The Gripper

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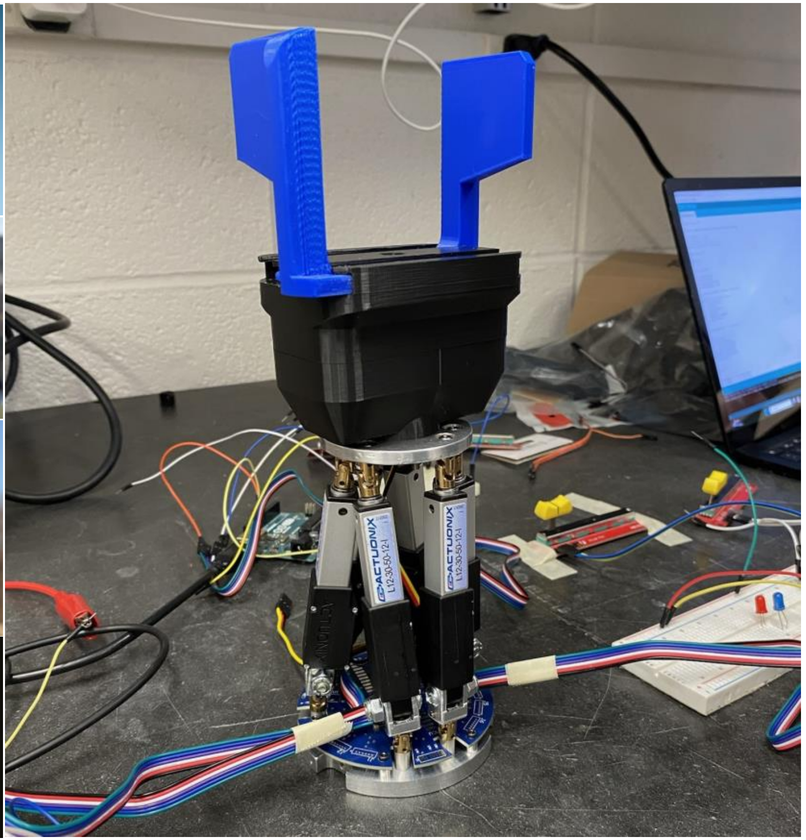


Project Overview

This project builds a robotic wrist designed to attach to the end of a larger robot (Sawyer Robot). The robotic wrist takes inspiration from a “Stewart platform”, where movement in all six degrees of freedom is achieved, simulating a human wrist. The benefit of this is that the Sawyer robot which the device is attached to no longer has to move several arms for small movements in any degree of freedom. This project also includes attaching a gripper to the top of the robotic wrist platform, so that objects, e.g. a tennis ball, can be picked up.

Problem Statement

Parallel jaw grippers for the Sawyer Robotic Manipulator lack the degrees of freedom to replicate the motion and flexibility of a human wrist. This project focuses on combining a 6 degree of freedom (DOF) wrist joint using a “Stewart Strut” platform and a parallel gripper.

By achieving more human-like movements with Sawyer’s robotic arm, the robot’s ability to carry out human tasks can be improved. This could have potential uses in the medical or prosthetic industries, potentially providing new solutions and improving the lives of many. The project will be carried out in conjunction with an ECE design team for the electronic and programming aspects of the device.

Figure 1. Sawyer Robot

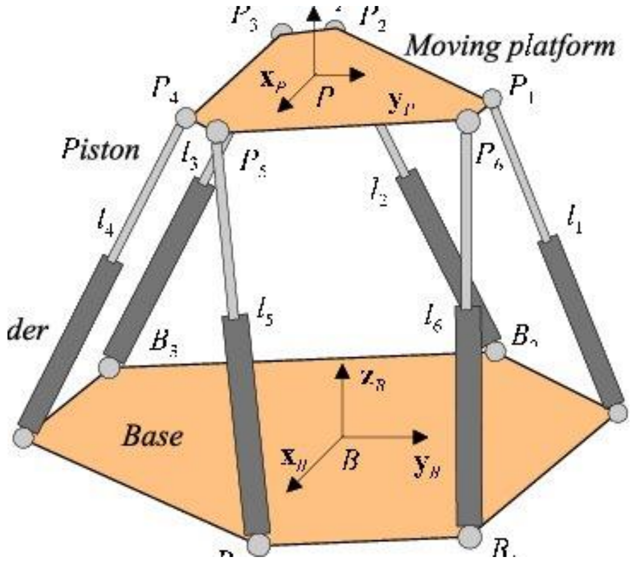


Figure 2. Stewart Strut Platform

Figure 3. Gripper

Deliverables, Requirements and Specifications

Deliverables:

