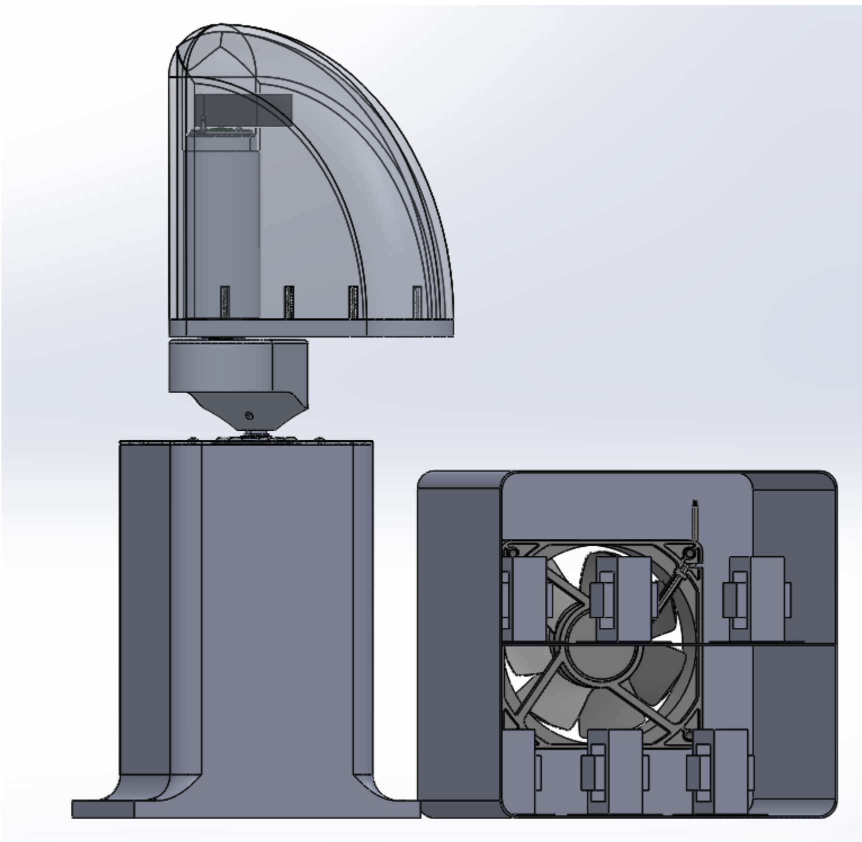
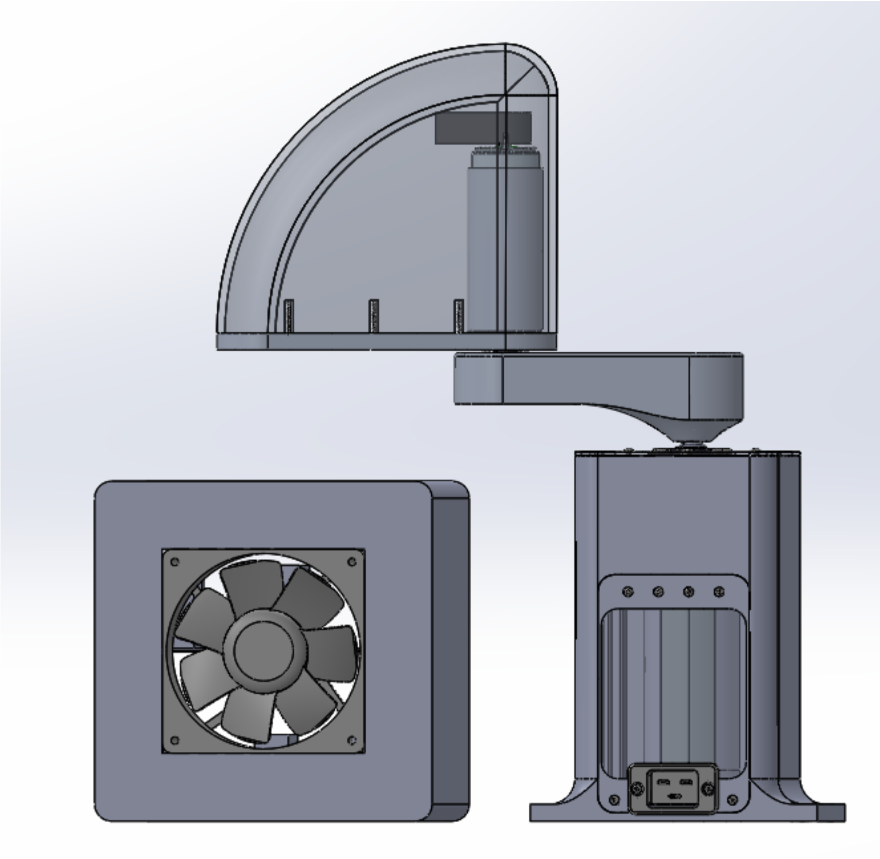
Night Rider's SCARA MECH report

Abstract: We describe the decisions taken for the mechanical design of the Night-Rider's SCARA robot. We also show how the structure is optimized for supporting a 3kg payload and having 2 degrees of freedom. We iterated our design by performing stress analysis and optimizing the arms to reduce weight while supporting stress.

Nomenclature

- Plastic deformation: deformation that permanently alters the shape of an object
- Elastic deformation: deformation that can be restored to initial shape after the force on the object is released
- Yield Strength: the stress point after which a part becomes permanently deformed (enters plastic deformation)
- Planetary gears: gear configuration where input and output shaft axis are aligned, with pinions and bull gear rotating analogous to the rotation of planets around a sun
- SolidWorks: CAD program used for designing mechanical parts using computers
- SimulationX: Simulation program for simulating the dynamics of our robot arm





You can notice on the right we cool our transformers with a cooling fan because they heat up

Mechanical design

RCGs

Requirements

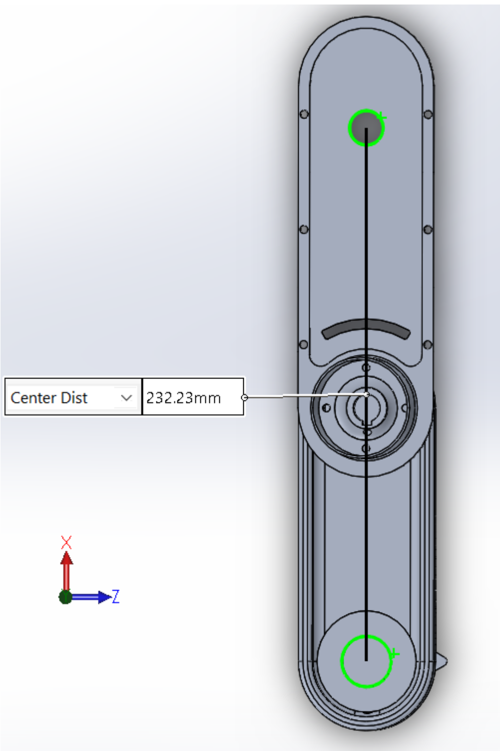
- Arm yield strength can withstand payload of 3 kg
- 2 Degrees of Freedom
- Uses precision drive system
- Power plug must be north american format

