Bio-Inspired Adaptive End Effector Capstone Report

Portland State University

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Abstract

The Bio-Inspired Adaptive End Effector capstone project aimed to design a device capable of picking up and manipulating two significantly different categories of objects, small hardware components and damp, loose food items. We represented these by using M2 and M5 bolts, washers, and nuts for the hardware, and spinach as our food item. The design process drew from examples found in nature as sources of inspiration and utilized a rapid prototyping and iteration approach to quickly identify design problems. Additionally, we considered the principles of Human-Centered Design (HCD) and Human-Robot Interaction (HCI) when making design decisions. This led to the development of a two-part gripping device, an outer gripper inspired by bird talons for grabbing the leafy greens, and a “mini-gripper” inspired by stag beetle pinchers for picking up the nuts, bolts, and other small parts. The end result of this project was a proof of concept design and 3D printed prototype for an end effector capable of meeting the design criteria, as illustrated by experimental data measuring the device’s ability to repeatedly pick up and move the target objects. The design is a solid foundation for future projects meeting this design challenge.

Introduction

Most current robotic end effectors are designed with a specific purpose in mind. They are capable of accomplishing that task effectively, but are not often adaptable to other scenarios. This project was conceived to fill this gap. Instead of acquiring and changing out the end effectors of a robotic arm for each potential application, one gripper could be capable of manipulating a large range of objects, making life easier for human operators and more affordable for factory managers.

An area that engineers draw inspiration from when addressing challenges like this is biology. The number of natural solutions developed by living beings is vast, with many species having different solutions to a wide variety of obstacles. Evolution over an extended period of time can be observed as nature’s version of rapid prototyping. Each iteration addressed a limitation in the previous design, improving its chances of survival. Many problems in the engineering world have been solved by biology over the years,

and by using that as an inspiration in the fundamental principles of design, projects may reach new heights.

This project aimed to use inspiration from nature to solve a multitude of problems while following a set of human-focused principles. The end goal was to create a device capable of picking up two categories of objects: small singular items for part kit assembly and larger, loose items with damp surfaces found in industrial food packaging. Specifically, our testing criteria used M2 bolts, nuts, and washers as our small objects and spinach as our food packaging sample.

Two main principles followed in the design process were Human-Centered Design (HCD) and Human-Robot Interaction (HRI):

Human-centered design is a process in which the needs of the end user are considered at every stage of development. The end goal is a product that is intuitive, easy to operate, and adds value to the consumer.

Our sponsor defines human-robot interaction as “the study of the understanding, design, and evaluation of robotic systems for use by or with humans. HRI examines how humans and robots communicate, collaborate, and coordinate actions in shared environments, involving sensing, decision-making, control, and human-factors considerations.”

HCD primarily influenced design choices surrounding assembly methods for the outer gripper. As the model was iterated, the design evolved to become easier to assemble and repair. HRI influenced the decision to use pneumatics as the actuation method, as the movement of this system was predictable for an observer.

Initial Design Criteria

The initial design criteria laid out by our sponsor described a desire to create a bio-inspired robotic end effector that prioritized the principles of HCD and HRI. Four weeks after the project began, the design criteria were refined to better align with the final object categories. While the focus was still on utilizing biological sources for inspiration, and the principles of Human Centered Design and Human Robot Interaction were always forefront, the sizes and types of objects we needed to grab changed.

The original objects were mostly handheld objects, as shown in the table below, and presented a wide range of potential challenges. Our new criteria focused on picking up small hardware and spinach, which required different gripper geometry than what we had been conceptualizing up to that point. Because of this, some of our initial brainstorming was less relevant to our design process than we would have preferred.

Scenario #	*Object Name*	*Material*	*Relative Hardness*	*Shape*	*Approx .Weight*	*Key Challenge for Gripper*
1 – Science Museum Exhibit	Coral Replica	Lightweight foam / silicone composite	Soft, compressible	Irregular, branching	~80 g	Gentle pressure control and adaptive contact on porous, uneven surface.
	Mineral Sample	Resin-coated rock fragment	Hard, rough	Irregular block	~400 g	Maintain grip stability on uneven, rigid geometry without slipping.
2 – Healthcare Supply Handling & Transport	IV Fluid Bag	Medical-grade PVC	Soft, flexible	Flat pouch with liquid motion	~500 g	Manage shifting internal mass and variable grip area due to fluid dynamics.
	Pill Bottle	PET plastic with sealed cap	Medium-hard	Cylindrical, slightly tapered	~60 g	Consistent grip during mobile transport; prevent rotation or drop when
3 – Consumer Electronics Assembly & Packaging	Smart phone Casing	Polycarbonate / aluminum	Hard, smooth	Flat rectangular	~180 g	Gentle, uniform grasp without surface marking; precise orientation control.
	Foam Insert	Polyethylene / polyurethane foam	Soft, compliant	Rectangular block with cutouts	~15 g	Avoid over-compression while ensuring stable lift and alignment.

Diagram of Initial Design Parameters

Design Prompt

The challenge for this project was to design an adaptive gripping device capable of picking up two categories of objects with significantly different material properties. The project needed to incorporate the principles of Human Centered Design and Human Robot Interaction, and draw from solutions found in nature when developing the design.

Objects that we needed to manipulate:

- Small hardware components off a tray
    - M2x8, M2.5x8, M3x8, and M5x25 screws
    - M5 washers and M8 mm lock washers
    - Additional metal brackets, washers, nuts and other components
- Spinach
    - Grab an equal amount of spinach each time
    - Place spinach inside a bin for packaging

Part Picking
Current goal:
Improve speed and consistency in picking small mechanical parts (screws, washers) from trays or bins for kitting and light assembly.
Stakeholder problem:
Human pickers struggle with repetitive strain, dropped fasteners, and inconsistent picking performance. Robots often fail to grasp tiny, flat, or rolling hardware due to low friction, precision limits, and lack of adaptive contact.
Unmet goal:
A gripper that can reliably pick irregular small parts on flat surfaces or bins without slipping, misalignment, or requiring complex fixturing.
Explicit request:
Develop an adaptive gripper that can grasp and lift very small metal components with stable contact, regardless of orientation, while remaining simple, safe, and easy to clean.

Sponsor-Provided Problem Statement - Small Hardware

Leafy Greens Packaging
Current goal:
Improve packaging efficiency for leafy greens while maintaining freshness, avoiding bruising, and ensuring the box closes properly without greens getting caught in the seal.
Stakeholder problem:
Manual handling often tears or bruises spinach leaves, and workers must carefully arrange greens so nothing gets trapped in the plastic packaging seams. Human handling also increases the number of touchpoints, raising hygiene concerns.
Unmet goal:
A gentle, adaptive approach to picking and placing soft, irregular spinach leaves (2–4 inches long) that reduces damage and improves consistency, while supporting food-safe handling practices.
Explicit request:
Develop an adaptive gripper that can gently grasp and transfer leafy greens without crushing, bruising, or contaminating them, while placing them cleanly inside plastic packaging so the container can be sealed without obstruction.