- CAD Model
- Kinematic Model
- Structural Analysis
- Stewart Platform Subsystem
- Gripper Subsystem
- Electrical Subsystem
- Metrology
- Test Data

Requirements:

- Motion plate must exhibit motion in 6 degrees of freedom.
- Mechanical system must interface with the Rethink Robotics Sawyer Platform.
- Design must allow power and signal wires to pass through uninhibited hexapods.
- Grippers must be able to grasp and hold a tennis ball.
- Must enclose MCU, motor controllers, voltage regulators and interfaces.
- The gripper must be interchangeable on the motion plate.

Specifications:

- Minimum translation in the x, y, and z coordinates in the base frame of 3 centimeters.
- Minimum rotation about x and y coordinate axis in the base frame of 30°
- Minimum rotation about the z coordinate axis in the base frame of 15°
- Maximum device height (cylinder envelope excluding the gripper assembly) of 15 centimeters.
- Maximum device diameter of 8 centimeters.
- A minimum payload of 0.5 kilograms to be held securely by the gripper.
- A maximum mass of the whole assembly (platform and gripper) of 2 kilograms.

Note: *A proposal was presented to the sponsor, and an agreement was reached to modify the height specification from 10 centimeters to 15 centimeters.*

Current Project Status

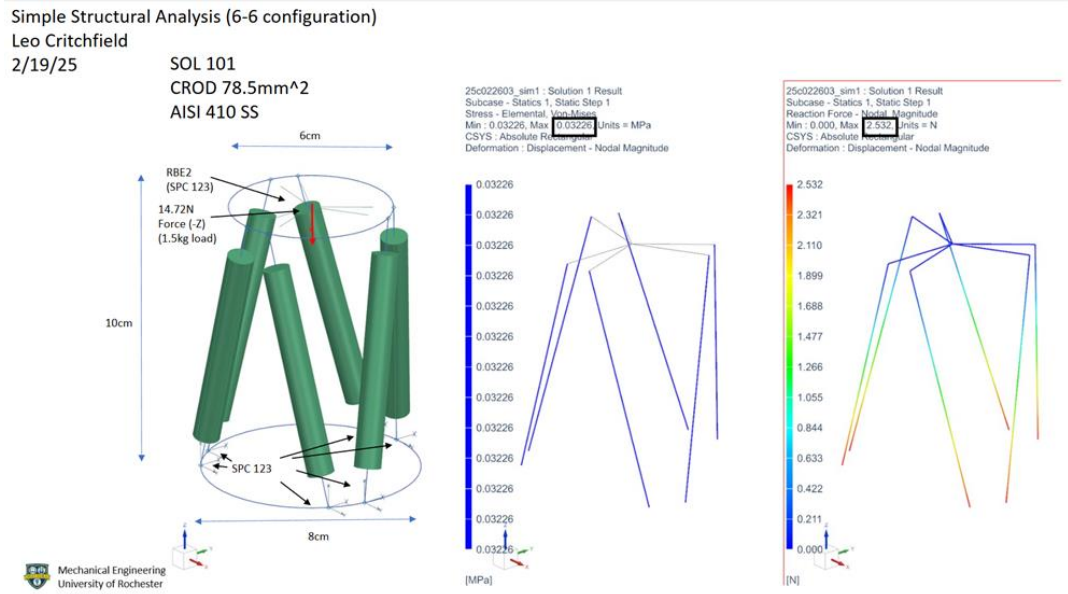
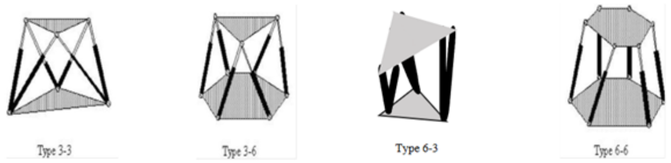


Figure 4. Structural analysis on NX of type 6-6 hexapod set up.



