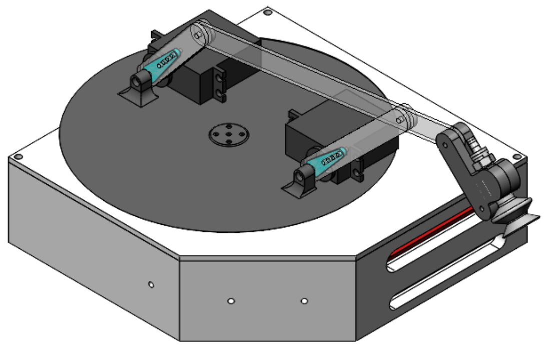

Object Sorter - R.O.D.G.E.

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Mechanical Engineering 154 Mechanical Engineering Design

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Background Information:

Our problem is to sort a set of objects based on their physical attributes. Many industries require the sorting of items based on different variables such as geometry, color, and size. Take for example the sorting of medical capsules or juice boxes with different flavors. These are commodities that run through a conveyor belt in large numbers for long durations, and thus, considering modern technology, having people manually sort these objects is a waste of time and resources, as using a robot would be more efficient, cost-effective, and accurate, and would negate any risk of injury. Automation would be insufficient for the purposes of this application as these objects have unique colors, geometries, and other physical characteristics. Accurately sorting a random set of objects requires a kind of logical reasoning similar to that of a human. This functionality can be achieved with the addition of sensors, commanding the information from those sensors with logical statements, and having a concise set of robot arms for efficient movement.

Task Assignment:

Our proposed solution is to design and manufacture a grabber arm robot that can sort objects by color and weight. There are three separate color parameters and two separate weight parameters. The user gets to input which metric they'd like to sort by. All in all, there will be 4 bins- 1 of them will be an unsorted pile, while the rest will be empty bins into which the robot will sort a subset of objects based on color and weight. The color sorting is done using the input from an RGB sensor, while mass sorting is done using the input from a pressure pad. Once the sorting has been completed, as indicated by an unengaged limit switch, the robot shall await new instructions while in standby mode.

We have a servo at the base of the robot to rotate the entire mechanism and another servo connected to the four-bar linkage's crank's joint; The joint servo will allow the fore-and-aft and top-to-down motion of the robot. The base servo will add a revolute joint to the four-bar linkage's end, enabling the rotation of the link directly connecting to the picker. The last actuator is an air/vacuum pump that controls the suction mechanism of the robot picker.

Motivation:

When conceptualizing the product, we were inspired by articulated robots. These robots have only rotary/spherical joints and usually have 6 or more axes of freedom. While we aren't planning to use any spherical joints, all our joints are revolute. These robots are used for applications such as spot welding, cutting, dispensing, inspecting, etc.; Basically, high-precision jobs. So, we wanted to design a product that not only had a decision matrix, in a sense, but a smooth, well-calibrated flow of movement.

List of Specifications and Requirements

- 4-bar Linkage
- Double-rocker - motor actuated w/ 2 DOF
- User age >= 12 years
- Lifespan > 3 months
- Easy to manufacture and source materials
- Simple to operate

- Sort objects accurately based on set parameters (color and weight)
- The base must rotate <=180 deg
- The picker must hold on to the object for the duration of sporting action
- The system must detect when sorting has been completed
- The system must be safe
- The system must sort in a timely manner
- The system must be easily portable
- The system must be built in an organized manner for serviceability

Conceptual design and sketches

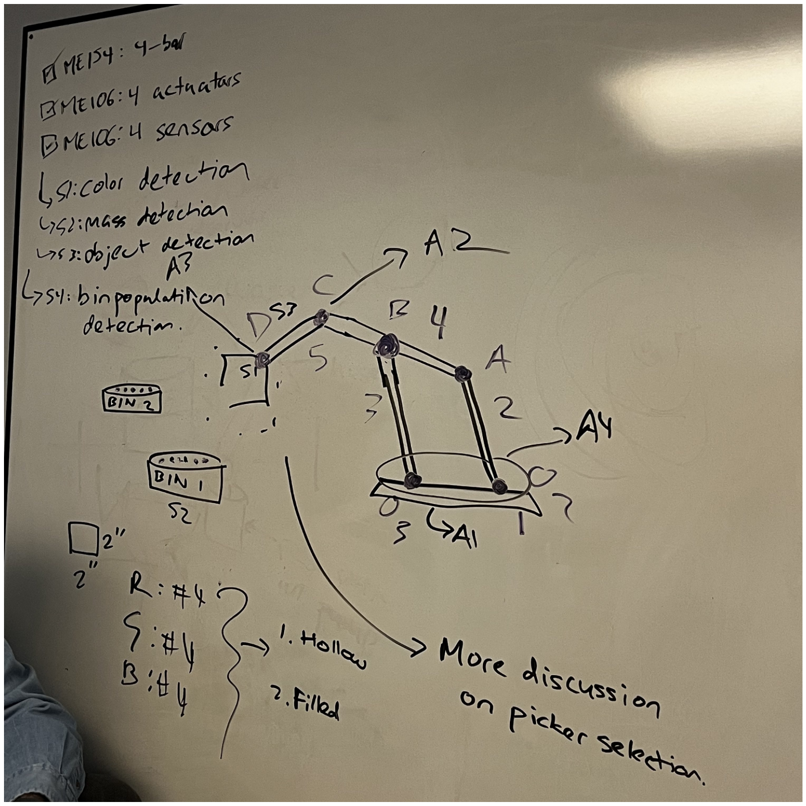


Figure 1. Prototyping and discussion of initial ideas.