Sponsor Provided Problem Statement - Damp Food Items

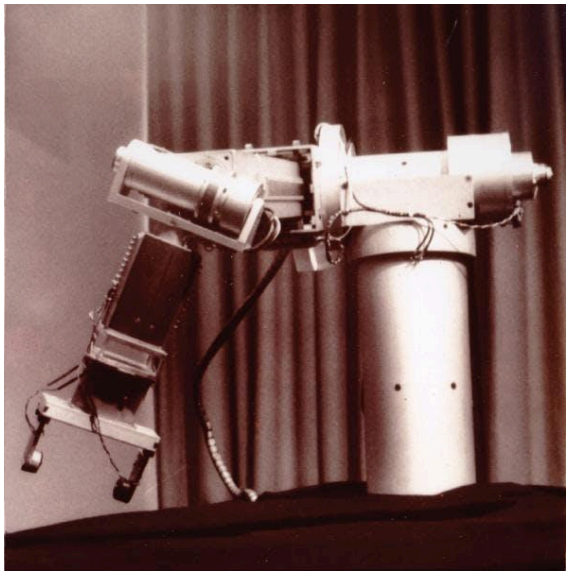
Background Research

Prior Grippers and End Effectors

Billions of dollars have been spent on the research and development of robotic grippers across a wide span of industries and applications. Only in the past 70 years have robotic arms begun to see heavy use in industrial applications. As these devices become both more reliable and more financially feasible for manufacturers, research to develop and improve robotic grippers has grown exponentially. The world has seen increasing interest and investment in robotic grippers from the automotive industry, leading researchers and companies globally to continue to develop and evolve the robotic gripper.

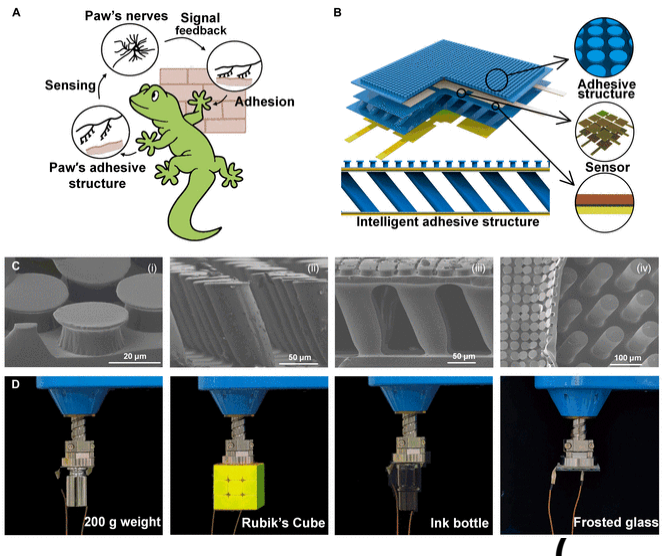
The most common modern robotic grippers used in industrial settings are based on the same design principles as the Stanford Arm. This gripper used two straight bar fingers that allowed it to maximize its stroke versatility, giving it the flexibility to deal with

a large variety of different sized objects. This design became known as the parallel gripper, and was developed by Stanford University student Victor Scheinman. Roughly 10 years after the original Stanford Arm was made a similar design was mass produced and used in industrial environments. The parallel gripper concept has been the subject of further evolution and iteration, and is still one of the most commonly used designs in industrial uses.



The Stanford Arm

A subset of robotic gripper design seeks to draw inspiration from nature to help improve power consumption, reliability, and adaptable functionality. One of the first examples of this was the tentacle arm, designed by Marvin Minsky in 1968, which was capable of holding a full grown person and had 12 joints. More recently, research has been done to attempt to replicate the gripping functions of the microstructure of a gecko' s foot. This was done by combining fluidic elastomer actuators with an adhesive inspired by the gecko's foot microstructure. By applying light pressure to the moving fingers the surface would grasp onto a wide range of surfaces and object shapes. These prototypes were lightweight which helped



adapt to a variety of robotic arms, reduce overall power consumption, and still maintain adequate grip strength.



A specific challenge that many robotic grippers struggled to address was adapting to objects that had a wide range of shapes and sizes. Researchers from Harvard tackled this problem by designing a tentacle inspired robot that was capable of picking up plants and irregularly shaped toys. This design functioned by pressurizing a hollow rubber tube with uneven walls causing the ‘tentacles’ to curl and wrap around objects to grab them regardless of shape.

An additional aspect of bio-inspired gripper research explored suction. Another group of researchers from Harvard created an octopus inspired tentacle that is able to curl around and suction onto objects such as mugs, foam balls, and inflatable medicine balls.The tentacle works by using two separate pneumatic systems that work together to grab objects. The design utilizes one valve that controls pressure to bend the arm, and another to control the suction of the vacuum. By adjusting pressure and vacuum, the arm can bend, wrap around, and suction onto objects and set them down.



Grasping in Nature

There were a number of potential nature-inspired grabbing mechanisms we discovered during our research. These mostly focused on suction, grasping, and pinching mechanisms.

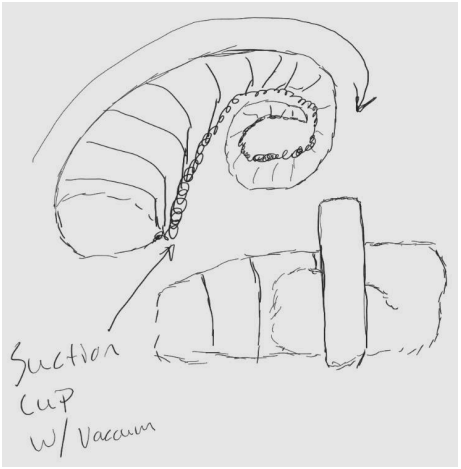
Suction in nature occurs when an animal creates a low-pressure area and a higher-pressure fluid outside rushes in to equalize it. Some examples of this include octopuses and clingfish, which use suction to attach to surfaces. Organisms such as humans and frogs create suction by changing the volume of their chests or mouths.

Grasping can take many different forms. We originally experimented with designing a gripper based on a bird talon, with three claws near the front and one smaller claw at the back. Hawks and other predatory birds have talons that are able to

wrap around differently shaped objects to grab onto either branches or prey. In other animals, such as primates, grasping onto objects can include grabbing things that are more delicate, such as fruit.

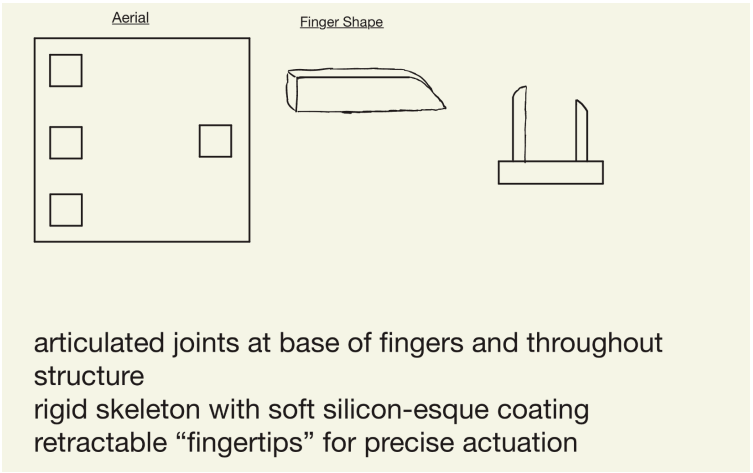
Pinching is often seen in insects, particularly with stag beetles. They are able to grab onto other beetles with their mandibles, and have enough control to wrestle each other. These are actually part of the beetle's jaw, giving them a significant amount of strength and precision, and are also used for tearing through tree bark to access food.

