturally opening and naturally closing with each pincher. We also collected data on how the high torque motor would impact the success rate of the gripper.

Item No.	Description	Size	Material	Weight (lbs)
1	1lb Box	1in by 2in by 4 in	Cardboard	1
2	1lb Basket	4 in by 4 in by 1 in	Plastic Box attached with a Loop	1
3	Coffee Can	4 in diameter	Aluminum	0.8
4	Tomato Soup Can	2 in diameter	Aluminum	0.76
5	Water bottle	2 in diameter	Plastic	0.47
6	Pear	2 in diameter	Plastic	0.11
7	Apple	2 in diameter	Plastic	0.14
8	Lemon	1 in diameter	Plastic	0.07
9	Electrical Tape	1 in diameter	Plastic	0.07
10	Small Block	1 in cube	Wood	0.02

Table 3.1: *Properties of Common Household Objects Used for Testing*

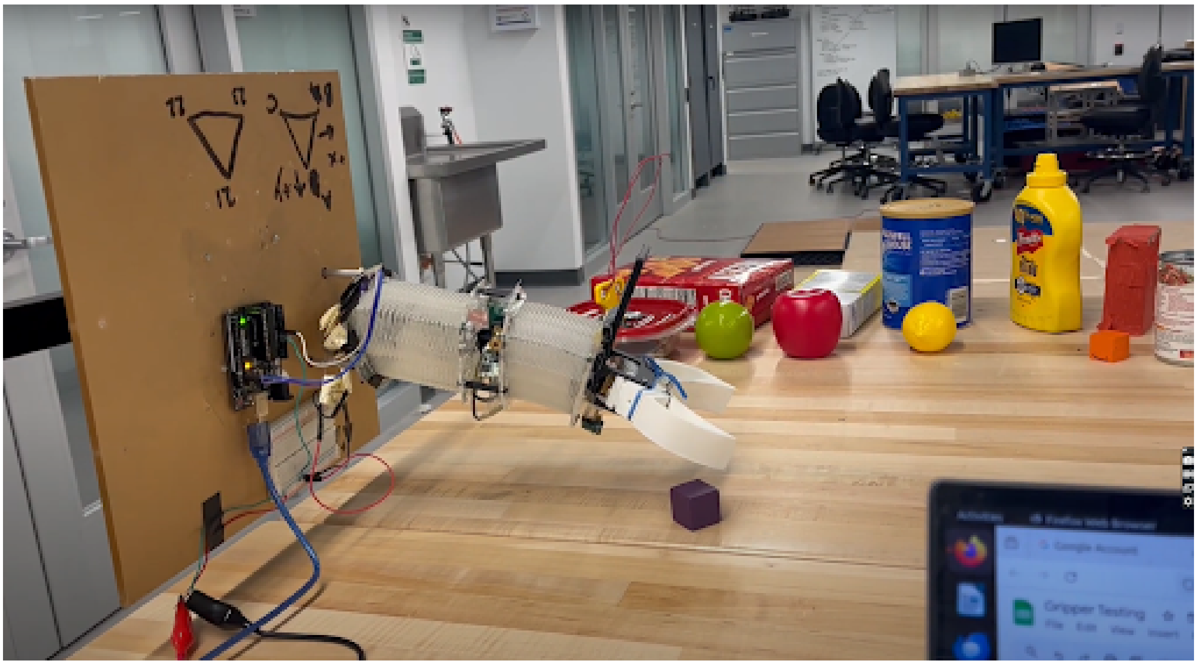

Figure 3.5: *Testing Set Up*

3.3.2 User Feedback

We worked with the Escape Room MQP Team to provide and gather user feedback on our respective systems. For this test, we had the robot set up in the same configuration as the gripper testing, however instead of one of our team mates operating the system we had other WPI students. As they used the arm to pick up various objects, we asked them to explain their thought process and took notes on how they moved the system. Prior to the experiment, we briefly explained the purpose of the system, but provided minimal instructions on how to use the system. This allowed us to evaluate how intuitive our controls were.

CHAPTER 4

IMPLEMENTATION

4.1 Mechanical Design

Our final design consists of two origami modules with a soft robotic gripper on the end. In total this arm weighs about 2 lbs and costs about 700 USD for materials. The full assembly is shown in Figure 4.1.

4.1.1 Module Design

We modeled our robot after an existing procedure created by the WPI Soft Robotics Lab.