Criteria	Type 3-3	Type 3-6	Type 6-3	Type 6-6
Max Stress (Force Applied -X)	0.166 MPa	0.276 MPa	0.276 MPa	0.251 MPa
Percent Difference from Baseline	-33.9%	+9.96%	+9.96%	Baseline
Max Stress (Force Applied -Y)	0.1917 MPa	0.319 MPa	0.319 MPa	0.247 MPa
Percent Difference from Baseline	-22.4%	+29.1%	+29.1%	Baseline
Max Stress (Force Applied -Z)	0.03321 MPa	0.0306 MPa	0.03189 MPa	0.03226 MPa
Percent Difference from Baseline	+2.86%	-4.99%	-1.11%	Baseline
Total:	-53.44%	+34.07%	+37.95%	0

Note: Force Applied = 14.715 N (1.5 kg weight) , Max Force in Type 6-6: **19.7N** (BCS)

Table 1: Table of stresses experienced in the mechanical system in the different Stewart platform types.

To decide which type of hexapod set-up to use we ran an identical FEA structural analysis on each of the hexapod types. This analysis showed us the stress experienced through each of the actuators and would allow us to compare the results of the different set-ups.

Type 6-6 would be considerably the easiest to manufacture because each individual actuator connects to the top and bottom plates, whereas all the other types have actuators connecting to another actuator which makes for a much more difficult manufacturing process

Criteria	Type 3-3	Type 3-6	Type 6-3	Type 6-6
Workspace (Range of Motion)	0	0	0	Baseline
Stresses (previous slide)	+1	-1	-1	Baseline
Ease of Fabrication & Assembly	-1	-1	-1	Baseline
Cost	-1	-1	-1	Baseline
Total	**-1**	**-3**	**-3**	**0**

Table 2: Pugh matrix of the different Stewart Platform setup, focusing on the applications the mechanical system will experience.

As you can see from Table 3, the baseline type (6-6) is the recommendation based on Pugh matrix results. Although type 3-3 performs the best under load, type 6-6 performs well enough to meet our specifications and is easier to manufacture and assemble.

Current Project Status

	Height (base plate to motion plate with 50% actuator extension) *base CSYS*	Diameter (maximum including actuators)	Max Translation (net from base coordinate system)	Max Rotation (net from base coordinate system)	Max Force (lifted force in direction of actuation with highest gear ratio)	Max Speed (speed possible with lowest gear ratio and no load applied)	Stall Current (max current at 12V operation)	Electronic Control (type of microcontroller interface, position output is a plus)	Mass (per actuator)	Interference Likelihood (chance of actuator bodies colliding with movement) *to be tested*
P8 25mm Actuator	100mm	80mm	24mm (Z), 66mm (X,Y)	90deg (Z), 60deg (X,Y)	155N	30mm/s	450mA	External Position Controller	26g	Medium
L12 30mm Actuator	130mm	80mm	29mm (Z), 86mm (X,Y)	90deg (Z), 60deg (X,Y)	80N	25mm/s	246mA	Internal Position Controller w/ analog position output	34g	Low
P16 50mm Actuator	150mm	90mm	48mm (Z), 120mm (X,Y)	50deg (Z), 90deg (X,Y)	300N	46mm/s	1000mA	External Position Controller	95g	High

Table 3: Simulation of multiple actuators and their respective specifications with a focus on the requirements for this project.

Criteria	P8-R (25mm)	L12-I (30mm)	P16-R (50mm)
Height Parameters	Baseline	-1	-1
Diameter Parameters	Baseline	0	-1
Translation Specifications	Baseline	+1	+1
Rotation Specifications	Baseline	0	0
Max. Force	Baseline	-1	+1
Max. Speed	Baseline	-1	+1
Stall Current	Baseline	+1	-1
Electronic Control	Baseline	+1	0
Mass	Baseline	-1	-1
Actuator Interference Possibility	Baseline	+1	-1
Total	**0**	**+1**	**-2**

Table 4: Pugh matrix of three linear actuators of choice, based on the mechanism of a Stewart Platform.

Once the hexapod type (6-6) had been decided, a decision had to be made regarding which actuator model would be used for the project. There were three options: P8, L12 and P16. There was a trade-off between these actuators in meeting the translation specifications and breaking the space envelope specifications.

According to Table 5, The L12 (30mm) is the recommended actuator based on the Pugh matrix results. While the P8 does outperform in some categories, the L12's slim profile, translation values, stall current, and especially its position feedback make it the best choice.