Brainstorming

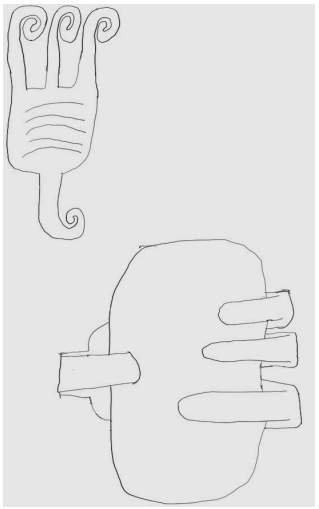


Our first design idea was a single tentacle or tail-like wrapping gripper that took inspiration from two different animals. The shape was modeled after a seahorse tail, specifically the square cross section that helps maximize the surface area that makes contact with the object being picked up. Suction cups aided by vacuum suction, inspired by those found on an octopus, would be positioned along the length of the limb. The design would have multiple vacuum cavities along a single surface of the grabber to allow for multiple grabbing positions.

The second idea was a 4-fingered mechanism with each finger placed in a separate corner of a rectangular soft silicone palm. This positioning would add stability when picking up objects of different shapes and sizes. The 4 fingers are placed symmetrically, with 2 of them on each side to distribute the force evenly and over a larger area than a more traditional parallel gripper design. Each individual finger would match the shape of our first design, the single tentacle, but with four fingers instead of a single wrapping tentacle. The other difference would be that the suction holes would have an exterior surface that flexes around the contact point, causing the object to open up a pressure



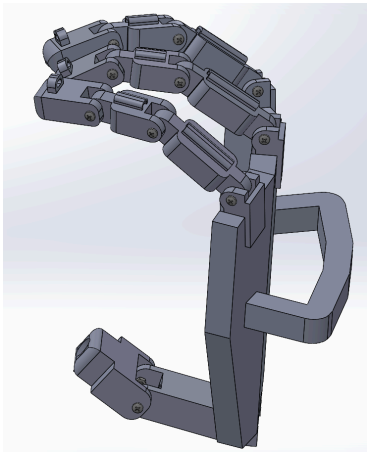
released valve which emulates a suction cup's seal. This would allow the unused suction holes to remain sealed during use, which would maximize the suction force on an object by reducing wasted energy.



The gripper took inspiration from a seahorse's rectangular tail shape as shapes for the fingers, which would maximize surface area. It would potentially include a soft layer over the top that is malleable and would adjust to what it's grasping. There were a number of potential actuation methods that could be used for this design, including vacuum or tendon based actuation. The design would include between 3 to 4 fingers, with some sort of palm.

Many of these initial ideas used some form of vacuum suction as either a primary or secondary force. This would have been appropriate for the scenarios provided for us in our initial prompt, but raised some concerns when the focus of our project shifted. Our new criteria involved picking up and manipulating small hardware components, and designing a suction mechanism that would have a small enough surface area to grab onto these parts was outside of our manufacturing capabilities. We decided to move forward with the hand-shaped design that did not include a suction component because of these potential complications.

First Design



Initial CAD Model

Our first physical prototype was based on imitating a typical human hand. We wanted the palm to be large so the gripper could collect as much spinach as possible, and the finger joints were designed to imitate the movement of human fingers. A downside of the larger palm was that the fingers were too far apart to pick up the smaller objects. We decided to address this by making a “mini-gripper,” which for this prototype was a drain snake inserted into the thumb. This would allow the user to move the thumb to aim the mini gripper separately from the rest of the end effector. However the drain snake had a limited bending radius, which restricted how large we could make the thumb.

During assembly we identified a number of issues. The large palm size in proportion to the fingers caused issues picking up the spinach, and the supports required for the print were difficult to remove. The 3-jointed finger design was also difficult to actuate in a controlled manner. This design used fishing line fed through holes in the joints to pull the hand open, and the hand was inconsistent in what order the joints would move in. Fully printing this prototype helped us identify these issues early, allowing us to implement fixes into our next design.



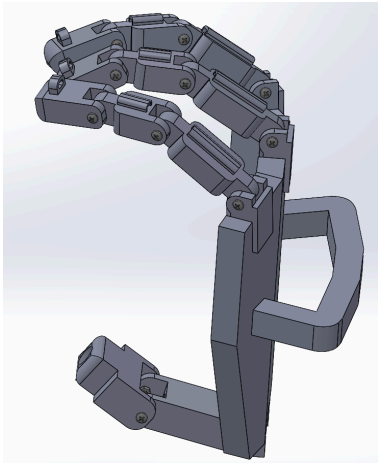
Gripper Palm with Supports

Outer Gripper Iterations

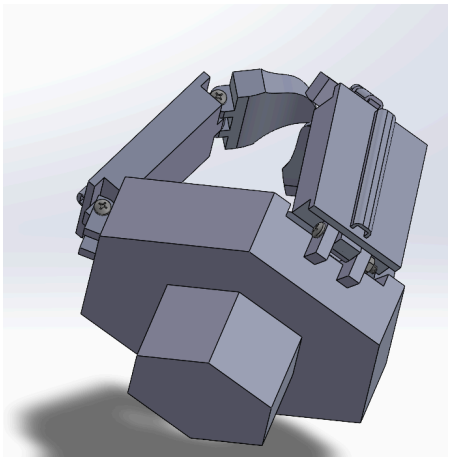
Our main challenge in this project was rapid iteration. From mid January to the end of April we developed a new iteration of our design once every two weeks, for a total of 7 additional versions after our initial prototype. This included a fully printed 3D assembly for each version of the design. The purpose of this was to quickly identify features that we wanted to improve on, as well as areas of concern, without relying

solely on digital models. This was a key aspect of our human centered design process, as physically creating the model helped us identify how people would need to interact with and assemble our model. There were also a number of issues that we encountered during our design process that we were only able to identify because of the time we took to print and assemble each iteration. Each of these versions, or iterations, of the design had noticeable changes, but the most visually significant was between the first and second design.

Second Iteration



Iteration 1

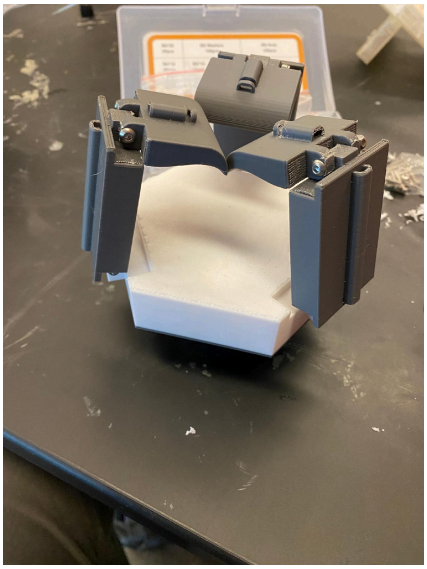


Iteration 2

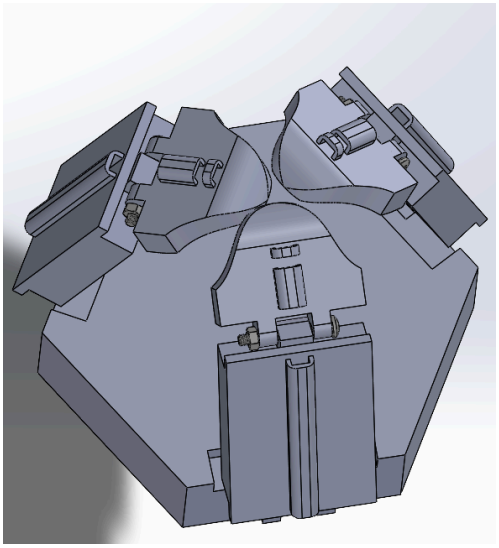
When developing our second iteration we started with our most identifiable problem, the palm. The curved shape, while ideal for maximizing surface area to hold objects, was not an effective design for 3D printing. It required extensive supports that were overlapping and difficult to completely remove, and the handle was large, awkward, and difficult to print. Our second attempt was smaller and simpler. This design featured three fingers that meet at the center of a hexagonal base which has a smooth surface. Instead of using the palm surface as a scoop, the three fingers come together in a pinching motion, inspired by a bird talon. To offset the loss of surface area from the palm, this design had wide fingers and fingertips. The palm also had a smaller hexagonal section that extended out the back to give the user something to hold during the testing phase. At this stage we didn't know anything about the robotic arm that this end effector would theoretically be used with, so we kept the attachment point generic.