A single robotic arm module is made up of the following materials:

- 3 folded PET sheets
- 3 Pololu micro metal gearmotors
- 3 custom motor drivers
- 100 pound fishing line
- 3 3D printed PET motor mounts
- 6 screws and nuts
- 3 1 inch standoffs and nuts
- 2 acrylic end plates
- Arduino Uno

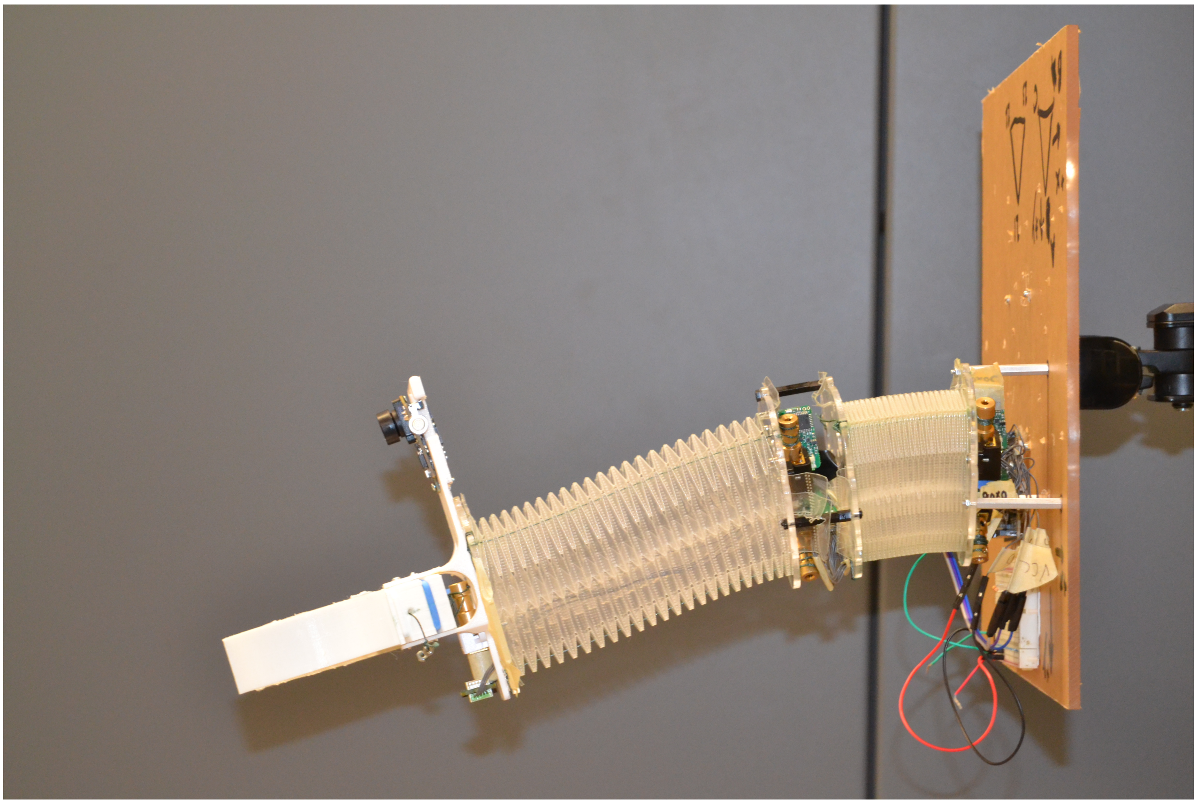

Figure 4.1: *Full Assembly of Robotic Structure*

- Breadboard
- Male to Male Wires
- 4 I2C cables

The PET sheets are first laser cut and engraved with folding lines using an Epilog Engraver Printer with the following settings: Speed 100; Power 7; Frequency 5000:

All sides are folded as shown in Figure 4.2 and attached to one another to create the triangular prism shape shown in Figure 4.3.

Once all sheets are combined a fishing line is weaved through the holes to create a tendon.

The end plates are made from 1/8th inch acrylic plates laser cut using the following settings: Speed 100; Power 100; Passes 2 as shown in Figure 4.4

The motors mounts are attached to the motors and screwed onto the bottom of the acrylic plates as shown in Figure 4.5.

The motors are attached to the bottom of the acrylic plate so that they do not interfere with the plastic folding, and also for easy access to mechanical and electrical components.

This design is fairly simple and very effective. The module system allows for the robot to work well with any number of modules, and modules can easily be added in and taken away.