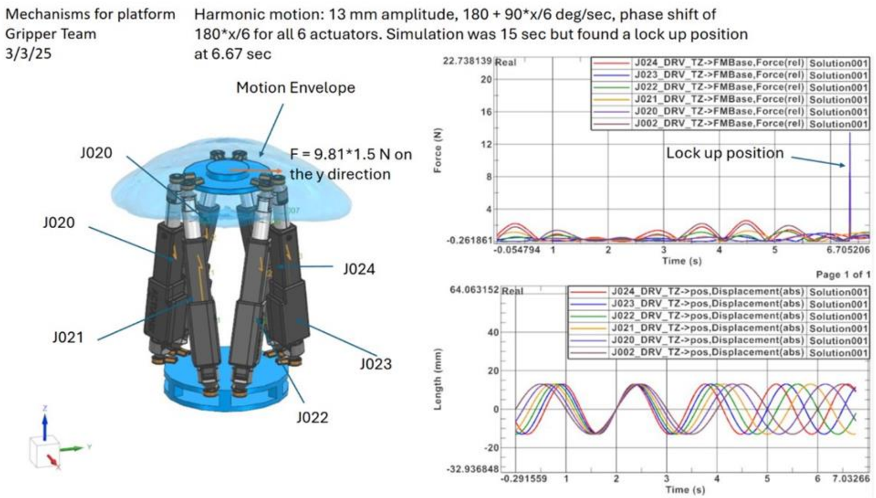


Figure 5:Mechanical simulation of the Stewart Strut and reactions on the base and actuators motion. Maximum reaction force spikes to ~14 N (lockup position).

Dynamic models of the L12 actuator were performed to inform the decision of which of three gear ratios to purchase. Higher ratios would be stronger but have slower movement and vice versa. In this model, the speed and phase of both changed together. And there was a lockup position with a peak force of ~14N. Due to this analysis, the fastest 50:1 L12 gear ratio was purchased because it can withstand up to 22N of force.

Current Project Status

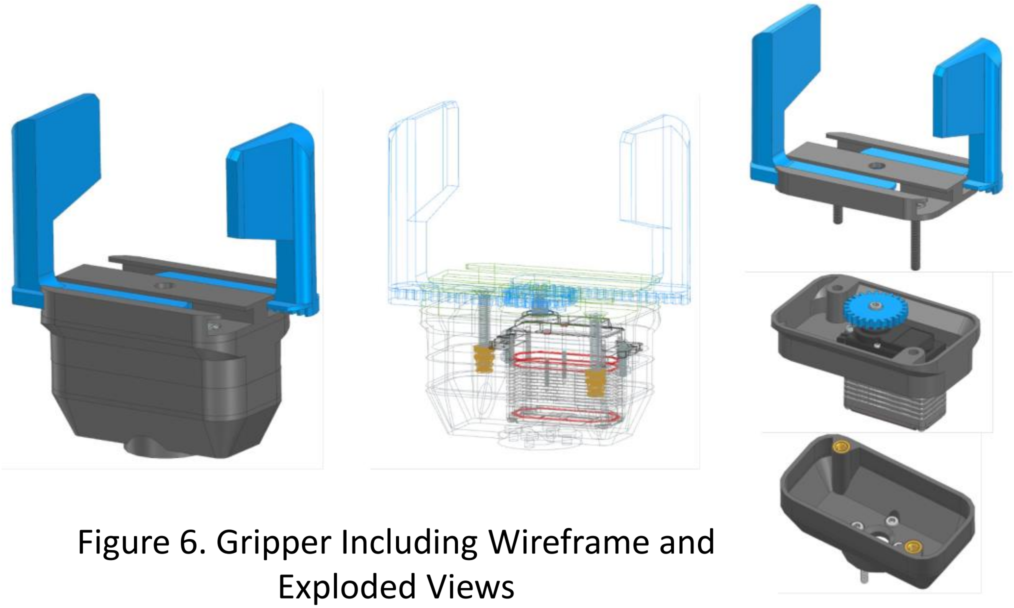


Figure 6. Gripper Including Wireframe and Exploded Views

Final CAD Design attributes:

- Modular removable 3D printed gripper
- Separated Sawyer and platform base plates
- Universal joints (fixed on base and free to rotate about top plate using with bushings and shoulder bolts)
- Custom actuator connectors (threaded top inserts and bottom connecting blocks)
- Base plate U-Joints risen with dowel pins and spacers for PCB clearance