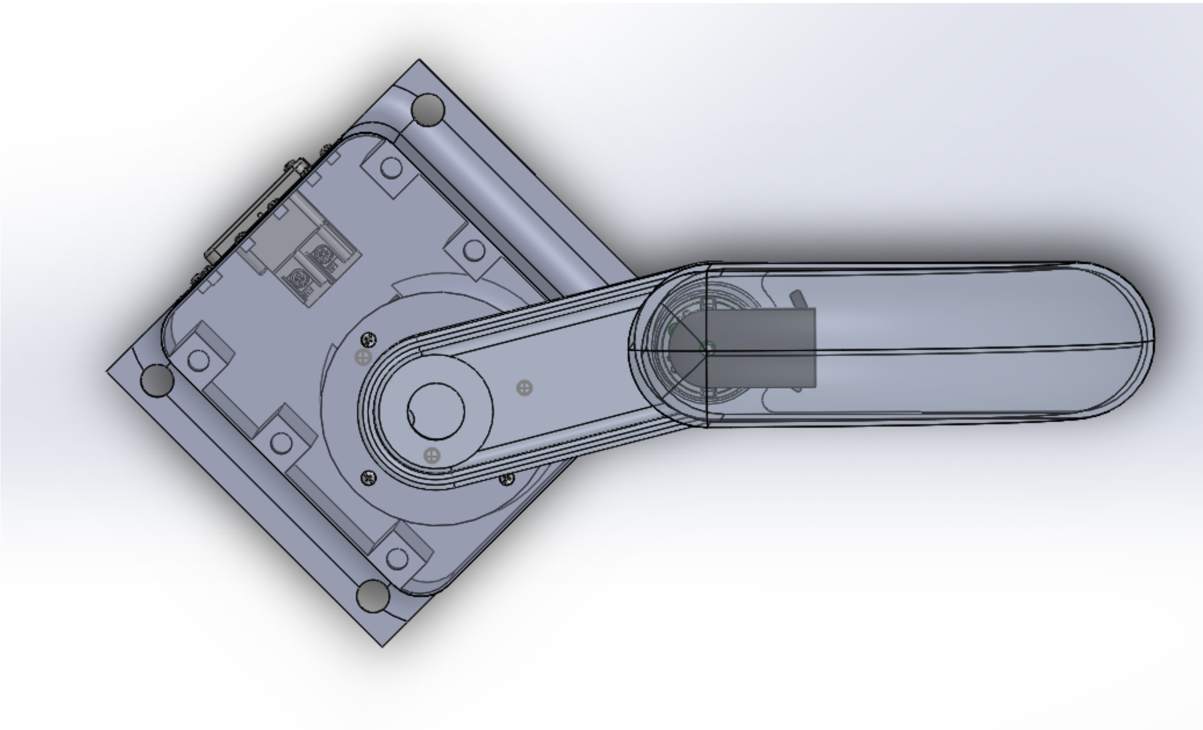
Constraints

- Arm reach must not be greater than 30 cm

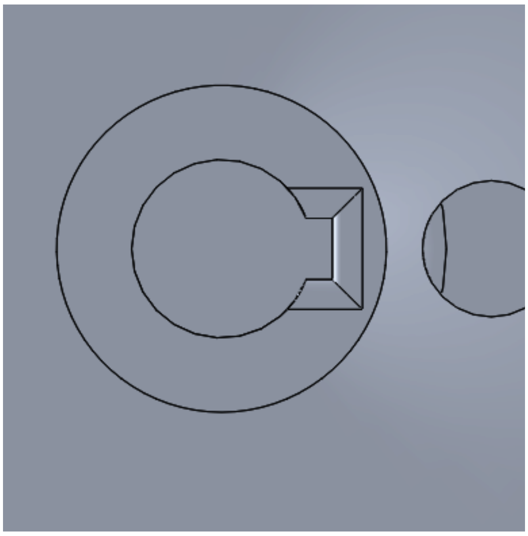
Goals

- Yield strength can withstand a force on first arm joint greater than 200N
- Arm's moment of inertia allows controller settling time less than one second
- End effector can reach similar speed to EPSON G3 250mm SCARA: 3,550 mm/sec





Structure: Support structure for shoulder joint

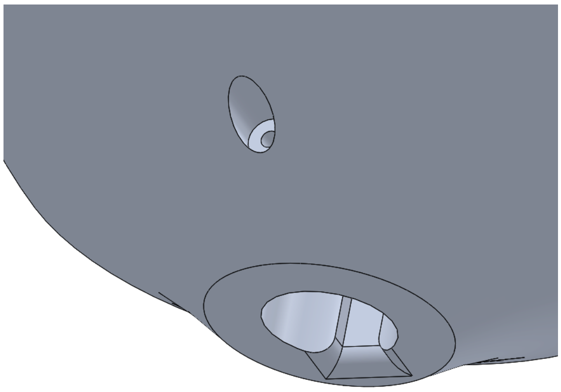


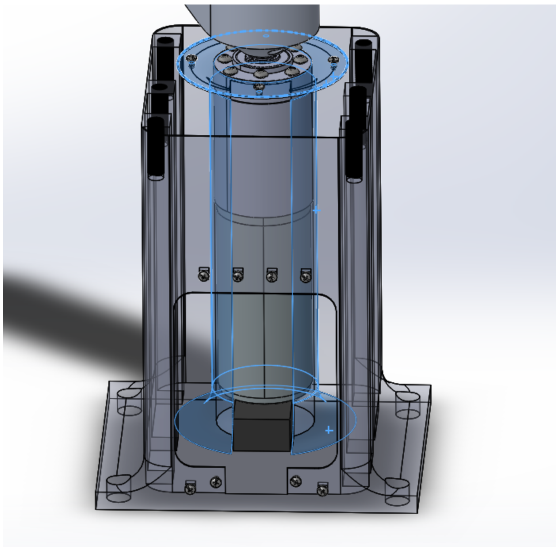
The shoulder arm joint is connected directly to the gear shaft in a lock and key style.