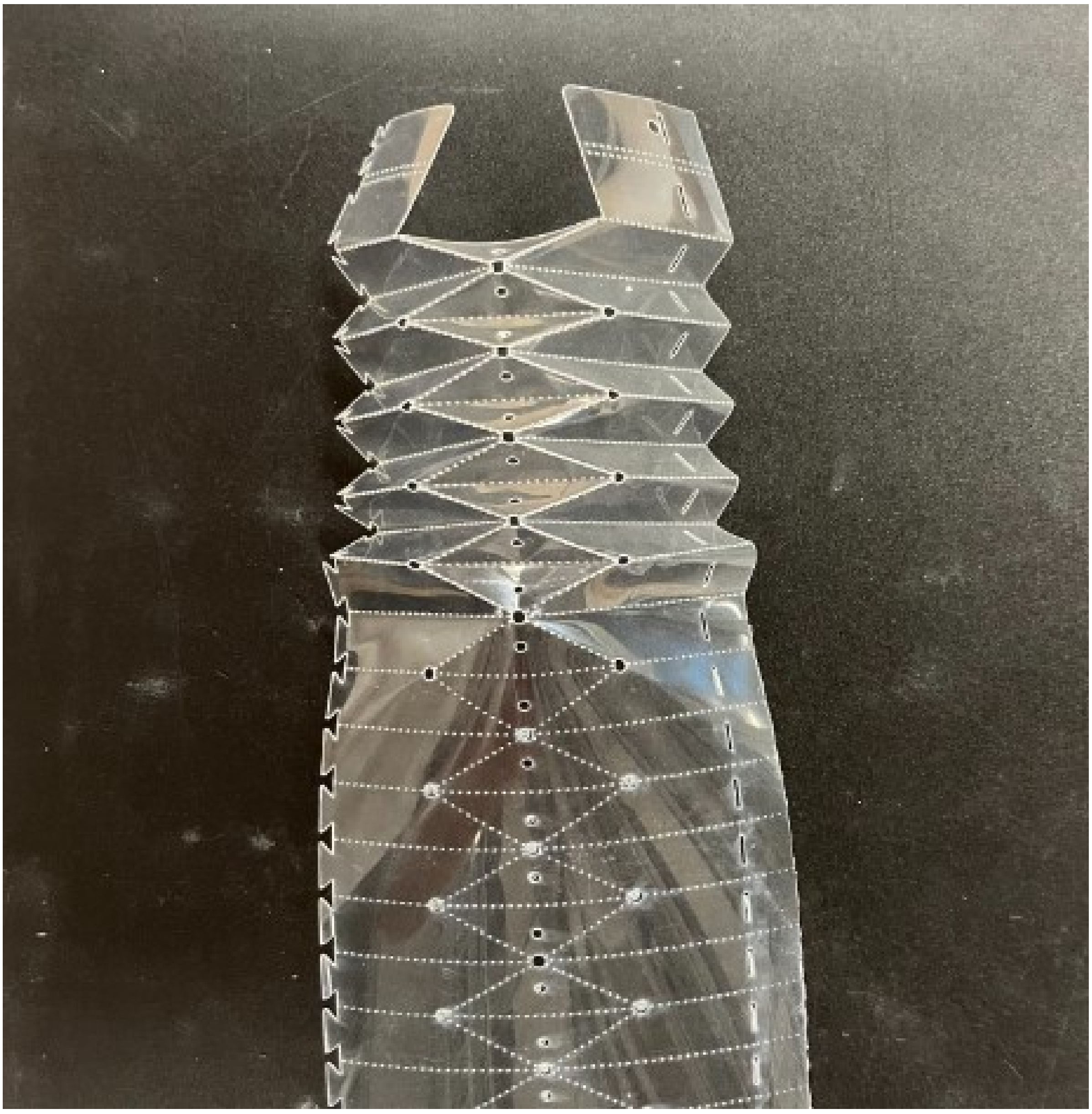

Figure 4.2: *Plastic*

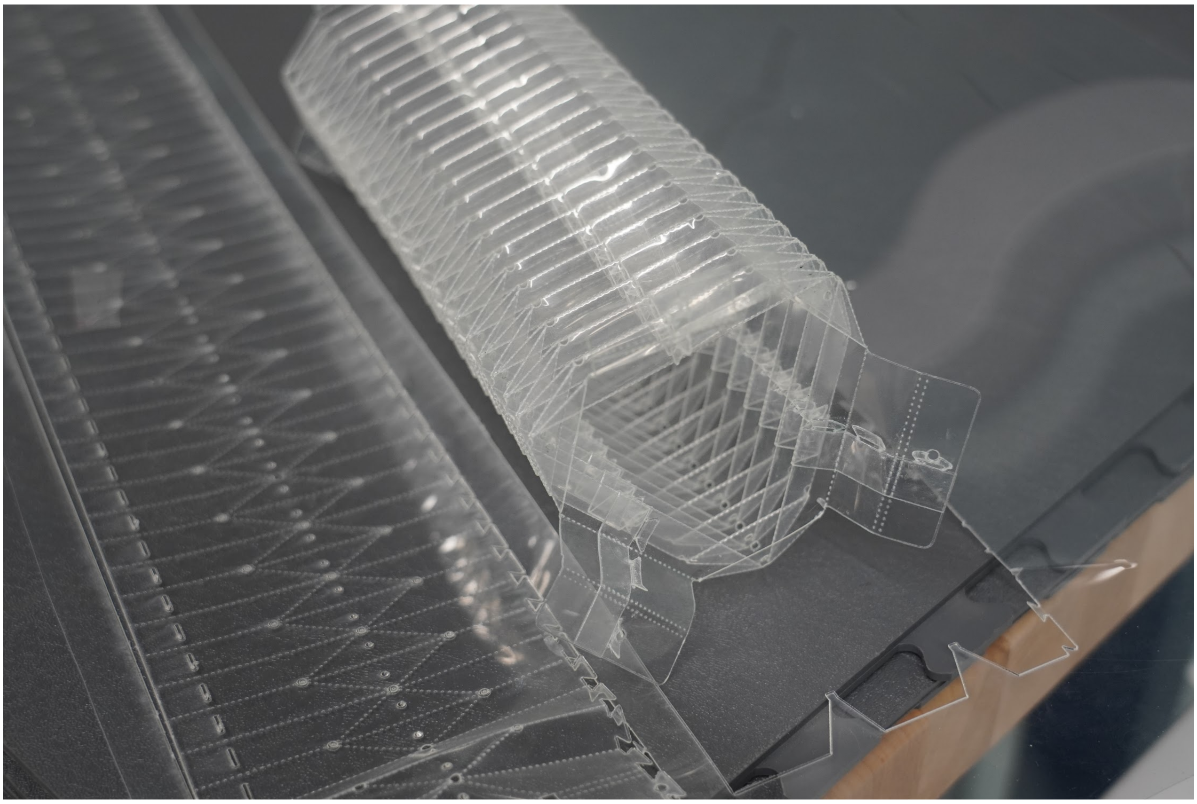

Figure 4.3: *Plastic Sheet Being Folded*

4.1.2 Gripper

The final gripper design has several key design features. The base of this design is printed out of PETG. This allowed it to be heat resistant when the gripper motor was in use for long periods of time. This also provided it with more strength than PLA. This base was also designed to connect directly to the acrylic plate and using minimal material to reduce the overall weight of the system. Additionally, this base also has a mount to attach the Pixy2 Camera to enable camera vision and object detection on the arm.

Notably, through testing we concluded that the naturally open configuration was more effective. This allowed the rubber band to hold the gripper open, but the motor to provide the torque to close it allowing it to grasp more tightly around the objects. The base of the pinchers also has meshed gears to ensure that both grippers apply the same amount of force at the same time when holding and object.

The final pincher design is printed out of TPU. It's walls are 0.1 inches thick, which allows it to easily bend to the same of the object it is manipulating. It also has a textured surface which helped it to grip objects better. Lastly, the curve on the print is reduced allowing it to pick up smaller objects but bend to larger objects.

For this design, we also chose to use the 1000:1 micro metal gear box. This provided an ideal