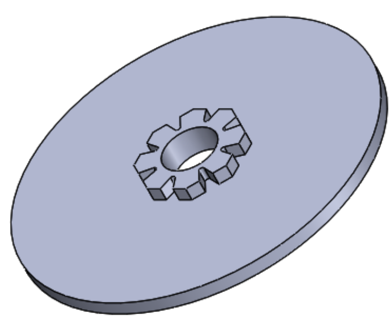


Figure 2. Concept Design of Rotating Base Plate

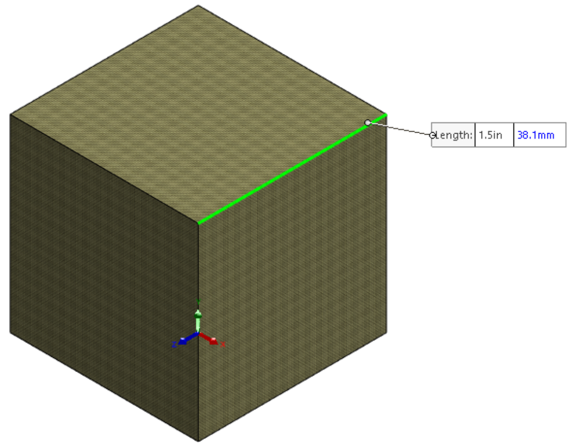


Figure 3. Prototype Cube Design

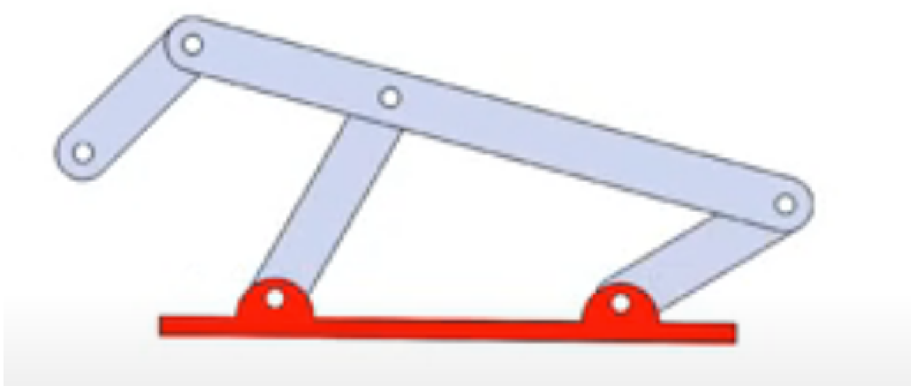


Figure 4. Prototype Mock-up of Four Bar

Introduction:

Four Bar Design

For our design, we chose a rocker mechanism with a coupler output with a fixed base and a servo actuating the whole mechanism between two positions. Those positions are the standby position and the grabbing position. During standby, the mechanism is to wait for a command and is retracted until it is in the presence of a cube on the unsorted ramp or until it is releasing a cube into the sorted bins. When in standby mode it will be traveling with the cube attached to it until it reaches a bin location. When in the grabbing position, the robot is to acquire the cube up and then drop the cube through the means of the vacuum pump.

Housing Unit & Sorting Bins

The initial constraints of the housing and sorting bins were based on the scale of the four-bar design and the total size of the entire assembly. The overall assembly is designed to be portable, aiming to be 18” x 18” x 24”. In order to fit the rotating base within the assembly, the housing and ramps terminate at a specific height. That height is constrained by the number of objects we wanted on the ramp with an angle of 45°. The sorted bins are also within that space constraint and are limited to the range of motion in which the rotating servo can rotate and the space that the objects require. The hobby servos that were specced out during the 4-bar analysis were able to rotate up to 270°, well past the required range of motion. We initially wanted to print semicircular bins to follow the arc of the four-bar as it rotated. However, we decided that a bin that large would be too difficult to print. The printing space was beyond the thresholds of our 3D printer and the printing times to cut it into multiple sections were not reasonable. Therefore, the sorted bin was set to be made out of cardboard. The main housing unit itself was designed to fit the rotating base’s servo and two bays for the respective Raspberry Pi Pico/Arduinos. The housing was then slotted for various spots for cable management and the suction pump mounting. The housing operates via three components. The main housing has all the respective dimensions to mount the components. The housing lid is meant to keep the components hidden. Recall that the device itself has 2 degrees of freedom. The 4-bar mechanism requires 1 servo to actuate between two toggle positions and the base requires 1 servo to rotate the entire assembly. The housing’s “rotating base” is the component that meshes with the base servo adapter.