These design changes led to a higher quality print and less issues with difficult to remove supports.

A problem that arose with this iteration was that the first attempt had fingertips that didn't mesh well together. The fingers that had lots of surface area also collided with one another, leaving a big hole in the middle. We redesigned the fingertip, drawing inspiration from a natural fingertip or claw that is curved and sharpens to a point, but there were still gaps between the fingers that made it difficult for them to pick things up.



Iteration w/ thick fingertips



Redesigned Fingertips

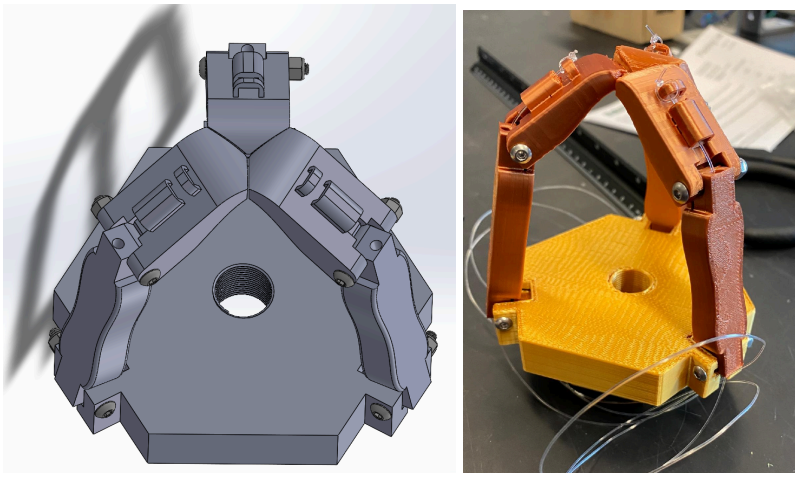
Another challenge that we began to explore with this model was how the fingers would remain in tension. We decided to draw from nature once again by basing the actuation method on tendons. The fingers would be closed in their natural state and by pulling on "tendons" in the fingers we would cause them to open. But how to keep the fingers closed?

Our first idea? Rubber bands. We glued cut up rubber bands in place to keep the fingers closed.This was an effective proof of concept, the rubber bands at each joint were able to keep the fingers closed and fishing line was used to pull them open. An issue we encountered with the rubber bands was that they had a limited lifespan, a number of them needed to be replaced in the two weeks that we were experimenting with this model. The glue used to hold the rubber bands to the model also eroded the rubber, causing additional damage. Rubber bands would not work as a final solution to

our tension problem, but did prove to us that our tendon-inspired design was worth exploring further.

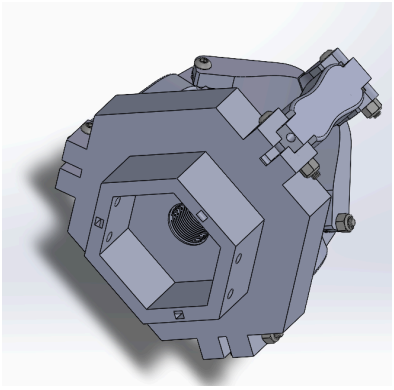
Third Iteration

We were much happier with this second base design when compared with our original model, so we decided to use it as the foundation for future iterations. Our next round of changes focused on refining the fingers. We noticed in our testing that the width of the fingers wasn't actually making much contact with our "spinach" (at the time, we were testing using deflated balloons). To reduce the amount of material that our tensioning method would need to be holding, we made the fingers thinner and gave them a somewhat biologically inspired shape, kind of like bone. We also changed the shape of the fingertips so that they would interlock cleanly without leaving any gap in between them.



Iteration 3

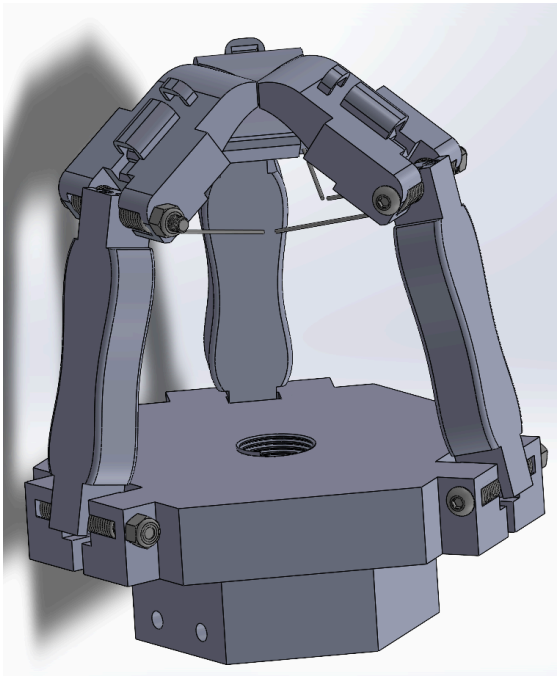
You might also be wondering, what happened to that drain snake grabber thing? We had the same question. At this stage in the process, we hadn't finalized which mini-gripper design we wanted to move forward with, or how much space it would take up, and we weren't sure how to integrate it into this design yet, so for now we put a threaded hole in the middle of the palm so that there was space for future designs to be tested.



Potential Mini-Gripper Location

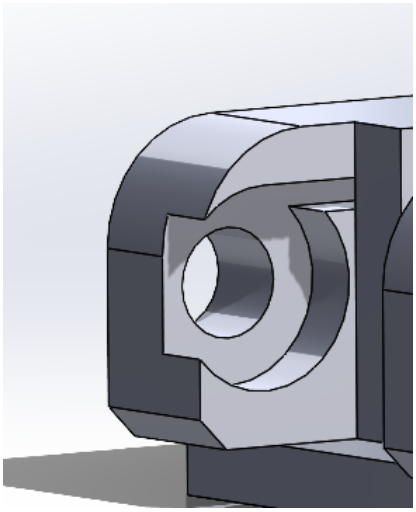
Fourth Iteration

An additional design challenge was determining how to tension the joints other than using rubber bands. Based on our time constraints and budget we decided to experiment with torsion springs. Our first design used 0.188” outer diameter springs with a resting angle of 225 degrees for the fingertip to midjoint connection, and 270 for the midjoint to base connection. These springs were chosen based on the angle that we wanted the fingers to be at in their rest position, and our desire to keep the diameter of the springs as small as possible to reduce how much the joint would need to be redesigned.