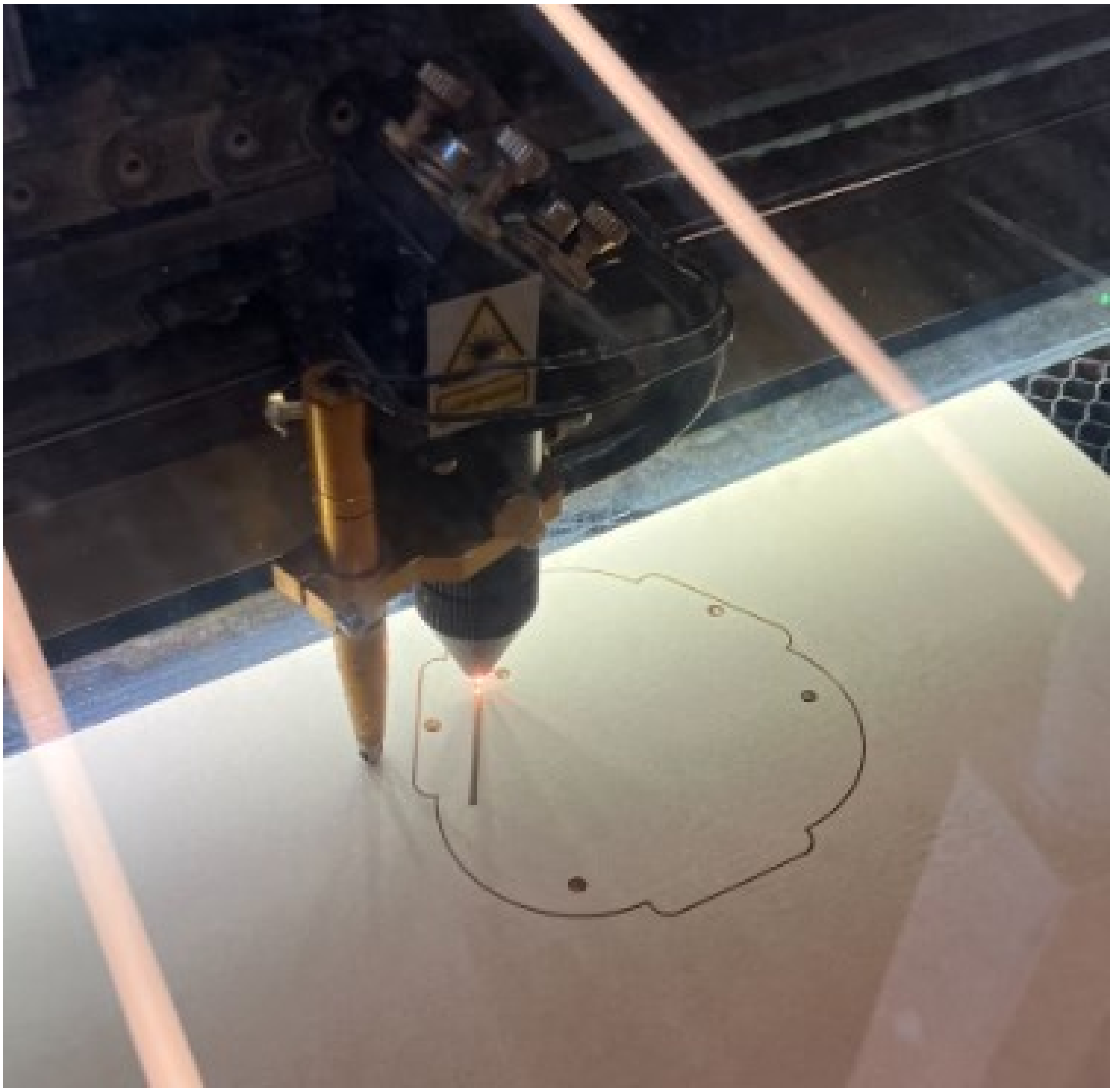

Figure 4.4: *Laser Engraving Acrylic Plate*

Figure 4.5: *Acrylic Plate and Motors*

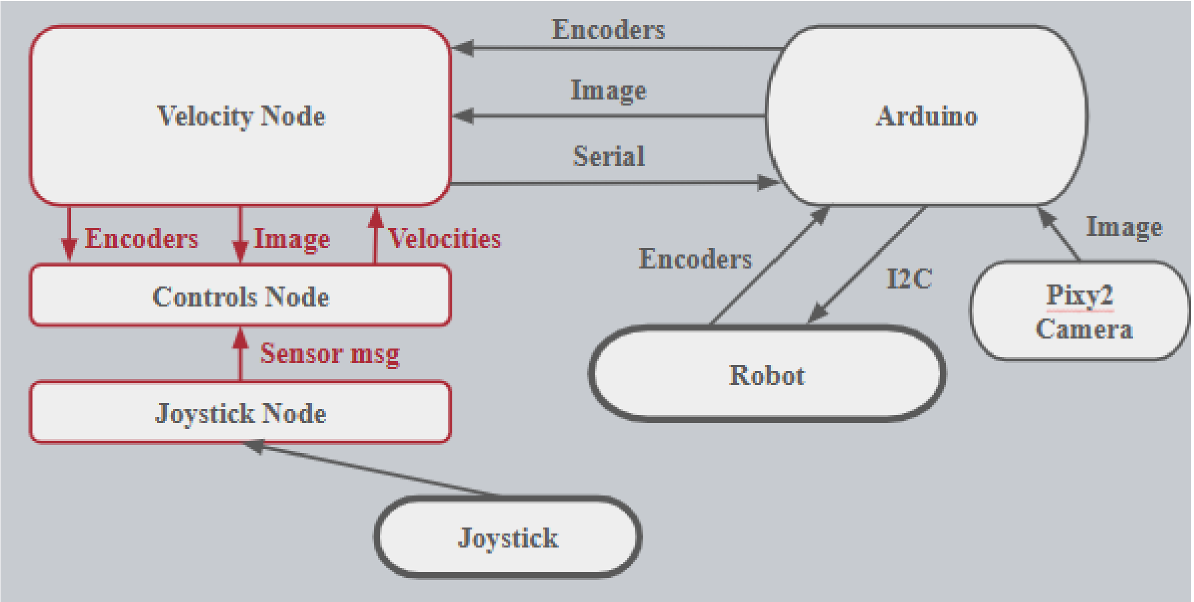

Figure 4.6: *Code Diagram of the Controls System*

torque to speed ratio without drawing excess current.

4.2 Controls

The overarching control system is demonstrated in Figure 4.6.