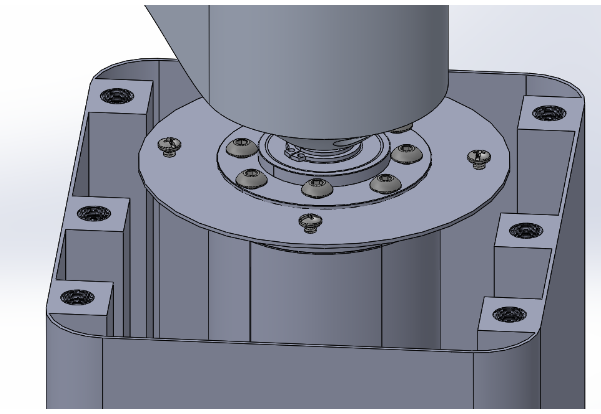
What supports the shoulder from tipping over is the structure that supports the gear and motor, highlighted in blue in the figure below. So our engineers made this support structure attached at the bottom to the base and screwed at the top to the base cover, preventing the gear and motor from tipping over with the arm.

Furthermore, filets ensure that the shoulder joint can support greater torque.

A screw can fasten the connection of the gear shaft to the shoulder joint.

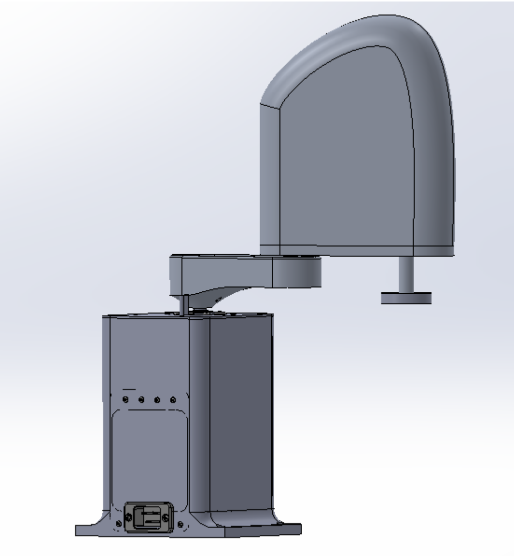




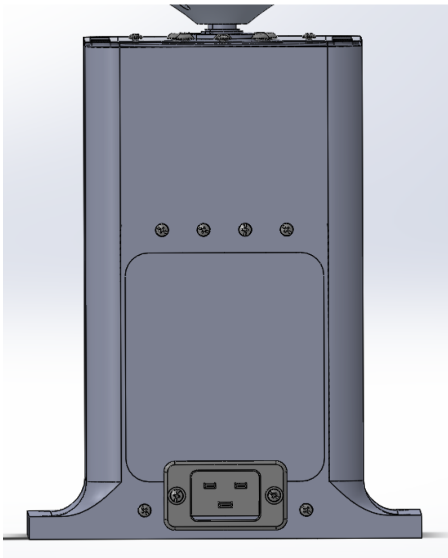


Covers: Base and arms, professional appearance

The cover for base and arms are smoothened at the edges for a professional appearance, and do not leave wires hanging out of the robot.

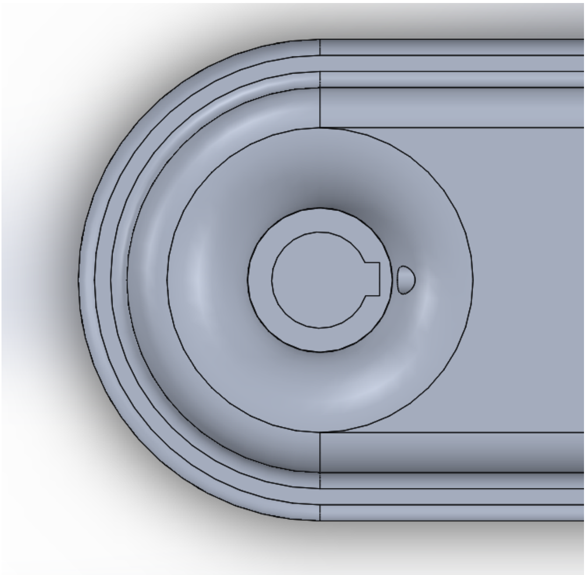


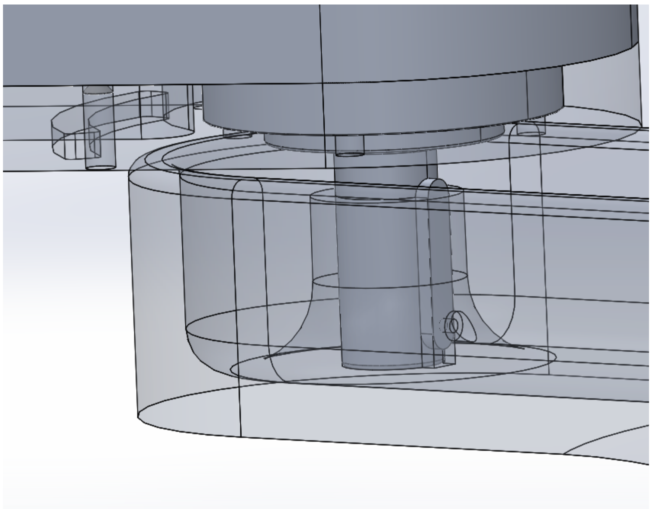
The covers were made under measures of the parts they are attached to, fitting well to the arms and base without sticking out at the edges.



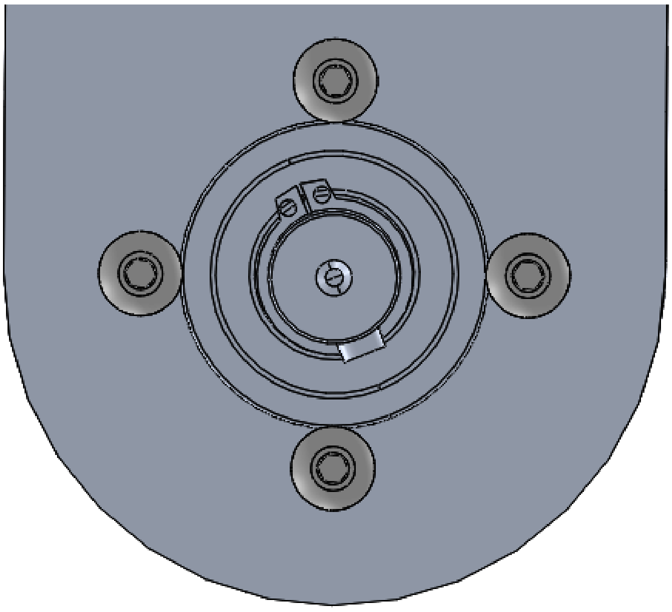
Interfaces: Shaft connections, parts, robot mount

The shaft connections were made to measure to fit the Maxon motors selected. The shafts are fastened with a screw to prevent motion up or down. Furthermore, we engineered the shoulder joints with filets to increase the resistance of the parts.