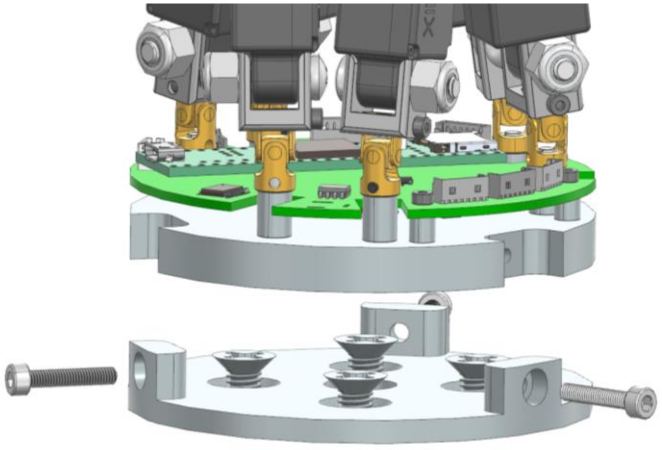


Figure 7. Platform Base w/ Exploded Views

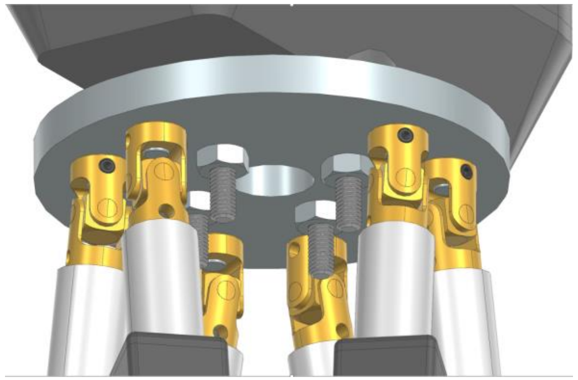


Figure 8. Platform Top Plate (below)

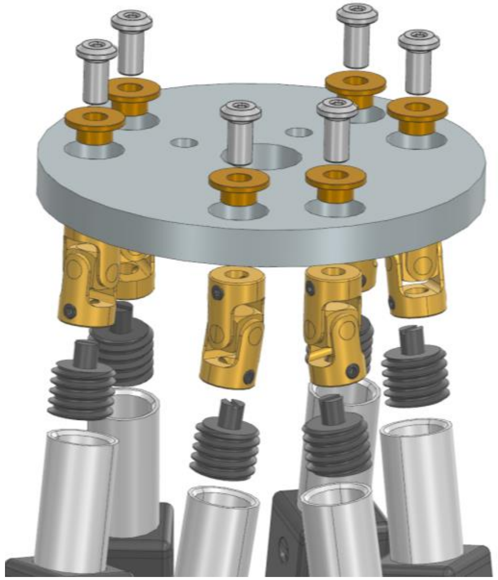


Figure 9. Platform Top Plate (exploded view)