If you know anything about electric motors you know that encoders are a super important piece of hardware. An encoder is the hardware in the motor which keeps track of how far the motor has traveled. In our case how far the motor has turned. Encoders can be very useful in many ways such as PID and other forms of control. But in our case we used them to ensure we don't over extend our motors which would result in the tendons connecting the acrylic to the PET sheets getting wrapped in the reverse direction which can cause problems driving the robot.

There were two main functions in which we used the encoder values from our motor: Prevent the tendons from unwrapping too far which would result in driving issues, and incorporate an automatic switch when expanding and contracting. The robot is made of two individual modules, and prior to encoders the modules were controlled completely separately from one another. The user had to manually flip a switch to control the second module. In the case of expanding and contraction we found the encoders could be helpful. The goal being for the robot to have an auto switch meaning that, if the robot is expanding, the first module would expand until it reached its maximum length and then the second module would begin to expand. Eliminating the need to manually flip a switch. We also did this in the reverse direction. When contracting, module two would contract until it reached its minimum length and then module one would begin contracting.

In all of this there was one additional roadblock which we needed to face. Our encoders are not absolute encoders. This means that every time the robot turns off, specifically the arduino loses power. The encoders reset and the value initializes. To put it in simpler terms if we drive the robot and then power off. When we power on again the robot will not remember where it is located. So to bypass this problem we created a home position, in which the robot should start every time. This ensures that the encoder's readings are consistent every time the robot is used.

The encoder values from our 7 motors have ten byte arrays which represent different things. The first two, represent the sent velocity to the motor. The next four byte arrays are the motor position. All from zero two hundred and fifty five. Each of these four byte arrays acted like a single digit in a base 10 number system for example when we count once we reach 9 we reset to zero and put a 1 in front of it to get 10. These four byte arrays acted in the same way except instead of base 10 it was base 255. The 7th and 8th byte array was the actual motor speeds. Byte arrays 9 and 10 represented the current draw for each motor. One important thing to note is that for these motors there are 12 ticks of the fifth byte array per rotation. Which means if the fifth byte array went from 0-12 it would mean that the motor had turned once.

Knowing this we were able to deduce that the most important byte array was the fifth one because our robot hits its maximum module length in less than 8 rotations. In order to use these encoder readings we needed to feed this byte array back to our ROS2 nodes. Having established a serial communication protocol with our Arduino, through our velocity-sub. We used our Arduino to write the encoder values into the serial monitor. Once this was done we needed to make edits to our velocity-sub node. Our callback now needed to read the data from the serial monitor and store these byte arrays in a message. Now having these in a message we would publish this data on the topic encoders. Which our logitech-joy node was subscribing to these messages. Having the encoder readings for every motor in our logitech-joy node., we were able to change our velocity outputs based on the encoder values allowing us to successfully implement an auto switch when expanding and contracting.

4.2.1 ROS2

The current system for the Soft assistive Robot at the start of the project was using the Linux operating system while using ROS packages for communication between scripts. Having previous experience with ROS2 humble this is how we decided to move forward. The ROS2 interface plays a huge part in the system and controls development of this MQP. ROS2 is the main source of communication between the various nodes we have. Without this there would be much less separation in the code and we wouldn't be able to use prebuilt scripts such as the joystick package which allowed us to easily read from our joystick. At the start of our project we received the repository to find that there was no ROS2 humble implementation. Which meant that we had to write all of our source code from scratch. That being said, having a repository with ROS code was a great reference. In the development of our nodes.

The major benefit of using ROS2 is, allowing communication between packages. One package being our joy-node package. This package is the package that takes in our readings from the joystick and publishes them out so they can be read by other nodes. At the start of using the joystick we had very little idea on how to move forward other than we needed a ROS2 node. After doing some research we were able to find a package online for the logitech joystick we ordered. Thee package connects to the joystick and publishes the sensor reading on a message of type sensor-msgs on the topic joy having these sensors readings in ROS2 we were easily able to develop some code to act as a subscriber to these messages this subscriber was in the logitech-joy package which we had created.

The logitech-joy package is a ROS2 package which was mainly created with its main function being to listen to the joystick readings but it quickly developed into more. After creating a successful ROS2 subscriber to listen to the joystick. We needed a way to send commands to the motors. We did this by listening to the joystick and depending on data in the sensor message we would send velocities to the robot based on the joystick. However it wasn't as simple as that,we quickly found that the arduino board we were using does not have the memory capacity to run a ROS2 node. This was problematic as the plan was to run a ROS2 node on the arduino uno to subscribe to the velocity commands which we were publishing. Now not being able to do this, it led to the creation of our third primary ROS2 node velocity-sub.