The elbow gear head is screwed to the second arm to prevent rotational motion from its momentum. The shoulder gear head is screwed to the base top cover and the motor support structure as shown in the previous section (the component highlighted in blue).



Components: appropriate choices, integrated into SW assemblies

Shoulder motor selection
The motor used on the shoulder is a Maxon RE 50 DC Brushed DC motor of 200 Watts. The wattage was selected based on our competitor robot, EPSON G3 250.

Shoulder gear selection
This shoulder motor is connected to a MAXON planetary gearhead of model GP 52C with a reduction ratio of 26:1. This gear is compatible with the motor chosen based on Maxon's online combination tool. The gear reduction ratio needed was calculated by looking at the maximum speed of the end-effector of our competitor robot (3550 mm/sec) and determining which speed the shoulder joint had to spin at to reach that speed. Based on the shoulder joint speed and the speed of the motor we picked, we found which gear ratio would reduce the motor speed to the desired shoulder speed. Secondly we looked at whether the gear shaft could support enough torque to support the weight of the arm. The number that tells this information is the radial load in the gear's datasheet. (refer to figure in Appendix)
Gear ratio Calculations

Radial load at shoulder gear: 0.25 meters * (3kg payload + 2kg arm weight) * 9.8 m/s^2
= 12.25 N*m

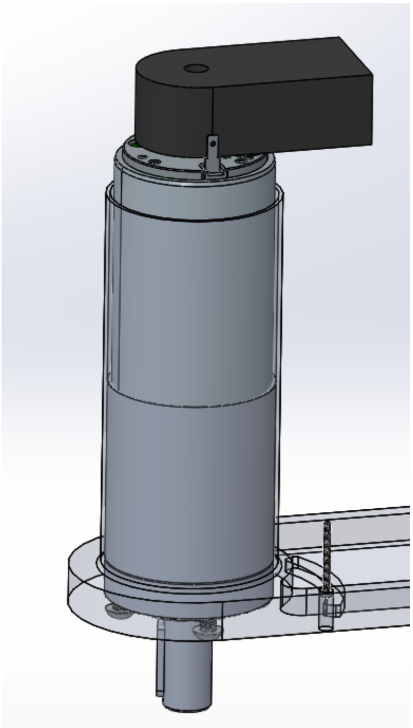
Meanwhile our Maxon gear supports 630N of axial load.

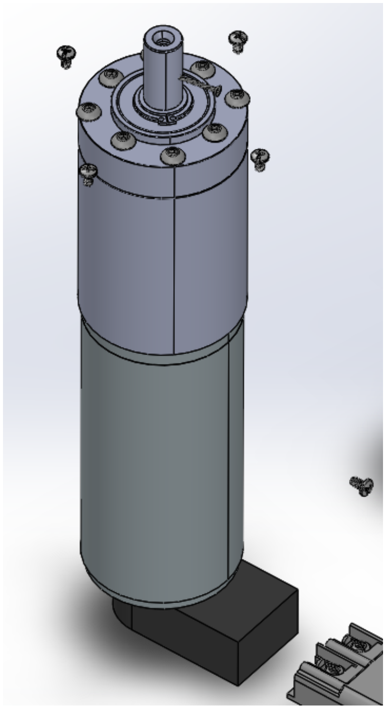
Elbow motor selection

The motor used on the elbow is a Maxon RE 40 Brushed DC motor of 150 Watts. This wattage was selected based on our competitor robot's elbow motor.

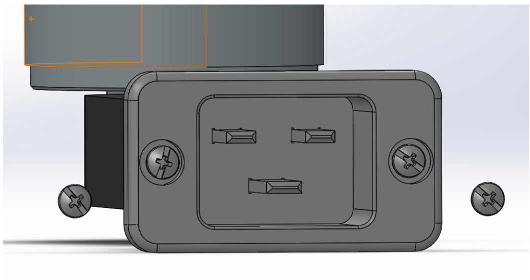
Elbow gear selection

The elbow gear is a compatible planetary gearhead to the elbow motor, model GP 42C. The gear ratio of 12:1 was selected to prioritize speed over torque, since the distance to the end effector is smaller from the elbow than from the shoulder, and the torque seen by the elbow motor is also smaller than the shoulder motor.