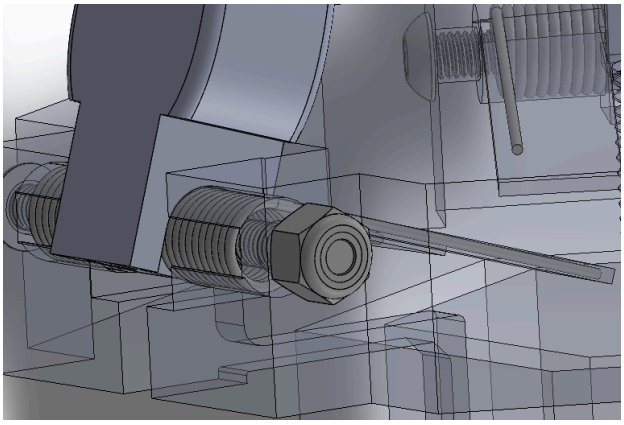
Iteration Four Full Model

Our design incorporated the springs by building them into each joint, using the existing bolts as shafts for the springs to wrap around. The spring legs fit inside cutouts in the finger components and the base which caused them to pull against the springs when opened. The force of the springs pulled the gripper back into the closed position.



Spring Cutout in Fingertip

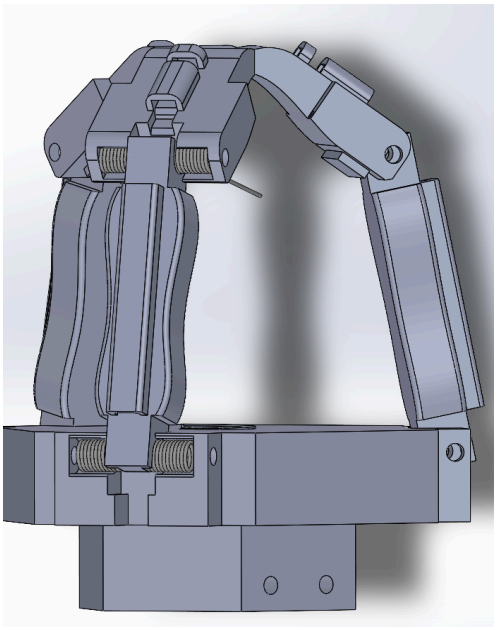
The initial spring choice was not strong enough to counteract the combined force of gravity on both the gripper itself and the spinach it was attempting to pick up. This time, we calculated the force required to keep the gripper closed based on the mass of the fingers and the weight of spinach we wanted to pick up. Comparing those results to the springs we had to choose from we selected 0.245 inch diameter springs at 270 degrees for both the fingertip and base joints. Each joint has both a left hand wound and right hand wound spring so that the forces being applied are symmetrical and keep the joint aligned. We also implemented a degree of pretensioning in both joints to make sure that the spring was applying enough force to keep the gripper closed. This was created by adding mechanical stops to the fingertip joint, and adjusting the angle of the cutout in the base.



Spring Leg Cutout in Base

Fifth Iteration

We had much more success with our second round of spring selections, but a side effect of our larger, stronger springs was that they were more rigid and required more space for expansion. This meant that they were unable to bend and squeeze into the slots that had been made for them, and that they didn't require as much external material to keep them aligned. Our next design iteration created more space at the joints by increasing the size of the spring cutout, both by making it longer side-to-side and by removing some of the material that "covered" the spring.

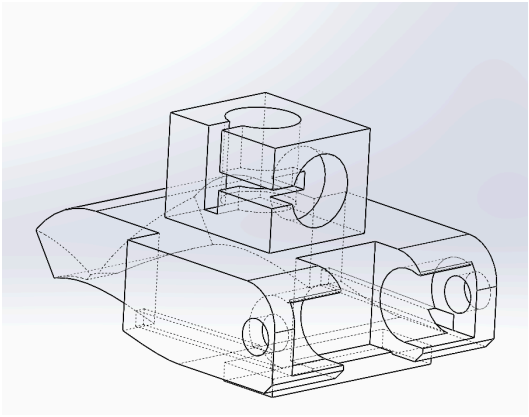


Fifth Iteration Full Model

We also observed that the force required to operate these new springs was enough to cause damage to the internal cable guide in the midjoint. In iteration 3 we had switched to internal routing to minimize the size of the midjoint, but this created a problematic shape for our moment arm. The string needed to make a relatively sharp turn to enter the guide, and instead it was starting to cut through the housing. We decided to go back to the exterior housing channel to create a more smooth path for the fishing line to follow.

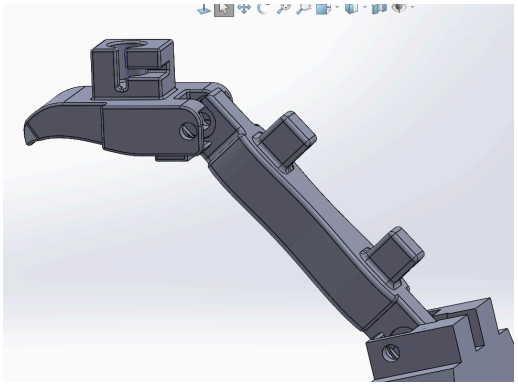
Sixth Iteration

Our issues with the fishing line reminded us that we needed a more permanent solution to our tendon analogous actuation method. Fishing line tends to stretch after repeated use, and we needed a medium that would have more consistency. We also wanted something that was less likely to break or come untied. Our choice? Bicycle brake cable.

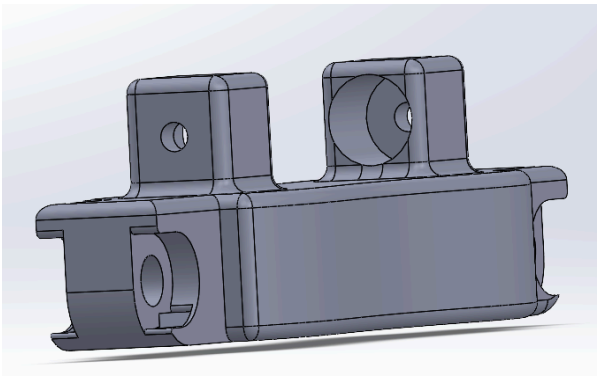


Fingertip with Brake Cable Mount

The brake cable would attach to the fingertip in roughly the same location that we had been tying the fishing line, and cable housing would be used to cover the bare cable in all locations except for the joints. At the joints the cable would be left bare to maximize its flexibility. On the midjoint a section of brake cable housing would sit between two posts to protect the cable.

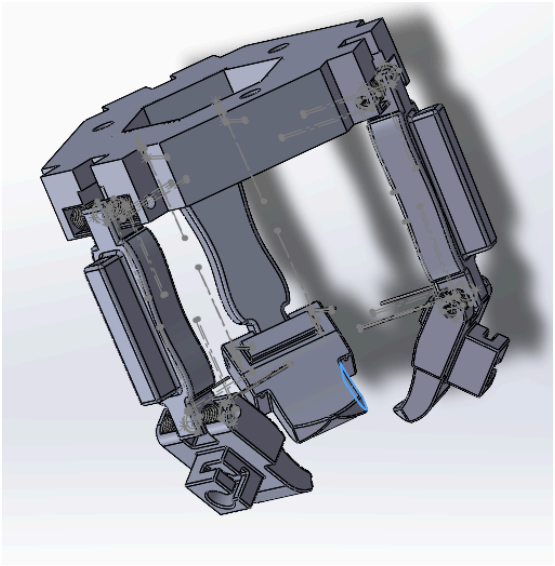


Complete Finger with Brake Cable Mount



Midjoint with Gap for Housing

This was the stage where the mini-gripper was able to be integrated into the model. The cutout in the center was changed to fit the shape of the mini gripper's housing and heat set inserts were added to the base for mounting. The iteration process for the mini gripper had been occurring concurrently with the outer gripper design work, and is laid out in further detail in the next section.