Velocity-sub is a ROS2 node whose primary focus is to send the velocity commands to the arduino. However there was still one problem: we cannot run a ROS2 node on the arduino. The solution to this problem was using serial communication. The arduino uno was capable of running simple serial read and serial write commands, we used this to our advantage. We first had the velocity-sub node subscribe to our logitech-joy node, and listen for the velocity commands which were being published. Our velocity-sub node would then take this message and send it to the arduino using a serial communication protocol. With this step complete the velocity-sub node was the communication bridge from the brains of our system to the arduino. Which later allowed us to use encoder feedback from the motors.

Chapter 5

Results

5.1 Gripper Testing Results

From our gripper testing, we obtained the results shown on Table 5.1.

It is clear to see that the best of the grippers was the third iteration of the the pincher design paired with the high torque motor. This configuration had an over all success rate of 80 percent when manipulating household items.

5.2 Varied Module Thickness

Using varied module thickness proved to be effective but not the right fit for this application. Doubling the thickness of the PET sheet increased the spring constant of the module making it stronger. The robot displayed less bending at full extension and was able to lift heavier objects without having to compress to increase strength and lift. This strength however came at a cost of range of motion restriction. The motors could not fully compress the module and would overheat or stall if the module was compressed to a certain point. Range of motion is crucial for a soft robot especially in the environment that it is being used in for this project. Ultimately, for the thicker module to be truly effective and rational to use, the rest of the robot would have to been strengthened as well, including stronger motors and fishing line. This would allow the robot to be stronger without having to give up any range of motion or risk to damaging other parts.

5.3 User Feedback

Generally speaking, the users found our design to be effective and intuitive. They were easily able to figure out which buttons to use to open and close the gripper system. With minimal

	Item No.									
Gripper Configuration	1	2	3	4	5	6	7	8	9	10
Finger and Palm	×	✓	×	×	×	×	×	×	×	✓
Pincher 1 Naturally Closing Low Torque Motor	×	✓	×	×	×	✓	✓	✓	✓	✓
Pincher 1 Naturally Closing High Torque Motor	×	✓	×	×	×	✓	✓	✓	✓	✓
Pincher 1 Naturally Open Low Torque Motor	×	✓	×	×	×	×	✓	✓	×	×
Pincher 2 Naturally Closing Low Torque Motor	×	✓	×	×	×	×	×	×	✓	✓
Pincher 2 Naturally Open Low Torque Motor	×	✓	×	×	×	×	×	✓	✓	✓
Pincher 3 Naturally Close Low Torque Motor	×	✓	×	×	×	×	×	×	✓	✓
Pincher 3 Naturally Open Low Torque Motor	×	✓	×	×	×	×	✓	✓	✓	✓
Pincher 3 Naturally Open High Torque Motor	✓	✓	×	×	✓	✓	✓	✓	✓	✓

Table 5.1: *Success of Different Gripper Configurations on various Household objects*

guidance they were able to figure out which button was required to reset the position of the arm. Additionally, moving the module to the left and right was also very intuitive.

The user struggled more with expanding and contracting the module and moving it up and down. Their instinct was to move the joystick forward and back to expand and contract the module, not to use the buttons. In hindsight, this makes sense as the joystick moves forward the robot should also move forward and visa versa. Once we had explained the buttons were used to expand and contract, the user was able to catch on without an issue.

Overall, this testing provided us with clear user feedback about how to make our system more intuitive. Throughout the testing process users ran into some general difficulties with some of the hardware in the system that we have been struggling with throughout the term. In the future it will be important to address these issues to get more clear feedback on other elements of the controls.

CHAPTER 6

Recommendations

While we are excited to have met the goals for this project, this is the first year that this MQP was run. This design still has many more improvements that could be made before it is ready to improve the lives of people with mobility disabilities. For this system as a whole, the next big step is to make it self-contained. Currently, to run the code and power the robot, this system must be connected to an external power source and laptop. Together these devices add lots of weight to the design and make it really impractical for daily use. In the next iteration of this project it will be important to find ways to add a battery to the robot and eliminate the need for a computer to be running with the system.

Additionally, this system is currently designed to be mounted directly to a table. This made sense for our lab testing set up, however it is also not practical for wheel chair users. Another step in this process will be to modify the mount of the system to easily attach to a variety of wheel chairs.

6.1 Mechanical Design

In its current state, the arm is able to pick up small common household objects that people interact with everyday. In order to improve its function it can be made stronger and increase its total range of motion. As discussed earlier in the paper, a thicker PET sheet increases the strength of the robot but requires stronger motors. For future work for this arm starting with higher torque motors and building around them with compatible parts, such as strong fishing line and 0.01 inch thick PET sheets, would help the robot perform better in the strength category.

As for the range of motion, the robot is very flexible in its current state, but is only made up of two modules. Adding more modules to the arm would make it longer, increase the degrees of freedom, and increase the overall flexibility. With each new module a new joint is created, which would give the robot the ability to take more than one path to an object, something that would be very useful for obstacle avoidance. Each additional module also allows the robot to have a larger task space without significantly increasing the weight of the design.