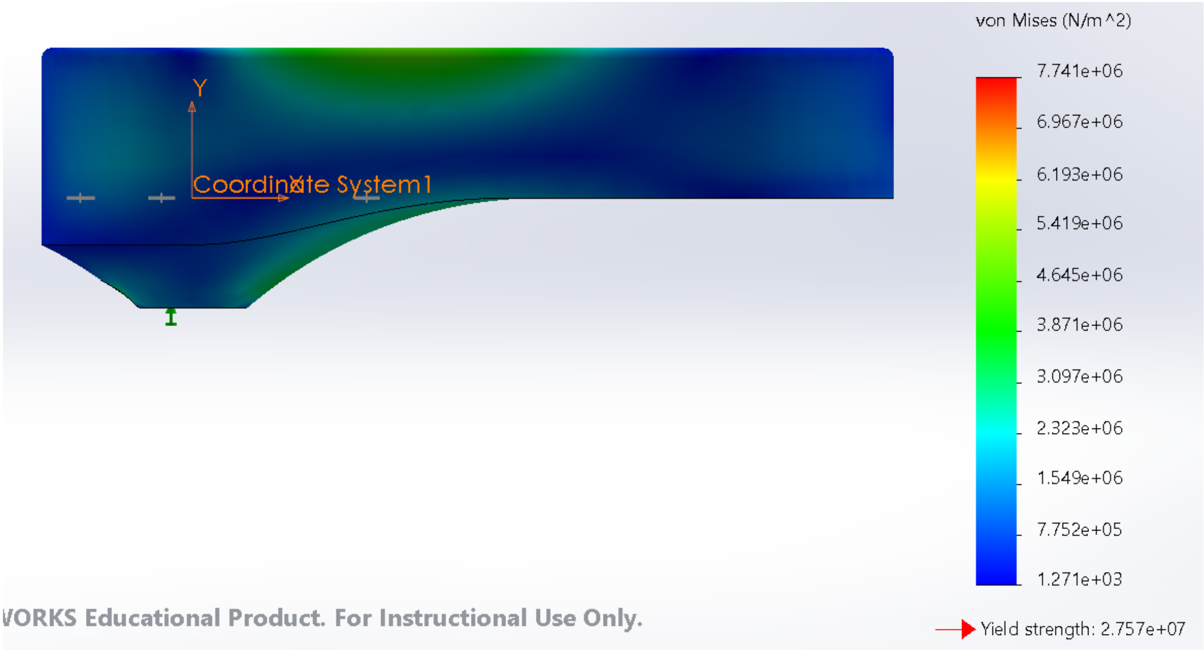


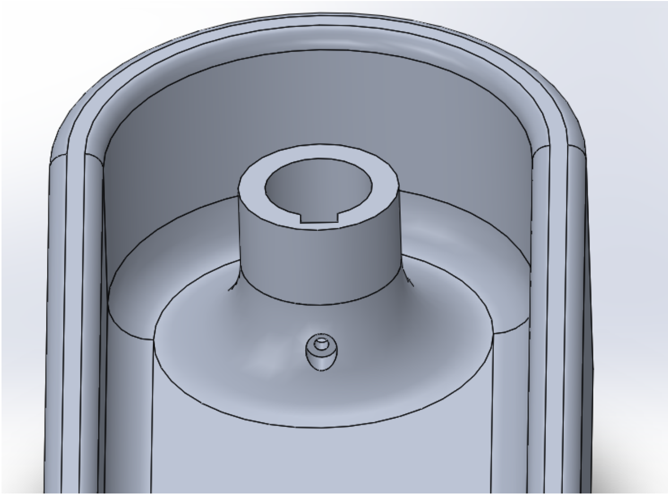
We chose a standard power plug connector for using the SCARA robot in North America.



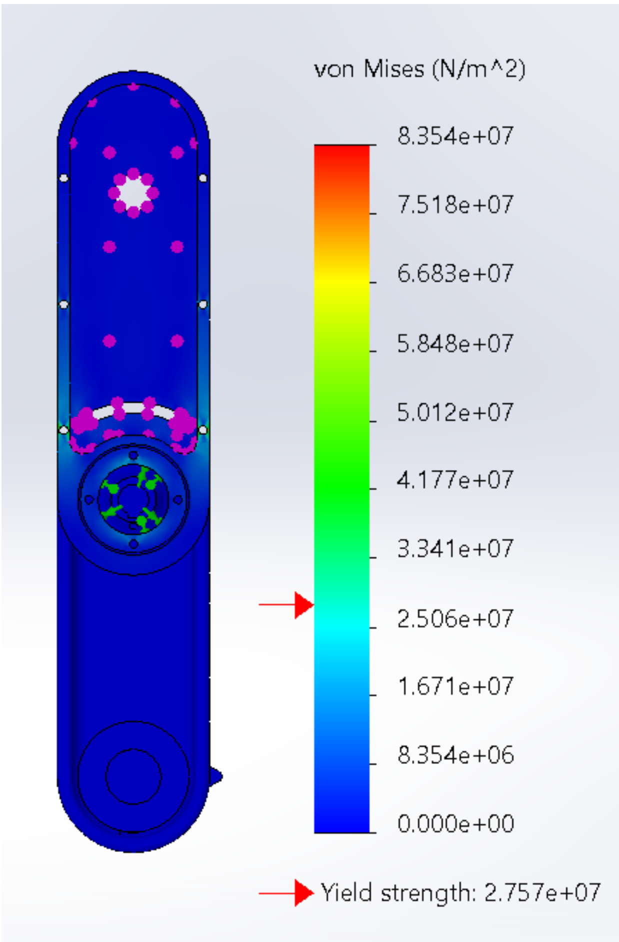
Stress and Strain: optimized geometry to satisfy RCGs

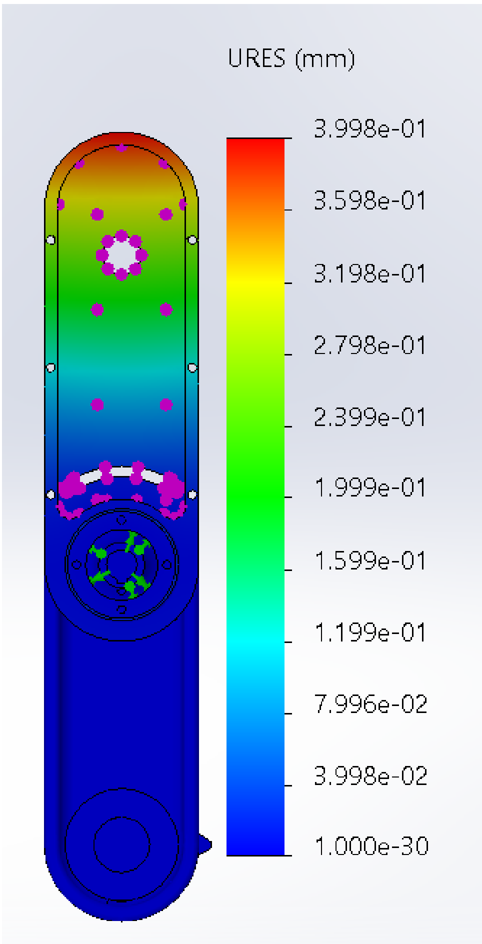
We optimized the first arm through iterations of stress analysis. We increased the strength by adding more mass to the locations bearing most stress (connection of shoulder joint to shaft) and less mass to the parts bearing less stress (inner center of the arm). As you can notice the shoulder joint connection is bulkier than the rest of the arm, and the inner part of the arm is hollow.





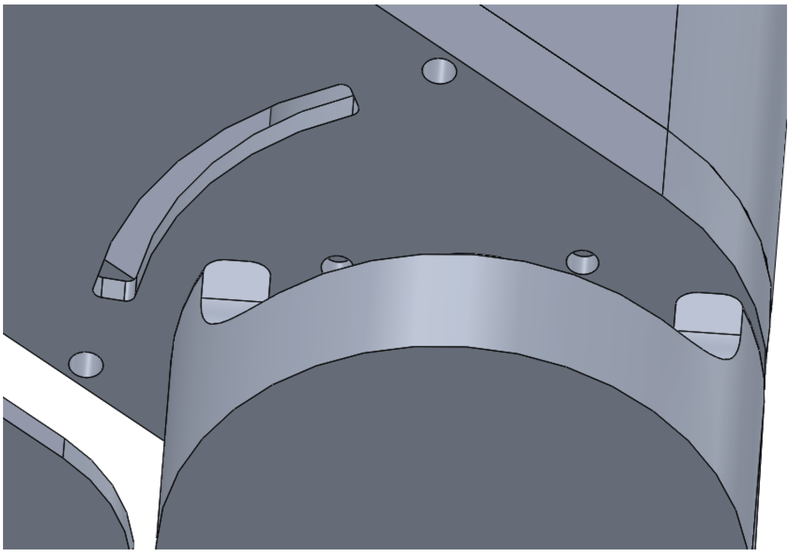
Furthermore, for the elbow joint, a 1 cm filet was added. For the second arm, we observed how much displacement the arm observes with a full payload of 3 kilos (30 Newtons applied at the arm), and the arm displaces less than 0.4 mm and does not reach the yield strength, which means it does not deform permanently (plastically), only elastically.