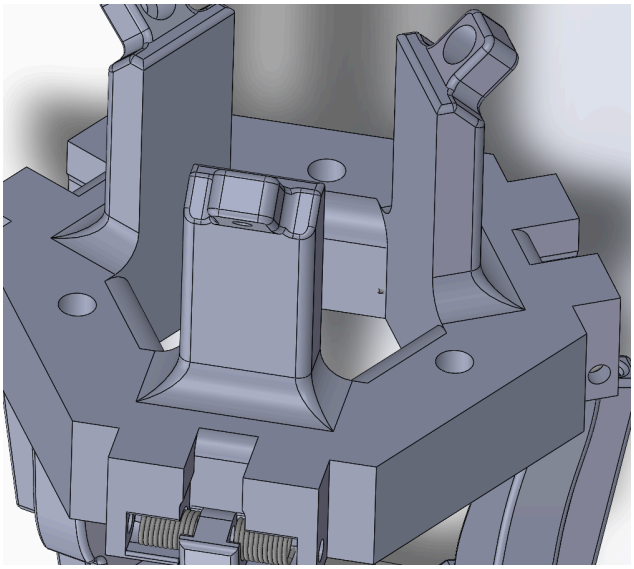


Iteration Six with Mini-Gripper Mounting Holes

Supports were then added to the base to guide the brake cable and provide a transition point for the bare cable to connect with the housing. This took the form of tall posts with a clearance hole for the bare cable on the end facing the finger, and a larger hole on the other side for the housing to sit in.

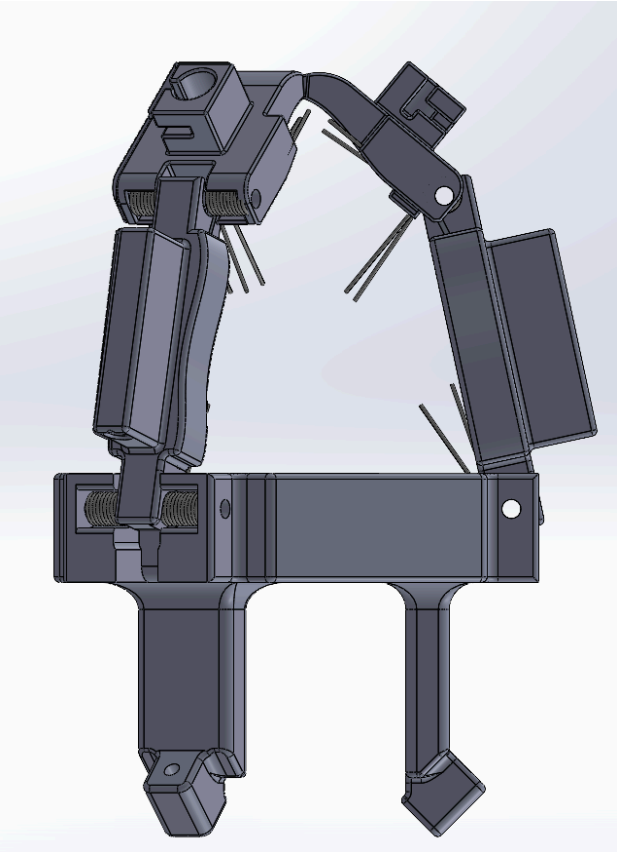


Gripper with Brake Cable



Base Cable Supports

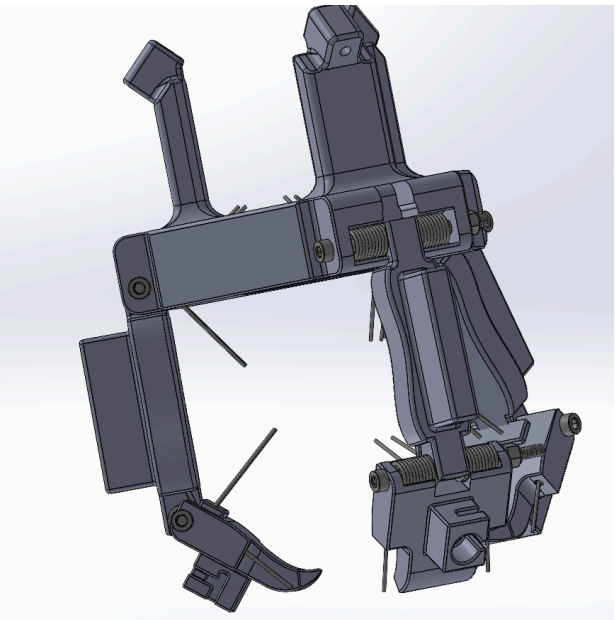
Seventh Iteration



Seventh Iteration Full Model

As we reached our penultimate design, the changes from the previous model were somewhat minor. We decided to use a 3D printed raised channel for the brake cable instead of the cable housing on the back of the midjoint, as we had issues with installing such a small piece of housing into such a tight space. We also raised the cable guide on the midjoint to create a better angle for the brake cable as it enters the fingertip, increased the thickness of the transition points from housing to bare cable on the base to help keep the housing from slipping out, and added more filets to improve the print quality.

Eighth Iteration



Final Outer Gripper Full Model

The final changes made for the outer gripper focused on increasing the strength of the grabber. Most of our grippers had only been hand-actuatable due to how quickly the designs were changing and the timeline for our pneumatic control access, but we were able to do powered testing with iteration seven. We discovered that once the system was hooked up to our pneumatic system, the routing of the cables was applying a small force that wasn't present in our earlier stages of prototyping. This force kept the gripper from completely closing. In order to mitigate this, we changed the springs to ones with a 0.312 inch outer diameter and a greater applied force. We also slightly increased the pretensioning angles in both the base and the fingertip. Both these changes increased the force holding the gripper closed and improved our ability to successfully pick up spinach.

Mini-Gripper Iterations

In the process of iterating our larger gripper design, we were struggling with how to create a device that could apply sufficient, localized force to pick up small hardware without also damaging the leafy greens. Our solution to this was to have two grabbers, a larger outer grabber for the spinach and smaller device to pick up the bolts and

washers. Our initial brainstorming led us to two valid designs: A pincher-based grabber inspired by beetles, and a suction grabber inspired by octopuses.

The granular suction gripper was built with two main parts, the gripper itself and the pneumatic system required to operate it. It was designed to take advantage of the reversible jamming phase transition, a phenomenon which causes fluids to temporarily behave like solids. We drew inspiration from a scientific report entitled “Universal robotic gripper based on the jamming of granular material” as their design was consistent and reliable for multiple different shapes and they provided in-depth data. Their design used a latex rubber membrane (0.3mm in thickness) to contain the granular material, to emulate this a balloon was used with approximately the same thickness. For the granular material their design used coffee grounds at an undefined grain size. This project’s initial design used traditional pour over coffee grounds, which typically have a grain size from 0.5mm to 1.0mm.