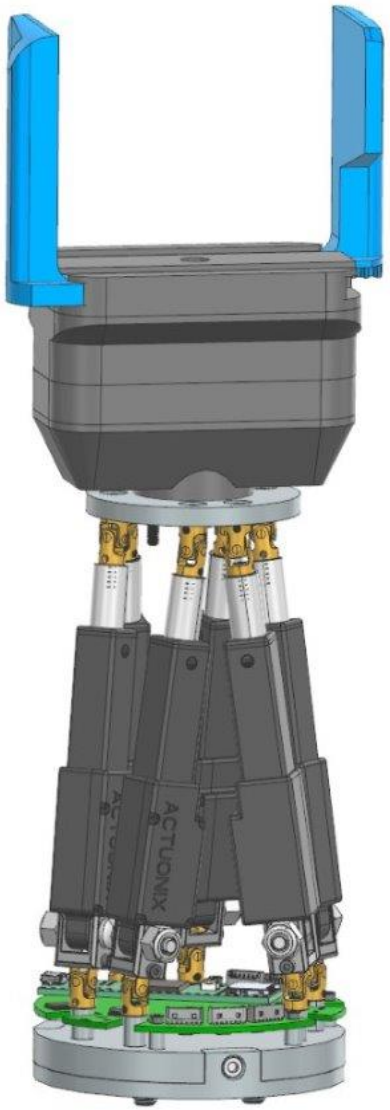


Figure 10. Complete Device

Current Project Status

Drawings

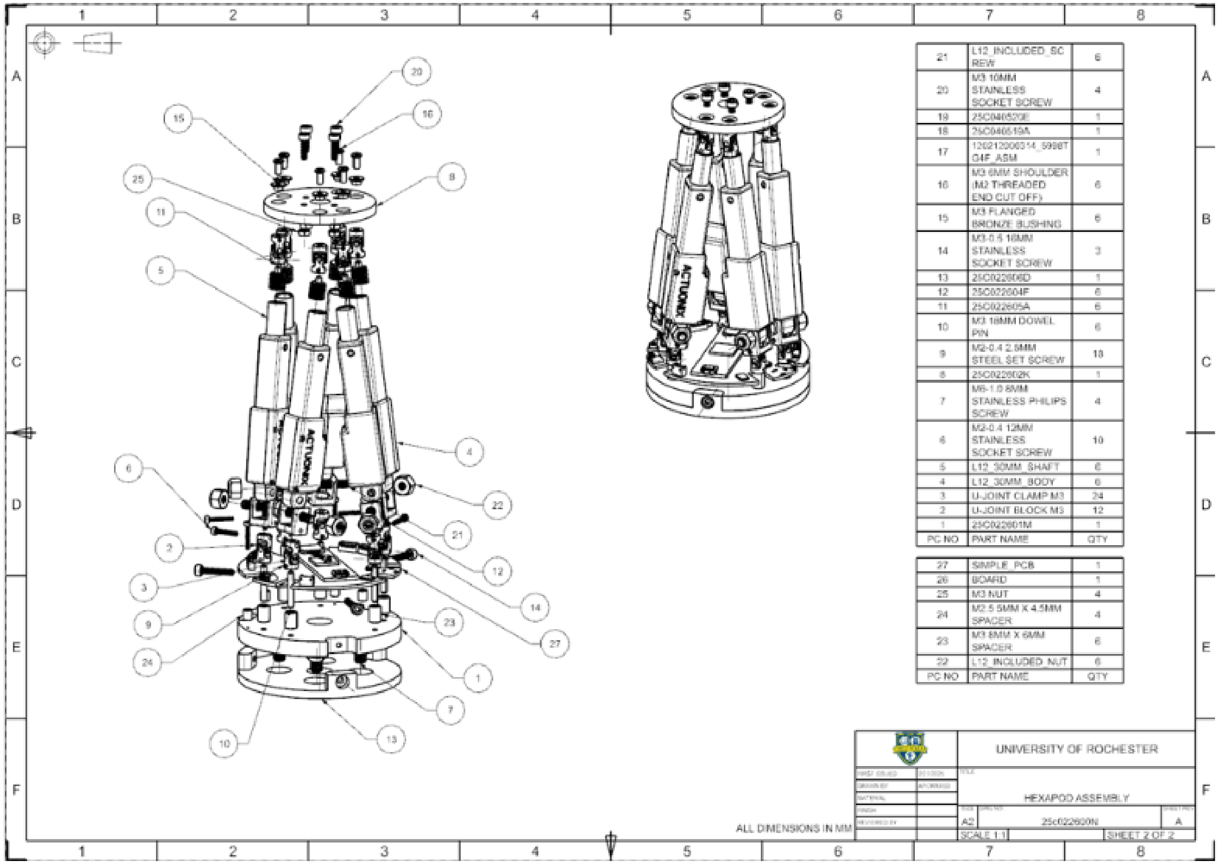


Figure 11. Platform Assembly Drawing

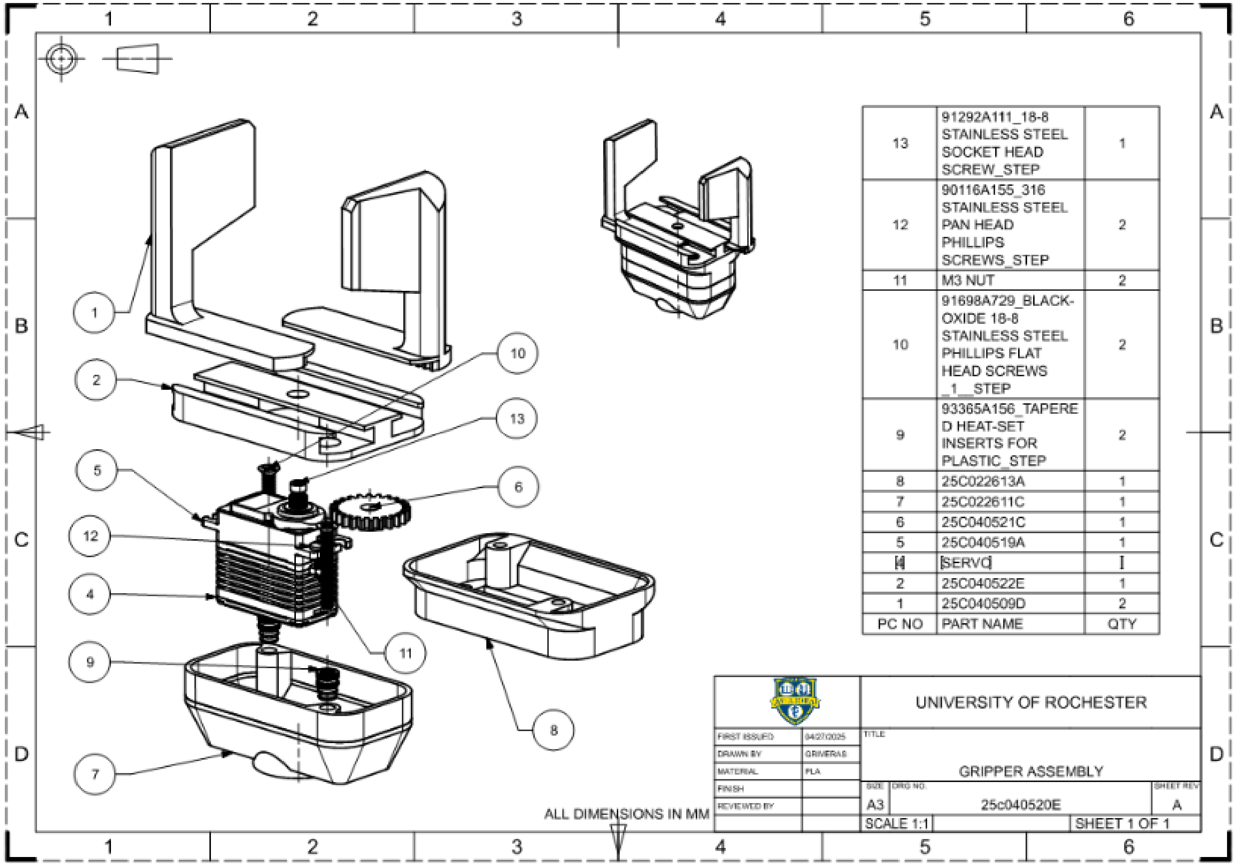


Figure 12. Gripper Assembly Drawing

Current Project Status

Although the electrical and computer team was responsible for controlling the Stewart platform, a simple control system was developed to collect preliminary test data. This system involved controlling each actuator using an Arduino and a power supply. A control