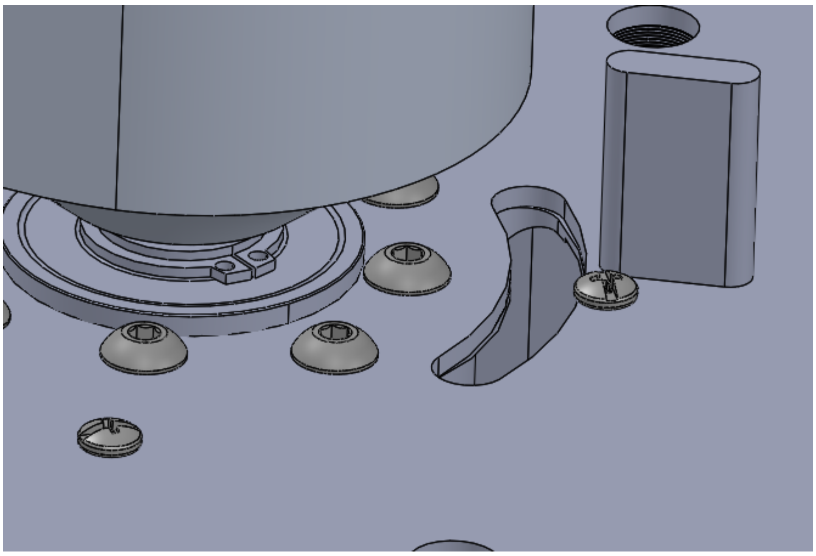


Cable routing: Features for mounting PCBs and cable routing

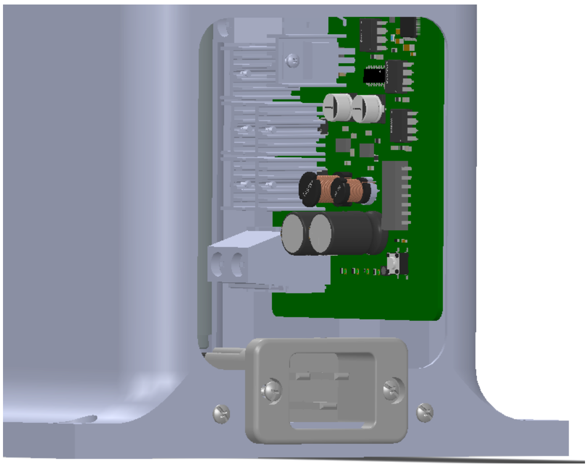
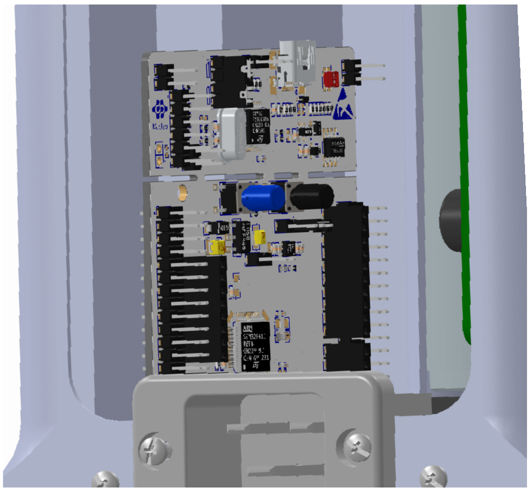
The cables are routed through the arm for a sleeker profile, and to ensure that the wires don't bend and break a slip ring is attached to the shoulder joint.



As you can see in the photos, we opened a U shaped hole at the bottom of the second arm and at the base for the wires to have some degree of freedom along the axis of rotation of the arm.



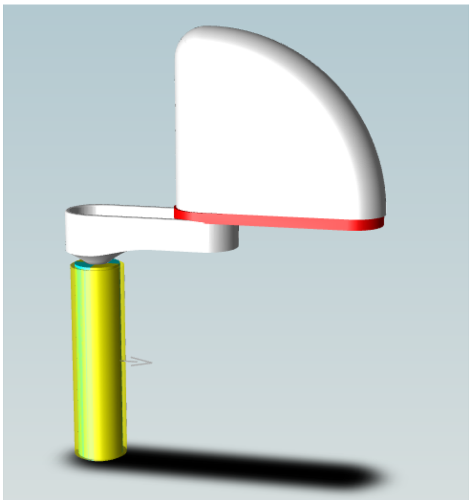
The high speed circuits for controlling the motors of the arm are placed inside the base so there is less time lag from shorter wires.

Assembly: Explosions and animations

You can watch an our full system working in simulationX clicking on this link
https://drive.google.com/file/d/1tKTDrCV6O7NEpdfUg66d5g7_XuLA9ePx/view?usp=s
You can also refer to our presentation for watching animations of two degrees of freedom in the first slides.
ttps://docs.google.com/presentation/d/1n3kAJIo56TWgJce3XFhBPlkxVRpuw0DutWY2NJ6HnE4/edit?usp=sharing