The soft robotic gripper can also be improved in a variety of ways, as different grippers can be designed to excel in specific applications. The current gripper has an all purpose design that is able to pick up different objects and shapes with its two pincher system. Adding more pinchers and creating a claw-like gripper with a both horizontal and vertical pinchers would be able to hold objects in a variety of positions. Additionally, another joint and motor could be added to the gripper where it connects with the modules. This would be responsible for orienting the end effector. This would allow it to rotate objects and as well as move them which is a helpful still for many daily tasks.

6.2 Electronic Hardware

One consistent struggle that this robot faces is with unreliable hardware. Throughout our testing process we found that the motor drivers would stop working all together or react unpredictably. We also faced issues of drift when using the encoders, where they would allow the motors to slowly expand or contract as the robot was suppose to be stopped. We discussed this issue with Tim Jones, a PhD student at WPI, and he informed us that this is a common issue that they face with these electronics overtime. For this system to be viable to help with daily tasks it must be durable and reliable as well. These motor drivers are far too unreliable to be effective in real life. Therefore another area to improve for the future, would be to design or outsource new motor drivers that are more reliable to create a better system.

Additionally, it would be important to include absolute encoders on these motor drivers. Our current system relies on encoders which reset each time the power is shut off. Absolute encoders would be able to keep track of their exact position, not just the change in their motion. This would allow for more precise and reliable controls as well.

6.3 Controls

Our current control system is simple yet effective. It allows the user to easily manipulate objects and maneuver the arm with the joystick. It also moves in the most optimal path using the encoders. However, there is always room for more autonomous improvements. As a result of the faulty motor drivers, we were unable to get the camera fully tested. Another group could use the base code and functionality that we set up, and fully implement this system. This camera vision is also currently set up to only be used to auto-center during expanding and contracting. Additional functionality could be added so that the robot is constantly auto-centering to help guide the user.

Camera vision could also be implemented to help with obstacle avoidance in the future. Once more modules are added, the camera vision could work with the user inputs to avoid walls, unwanted objects, or other items that may be in the way of the robots path of travel.

Based on the user feedback, a small change that could also be made would be to switch the expand and contract with the up and down controls. Users seemed to naturally gravitate toward moving the joystick forward and back to expand and contract. We could then use the buttons to move the robot up and down. This simple change could help make the system easier for users with minimal instruction.

6.4 Additional Testing

Lastly, once all of these changes have been made, the next step would be to test this system with a larger and more representative sample of users. The feedback we have currently collected represents students without mobility disabilities who are familiar with other robotic technologies. While there feedback is extremely helpful, it does not represent the target audience of this product. To effectively create a system that will help individuals with independent living and daily tasks, it is important to build this system with their feedback in mind. Therefore, it is recommended that in the future, this system is fully tested on a more larger and more representative sample of users to ensure it meets their needs.

CHAPTER 7

CONCLUSION

We are proud that our final system was able to meet all of the design goals. To recap, mechanically we aimed to keep our robot under a 1000 USD budget and under 10lbs. Our robot currently costs about 700 USD and only weights about 2 lbs (excluding the laptop, mount, and external power source). Additionally, we wanted to adapt the origami modules to be able to effectively lift 1 lb. These modules were able to successfully complete this goal while the arm was mounted vertically. Lastly we wanted a gripper design that could manipulate most household items and effectively hold items of different shapes, weights, and sizes. The soft robotic gripper that we designed was successful in picking up most of the household items in our tests. Additionally, we were able to meet our controls goals as well. Primarily we focused on creating an intuitive control system. Through the use of the joystick and encoder values, we were able to implement a system that was easy to use with minimal instructions. Another goal was to be able to have this system react in real time accurately, but be forgiving to user error. The camera vision helps to accomplish this. The controls are able to react in real time, and the camera helps with stability so that the system is accurate and allows for user error. Lastly, we had hoped to implement this all while upgrading the software from R0S1 to ROS2, which we were able to do in our final project. Ultimately, this design was able to accomplish all of the goals that we had set for the initial version of this project.

7.1 The Importance of Improving Assistive Technologies

As technology continues to evolve, it is important that people intentionally find ways that it could be used to improve the lives of others. Accessibility can be difficult for people with disabilities, not all spaces are accommodating and the support they may need can be expensive. However, this project highlights one of the many ways that we can use new technologies to make our world more accessible for all people. Soft robotics provides a safe and affordable aid to help those who struggle to live independently as a result of lack of motor function. With a device like the one created in this project, many people's lives could be improved for the better. For this reason, it is important that we continue to find ways to use new technologies to assist those who need it the most.

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