code was created to operate the actuators through an interfacing linear potentiometer. The Quantum X FaroArm® located in Gavett 121 was used to scan the assembly and measure displacements relative to the base coordinate axis, ensuring accurate data collection. The system passed all the specifications.

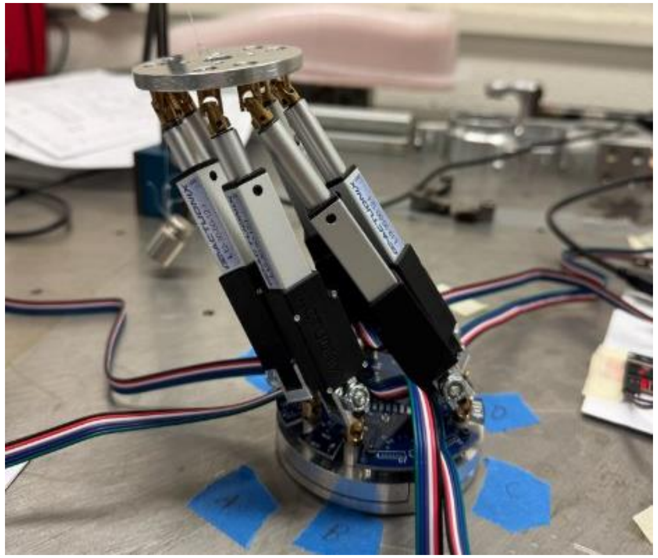


Figure 13. The system which has been translated in the x-direction during testing.

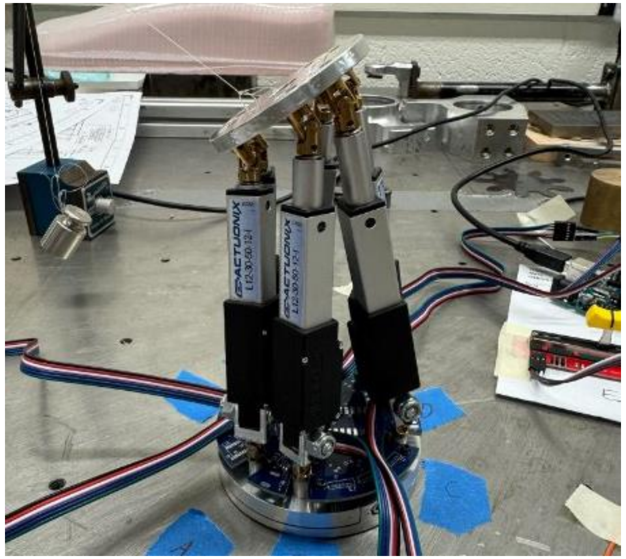


Figure 14. The system which has rotated about the x-axis during testing.