SimulationX



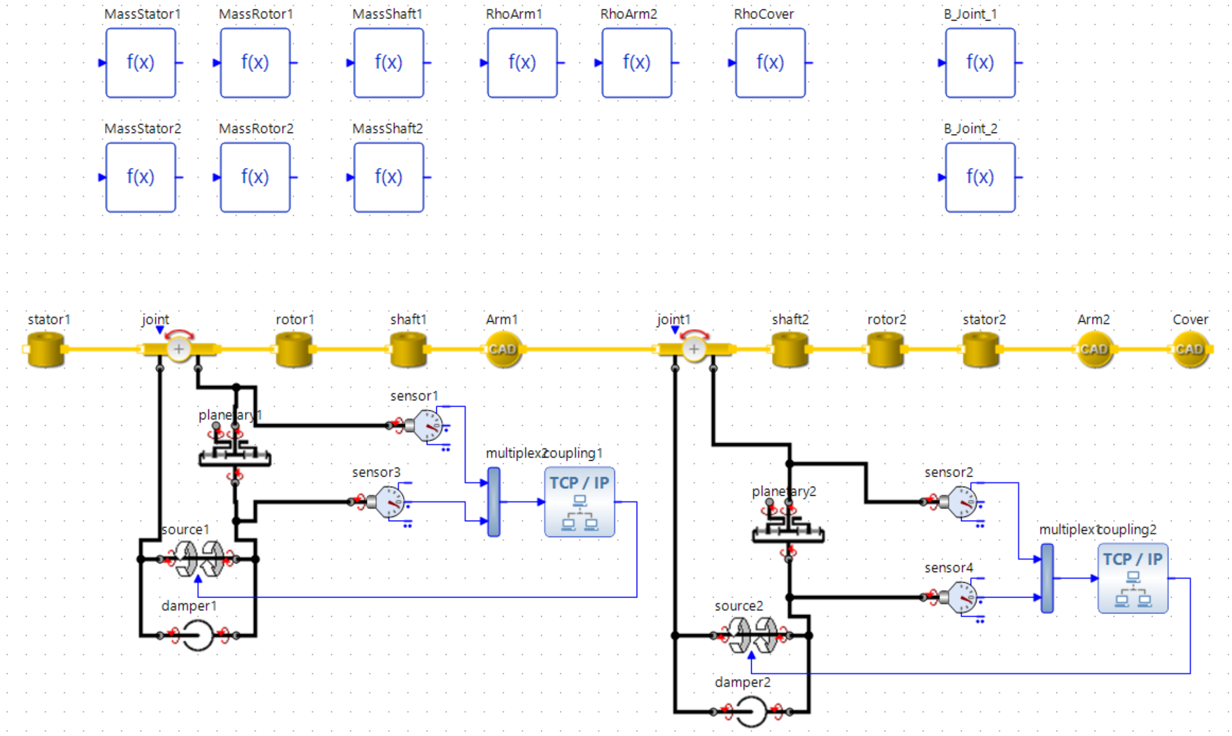
RCGs

Requirement

- Use moment of inertia and mass information from motor datasheet
- Use parameters for easily changing mass properties of arm and cover
- Connect with simulink through TCP/IP block

Goal

- Include both arms and cover CAD models for simulating realistic moments of inertia



Complete: all inertias, frictions, accurate parts, materials

Arm one

motor friction calculation = torque constant * no load current / (2*pi / 60 * no_load_speed) = 0.00001611607955 Nm*seconds

gear friction calculation Bgear*omega^2 / (total_power) = 1 - efficiency*80%

- 1 - efficiency represents the percent power lost
- the 80% multiplying efficiency is to add extra friction to datasheet efficiency number

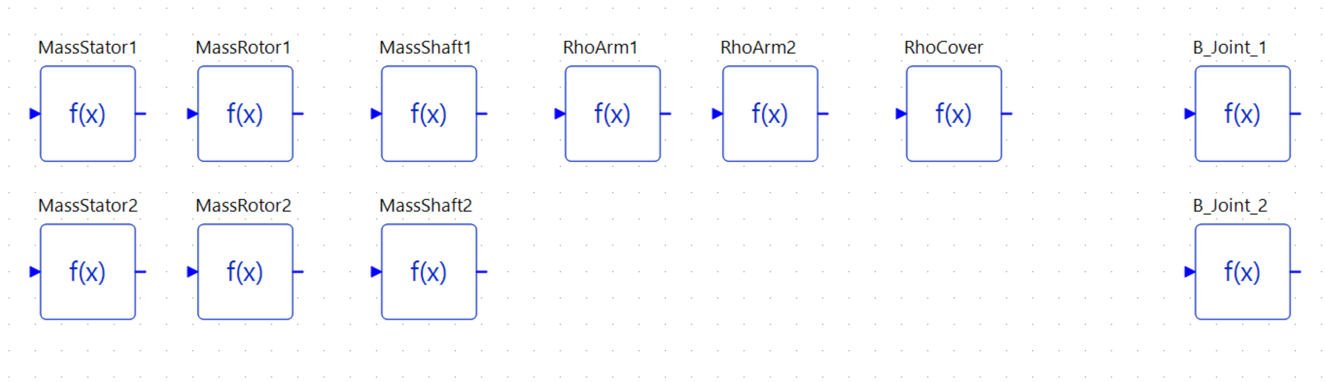
Therefore B gear = (1 - efficiency*80%)*max_continuous_power / (no_load_speed * 2*pi/60) = 0.0003067 Newton*meter*second

Organization: Clear layout, visual adjustments

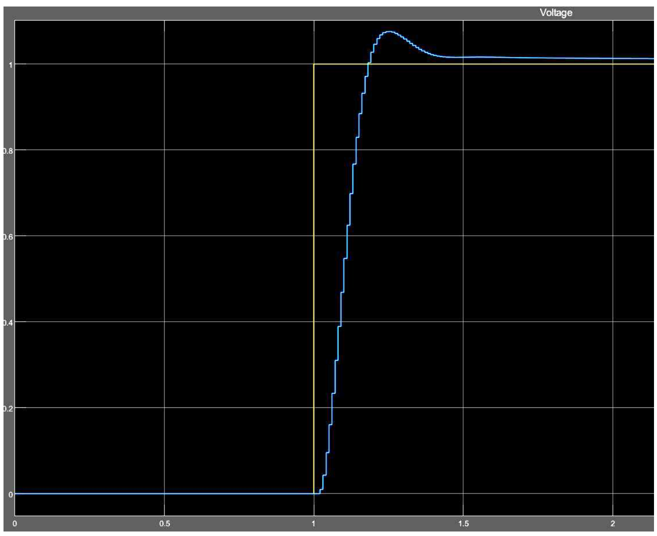
The model in SimulationX is organized into a left and a right system. The left is the shoulder motor and first arm, and the right is the elbow motor and second arm with cover.

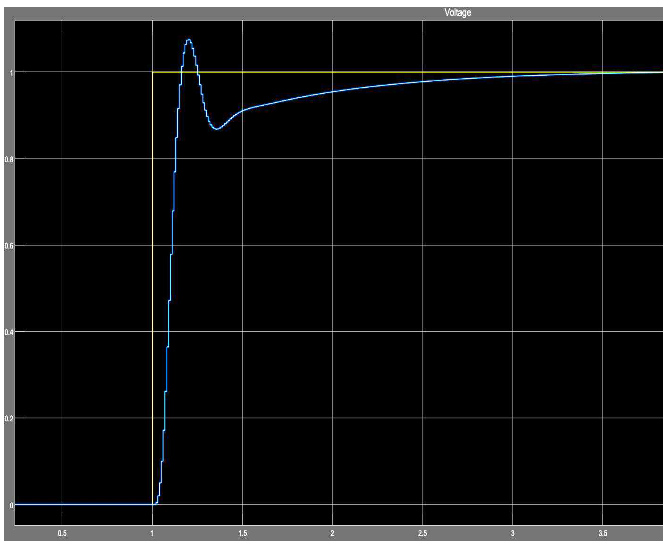
Adjustability: external parameters, references

We used function blocks to increase adjustability of the SimulationX model. This allows us to change the mass density of our parts to quickly test the effect of having a different material in the dynamics of our model.