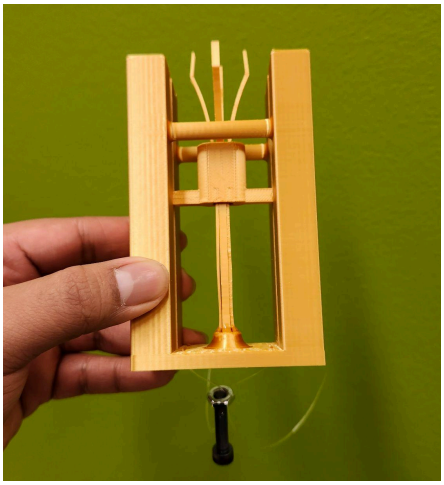
The pincher grabber used a much simpler mechanical design. It was made from 3D printed material and modeled after a drain snake used to retrieve small objects. The grabber had four prongs that naturally flared outward under no load. When a string at the base was pulled, it would pull a slider that closed the prongs and would return back in place with extension springs. The general idea of a pincher mechanism was drawn from beetle mandibles.

We decided to move forward with the pincher grabber design because it was more consistent and easier to integrate with the outer gripper. While the granular suction could pick up larger objects from piles, it struggled with grabbing just one of the smaller nuts or bolts. The pincher gripper’s narrow grabbing area gave it more control over what it was attempting to pick up. It could target individual objects more accurately, especially in a pile test. The pincher also did not require pressurized air, suction, filters, or tubing, all of which were necessary to operate the suction grabber. This made the design simpler and more straightforward, limiting potential points of failure

In order to highlight HCD principles, a priority was making the design reliable, understandable, and easy to operate. The mechanical aspect of the pincher was easier to understand because the prongs clearly open, close, grab, and release. The suction system was more complicated to maintain and understand.

The pincher was also a better choice when considering HRI.According to the criteria, a robot's actions should be predictable so that users can trust the system. The advantage of the pincher over the suction grabber in regards to HRI came down to its more obvious behavior. The suction gripper was harder to predict, especially when grabbing from piles, because of its larger contact area. This made it unclear whether it would grab one object, multiple objects, or none at all.

The pincher was designed to imitate how fingers, claws, or stag beetles grasp objects. Instead of relying on suction, it mechanically makes contact with whatever it is trying to grasp from multiple directions. The four prongs give the gripper functionality like fingers, allowing it to surround and pinch the object rather than simply pressing onto it. This was needed for our design as we needed to maintain control of the object, rather than simply pick it up.



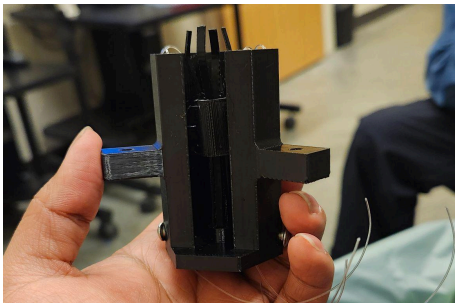
First Iteration

The first iteration of the pincher was used for testing purposes.The model above was created as a proof of concept in order to conduct comparison tests between the granular and pincher designs. Fishing line was used to pull on two 44.5 mm extension springs, applying symmetrical tension to the gripper by pushing on a central slider. The horizontal posts towards the end of the pincher were used to support the test structure, prevent frame failure, and limit the range of the sliding mechanism.



Second Iteration

The second iteration was created after testing between the granular and pincher grippers was completed, and it was determined that the pincher was a better fit. This iteration focused on ensuring that it would fit within the dimensions of the hole that was located on top of the outer gripper. The hexagonal shape of the housing helped strengthen the frame. The bolts on the side were added to replace 3D printed hooks that kept the springs in place. This version also implemented four sections of fishing line instead of two. This change ensured the tension was equally distributed and made sure that the middle slider would not be creating undesired friction.



Third Iteration

The final iteration of the pincher focused on integrating it with the outer gripper. This version of the gripper was shorter than the previous one, which introduced a challenge as the slider relied on the previous housing length to fully engage the pincher. To circumvent this, several methods were used which included increasing the length of the slider, changing where the strings were attached to the slider, reducing the length of the springs, and slightly increasing the length of the housing unit.

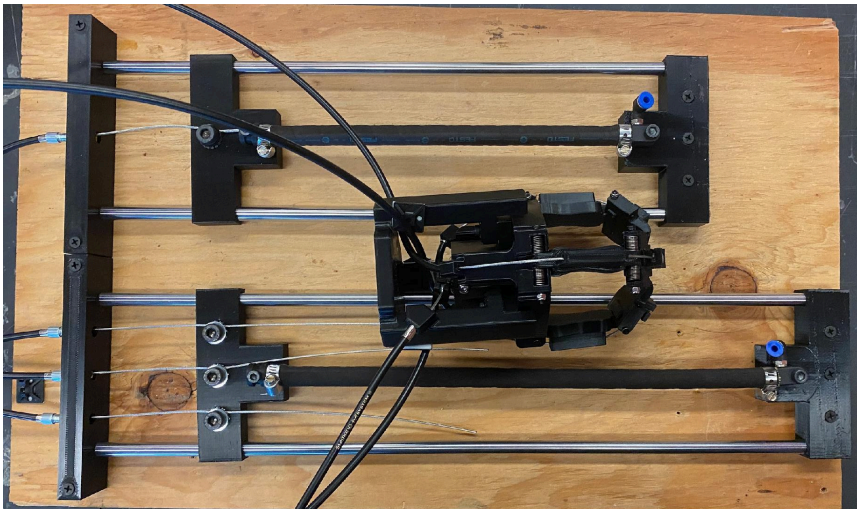
Pneumatic Control

By examining how tendons work in living beings such as humans, a routing system for cables was implemented. In nature, tendons are pulled by their muscles to actuate appendages, in this case fingers. Braided Pneumatic Actuators (BPA) were implemented as an artificial muscle to fill this role. The BPA is made of aramid fibers woven together in a diamond-shaped pattern. When an internal pressure is applied to the rubber sheath, the fibers stretch, causing the length of the tube to contract similarly to a muscle. This contraction is then used to displace the cables, simulating the effect of a muscle contracting to pull a tendon.

By pretensioning the BPA with the springs in each finger, and fixing the far end to a rigid object such as a board, as air is added to the system the fingers contract, and as air is removed, the springs return the fingers to their resting position. We developed a testing station for this using various 3D printed parts as well as machined guide rails to reduce friction and keep the system consistent between trials.

BPAs were an effective actuation choice because of their mimicry of real muscles, as well as their energy efficiency. By relying on pneumatic control, power is only required to fill an air tank and engage the solenoid, and the amount of air consumed with each actuation is minimal.