Figure 15. Final Assembled Device

Specification	Required	Tested	Pass/Fail
Minimum translation in the x, y, and z coordinates in the base frame.	3 cm	Z: 2.93 X: 4.3 Y: 4.1	PASS
Minimum rotation about x and y coordinate axis in the base frame.	30°	X: 33.1° Y: 38°	PASS
Minimum rotation about the z coordinate axis in the base frame.	15°	60.8°	PASS
Maximum device height.	15 cm	14.94 cm	PASS
Maximum device diameter.	8 cm	8 cm	PASS
Minimum payload to be held securely by the gripper.	0.5 kg	0.8 kg	PASS
Maximum mass of the whole assembly	2 kg	0.674 kg	PASS

Table 5. Test data obtained against specifications values.

Conclusions/Future Work

Future work

Design:

•Sawyer plate and bottom plate – Different method to connect and constrain the two plates

•Shell more of the material out to save weight

•Single piece base to reduce complexities and enhance strength

Manufacturing:

•Sawyer plate and bottom plate machined as an assembly to improve alignment of holes

•Universal Joints from scratch to reduce slack

•All pieces in the HAAS for faster manufacturing and repeatability, also improving alignment and orientation of actuators

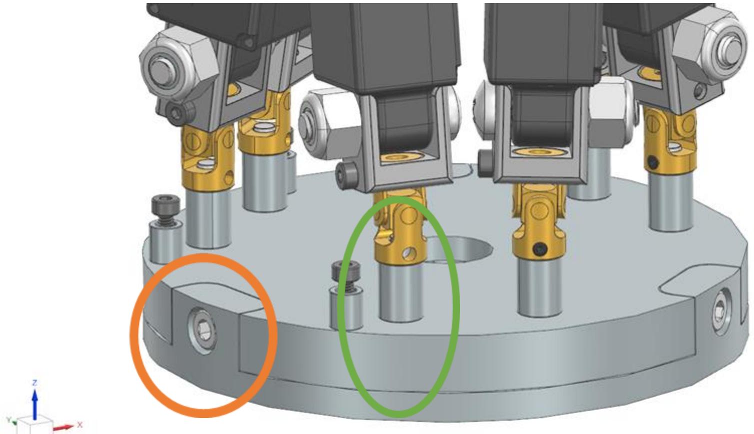


Figure 16. In green, it would be better if these were one piece of aluminum. In orange, a better solution to attach the plates could be found.

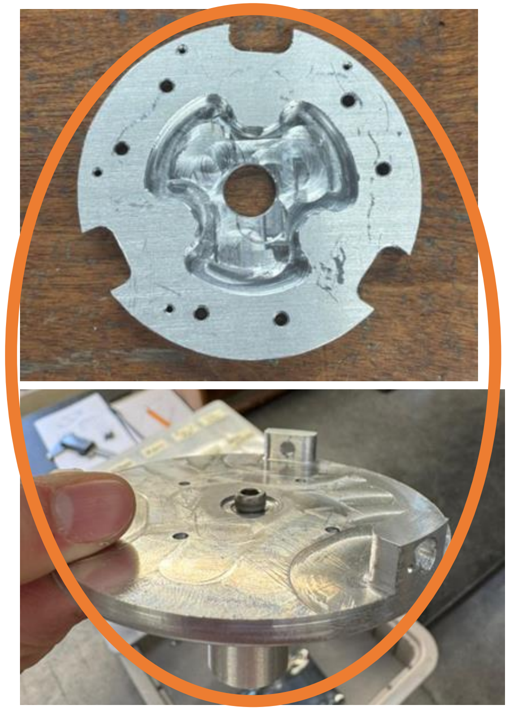


Figure 17. More material can be removed to save weight, and method of hole alignment could be improved.

Figure 18. The two base plates joined with the risers.

Acknowledgements

The team would like to thank our sponsor Professor Thomas Howard, as well as Professor Muir, Chris Pratt, Jim Alkins, Bill Mildenberger, Alex Prideaux and Samantha Kriegsman for all their support and guidance throughout the project.