Results: simulation outputs, verify RCGs, saturation and non-linearity avoided





Sensitivity: effect of bearing wear and damage on performance

In our function blocks to adjust model parameters, we can change the friction of bearings to quickly simulate the effect of bearing wear on the system performance.

Application

RCGs

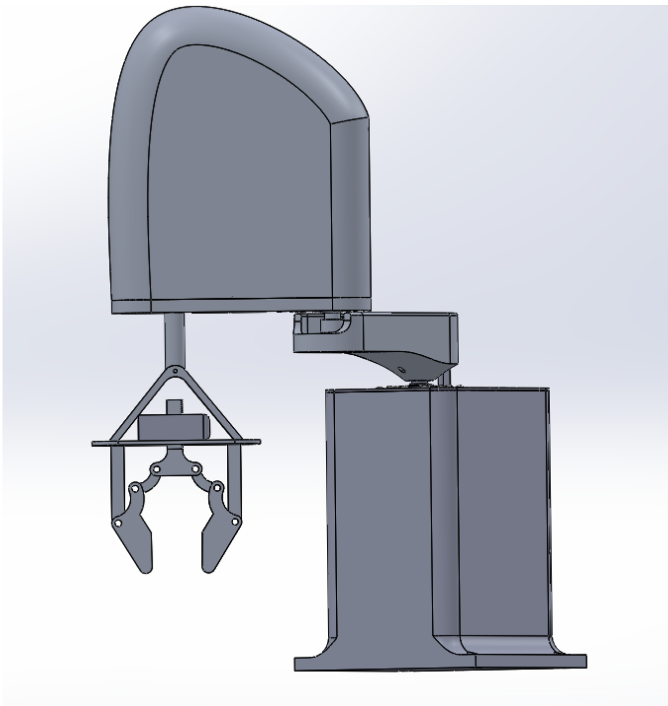
Requirements

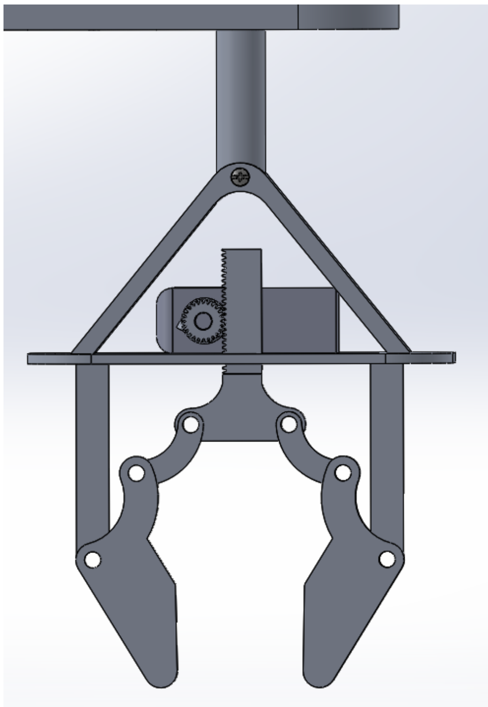
- Pick and place

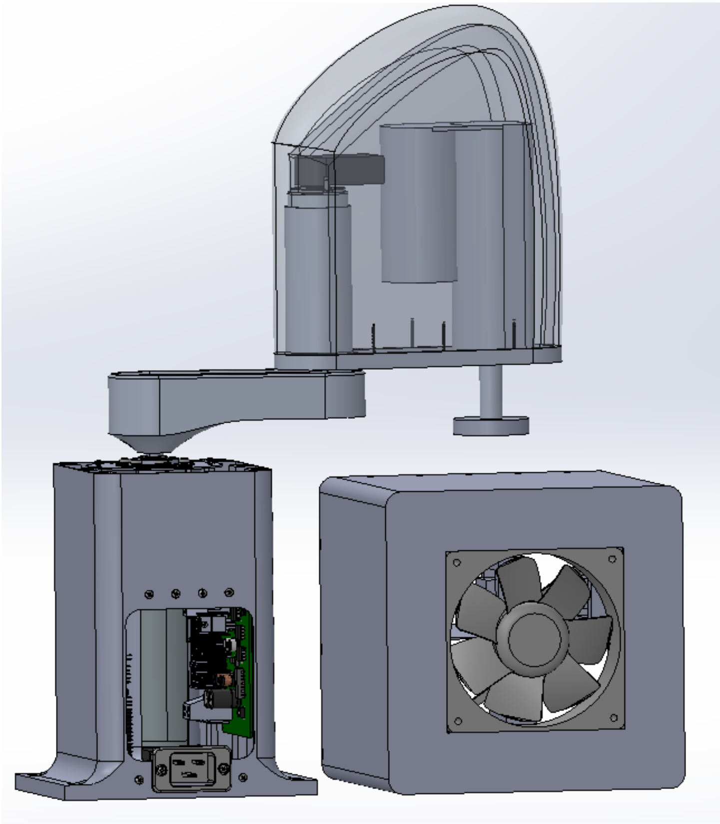
Goals

- Have an electromagnet and a gripper attachment

Special features: application specific physical features







Efficacy: satisfied RCGs

We satisfied the 2 degrees of freedom requirement, as can be seen in this animation: https://drive.google.com/file/d/1TTBixLRsF5C49UdPJaT79G3jAvJWmKQo/view?usp=sharing and the full system animation in SimulatioX
https://drive.google.com/file/d/1tKTDrCV6O7NEpdfUg66d5g7_XuLA9ePx/view?usp=s

Cost: trade-offs, materials, components

The material at the base and arms of the motor is 1080 Alloy, which is to increase the strength of these parts since they fulfill a structural purpose. The cover for the second arm is made of plastic, to reduce weight and increase ease of manufacturing.

One tradeoff that we made was minimizing weight at the arms while maintaining strength by making a complex geometry but this will come at a greater cost of manufacturing.

Bill of materials

- Maxon motor for shoulder
- Maxon motor for elbow
- Maxon gear for shoulder

- Maxon gear for elbow
- Encoder for motor 1
- Encoder for motor 2
- Alloy 1008 cost
- Manufacturing costs
- PCB costs

Appendix

- Drawings
- Circuits
- Mathematics
- Excerpts (1 page from data sheet)

References

https://www.maxongroup.com/maxon/view/content/index
Bearing radial and axial load diagram
https://www.bearingtips.com/wp-content/uploads/2017/06/SKF-loads-diagram.jpg