Final Iteration of Complete Design

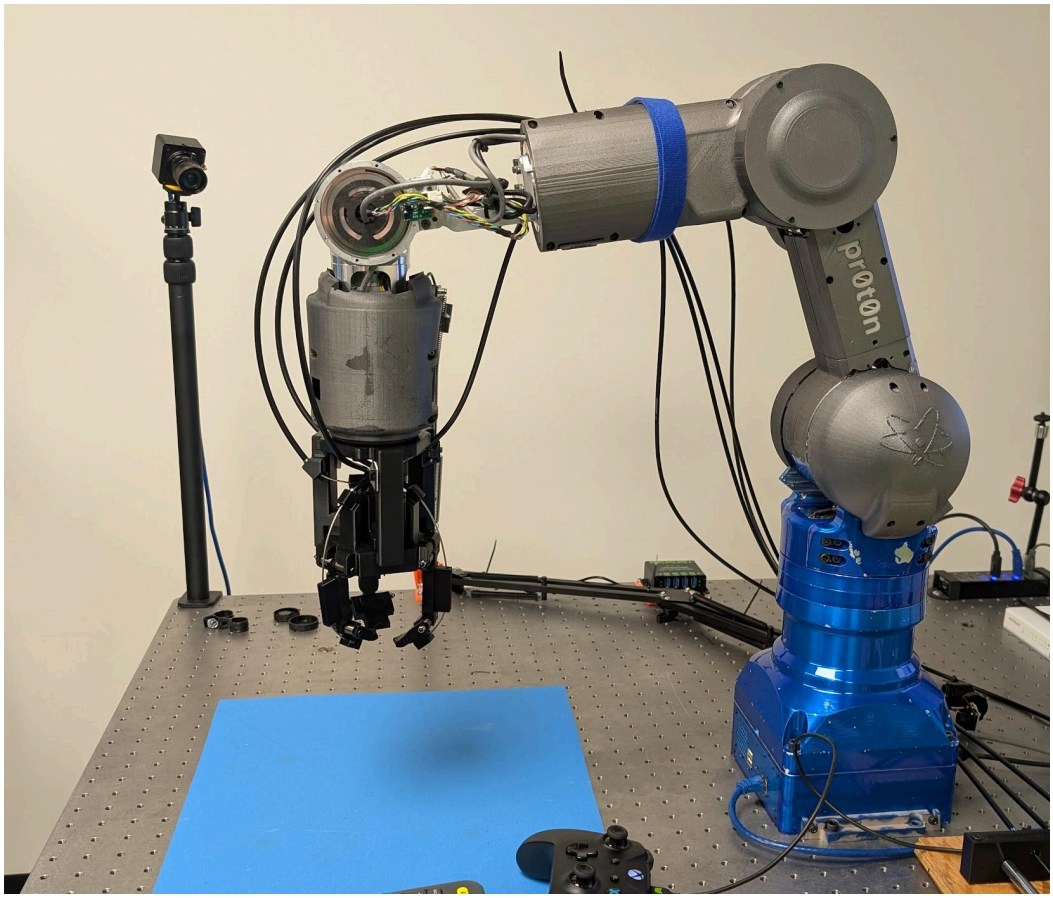


Complete Model with Brake Cable and BPAs

The final model includes the talon-inspired outer gripper, beetle-inspired mini-gripper, and the mounting plate for the robotic arm. Each piece attaches together through three bolts that go into the base of the outer gripper, making it simple and intuitive for operators to attach and remove. The hole pattern on the current mounting plate is based on the UR5e tool mount, but could be modified for other mounting applications. Because of this attachment system, both the large and mini grippers can independently be attached to the mounting bracket, granting operators greater customization options for what system best meets their needs.

The model was able to successfully pick up both the spinach and the small hardware components. While spinach manipulation was reliable, picking up the smaller washers was less consistent. There were also consistency issues when transitioning from hand actuation to a robotic arm, but this phase of testing was time-limited and these issues could likely be resolved with further development.

At this time the end effector has no integrated sensing or sensor response. This is primarily due to budget, time, and resource limitations and is an area that could potentially be explored by future capstone teams.



Final Design Mounted on pr0t0n, Courtesy of Electron Robotics

Experimental Data/Testing/Analysis

Early testing between small gripper designs showed the pinching grabber outperformed the granular suction design in reliability, repeatability, accuracy, and precision. When picking up singular objects, the granular suction grabber was only consistently successful for larger sizes of bolts as it had a heavy dependence on grain size, while the pincher did not have this limitation. Inaccuracies in the data collected for the pincher were found to be due to operator error as the testing apparatus was unable to accommodate an overhead view.

Testing completed on the iteration 5 outer gripper sought to determine how reliably a constant amount of spinach confined to a $0.196m^2$ area could be picked up and placed into a container. Being completed with a bare gripper and gloved fingers separately, this test was used to determine whether a revision to finger size, shape, or

material was necessary. The data showed an average total displacement of roughly 88%, and an average loss of roughly 1.5% across ten trials. The results were negligible whether the fingers on the end effector were covered or free. This data confirmed the shape of the design did not need another major redesign.

Final testing completed using the final gripper design aimed to test five different scenarios: a pile of spinach from a flat surface, spinach from an infinite source, a single M2 screw from a flat surface, a single M2 washer from a flat surface, and a single M5 screw from a flat surface.

Table #1:M2 Screw from Flat Surface

Test #	Picked Up Hardware	Dropped on Target	Trial Notes:
1	yes	yes	
2	no	no	
3	no	no	
4	yes	yes	
5	no	no	
6	yes	yes	Started positioning myself closer to pick up location
7	yes	yes	
8	yes	yes	
9	yes	yes	
10	yes	yes	

Table #2:M5 Screw from Flat Surface

Test #	Picked Up Hardware	Dropped on Target	Trial Notes:
1	yes	no	Stuck in between fingers 3 on 1 side
2	yes	yes	
3	yes	yes	
4	yes	yes	
5	yes	yes	
6	yes	yes	Hanging vertically during travel, 3 prongs on 1 side
7	yes	yes	3 prongs on 1 side
8	yes	yes	

Test #	Picked Up Hardware	Dropped on Target	Trial Notes:
9	yes	yes	
10	yes	yes	3 prongs on 1 side

Table #3: Spinach from a Flat Surface

Test #	Initial Load (g	Measured	Not picked up (g)	Not picked up # of leaves	Dropped	Dropped # of leaves	Trial Notes:
1	30	26	1	2	2	2	
2	29	25	4	6	0	0	
3	29	24	5	9	0	0	
4	29	25	2	5	2	3	
5	29	21	6	10	1	2	Misaligned to bowl dropped 1
6	28	22	5	9	2	3	Misaligned to bowl dropped 2
7	29	24	4	6	0	0	
8	28	15	14	21	0	0	
9	29	25	3	7	0	0	
10	28	24	4	8	0	0	

Table #4: Spinach in a Container

Test #	Final Load (g)	Dropped (g)	Dropped # of leaves	Trial Notes:
1	23	1	1	
2	24	0	0	
3	26	0 to 1	1	1 leaf hit edge of bowl while dropping pile into it
4	20	0	0	
5	9	0	0	
6	10	1	1	Wind blew out of bowl during dropping process
7	34	2	4	2 landed on rim during drop and 1 stuck to finger with rough surface from bad print quality and fell out of bowl, 1 dropped during travel

8	0	0		Skimmed over leaves
9	18	2	3	1 dropped during travel and 2 stuck to rough finger and fell outside of bowl
10	35	0	0	

Future Areas to Develop

One of the primary areas that would need to be developed further in this design is considerations surrounding food safety. This would include a pivot from 3D printed plastics into a foodsafe material, likely some type of metal. Additionally, gaps between joints would need to be covered to avoid pinching and reduce contamination hazards. Cable material and housing would likely also need to change to meet food safety standards. Changing the material of both the gripper and the actuation methods would likely require spring sizes to be adjusted to account for the new weight of the device.

Another area that could see improvement would be the cable routing. As the cables exit the end effector and approach the fluidic muscle they become somewhat unwieldy, and this was not able to be addressed before the completion of the project. Having the cables exit the top in the same position and be bundled together would greatly reduce the amount of time spent tensioning and tuning the fingers before operation and help them stay in tune for longer periods of time.

A potential design option that was considered early in the project was using force sensors to apply a variable amount of force to an object depending on its malleability. This would involve implementing sensors in each fingertip to measure how much force is being applied by the gripper, and a control system that allows the force applied to be variable instead of two-state. We did not end up having the requisite experience or resources to pursue this concept along with designing the rest of the end effector, but this could be an area of exploration for a future capstone.