Servo Selection

A big concern for the project was selecting servos that would be powerful enough to actuate the four-bar and easy to use and program. As we proceeded, we looked at a multitude of different servos and came up with the selection of the M45CHW Cordless Servo and MG996R Servo. For the base servo, we wanted a servo with enough torque and power to be able to actuate the entire assembly. Our aim was to have the base rotate roughly 90 degrees so we went with one that could do 270 degrees. As a coreless motor, its actuations were much smoother and better to program as positions were more precise to work with. For the MG996R it was your base hobby grade servo that came in bulk and it operates smoothly. Thus, we used it for the actuation of the four-bar.

We went with hobby servos as they were off-the-shelf parts and had linkage attachments made which could be easily implemented for connecting and assembling the four-bar design. With that in mind, Servos were made to be metric so this was the basis of the overall design of our project for how we would make everything. Thus knowing the off the shelf linkages were attainable we were able to make holes and acquire hardware easily for it.

Suction Device

The suction device makes use of the following components- a 4.5V air/vacuum pump, a 6V solenoid valve, a clear plastic tube, a suction cup and its hose-to-thread adapter. While all the components are mounted within the housing, the tube and the suction pump are mounted along/on the four-bar, therefore weighing ~20 g over it; this is a negligible amount of mass which is, for the most part, distributed along the span of the four-bar. Due to other components being powered by a common rail, we've opted to run the pump at 6V as well. Fortunately, it is still safe to run the pump at that voltage, and so is also capable of maintaining a firm grip on a 75 g block. The logic behind the valve is that when the servos are at a certain bin position and picking/dropping position, it will deactivate. However, we weren't able to go through with this because the valve needs to be actuated by a signal and our microcontroller's I/O pins don't have enough current passing through to signal the valve. So, we decided to activate/deactivate the pump using an NPN resistor.

Cubes

Cubes were selected as the most appropriate object for our robot to sort because they have flat surfaces that are easy to pick up using suction and are regular on all sides. We 3D printed 9 cubes, varying in color and weight. The differences in color and weight can represent different flavors or pills in manufacturing processes. To vary the weight, we put varying amounts of coins in each cube. We decided to paint the cubes vibrant shades of red, blue, and green. By painting such vibrant shades, we were able to narrow down any sources of error considering we're using a low-budget color sensor. The result was 3 1.5in x 1.5in cubes of each color, each in a light, medium, or heavy weight. It's important to note that these cubes were printed with PLA, and due to slightly unideal printer settings, experienced a bit of warping on the surface that contacted the build plate. The surface at the very top of the print came out to be extremely smooth which is also not ideal for a firm suction grip. We could've addressed this by deforming the surface slightly.

Coding

```python
# Sort function outputs correct bin_dex
def sort(mode, tol, mass_reading, color_reading):
    bin_dex = -1

    if mode == "MASS":
        if not masses: # list is initially empty; records very first mass and assigns bin to that set of masses
            masses.append(mass_reading)
            bin_dex = masses.index(mass_reading)

        else: # after list is populated with at least 1 mass recording
            for x in masses:
                if abs(x - mass_reading) <= tol: # if under tolerance, object will go to same bin
                    bin_dex = masses.index(x)

            if bin_dex == -1:
                masses.append(mass_reading) # appends only if new mass set is detected
                bin_dex = masses.index(mass_reading)

    elif mode == "COLOR":
        sensor_RGB = [color_reading.red(), color_reading.green(), color_reading.blue()]
        bin_dex = sensor_RGB.index(max(sensor_RGB))

    # print(bin_dex)
    return bin_dex
```

Figure 5. Snapshot of our code

The above code is essentially the design matrix for the sorting. Based on the user input, a mass tolerance that we've set experimentally, and inputs from the pressure pad and RGB sensor, we carry out a set of conditionals. The conditionals, all-in-all, change the value of a variable *bin_dex* which represents the index of each of the bin positions. These indices correspond to the angles that the base servo must turn to, depending on the color or mass detected.

We've had success with sorting based on both metrics, but there's definitely some sources of error with the mass sorting. It mostly had to do with the fact that our pressure pad is on a slope and so the delta between the normal force applied by the two differently weighted cubes is reduced. As such, the range of analog values we get from the pressure pad overlap a lot. We attempted to mitigate this by taking the average mean reading over the course of a longer duration, and while this did improve the sorting results, the robot wasn't sorting accurately consistently. We would address the issue by making the surface below the block closest parallel to the ground, if we had the opportunity to.

Detail design

Synthesis of mechanism (Graphical)

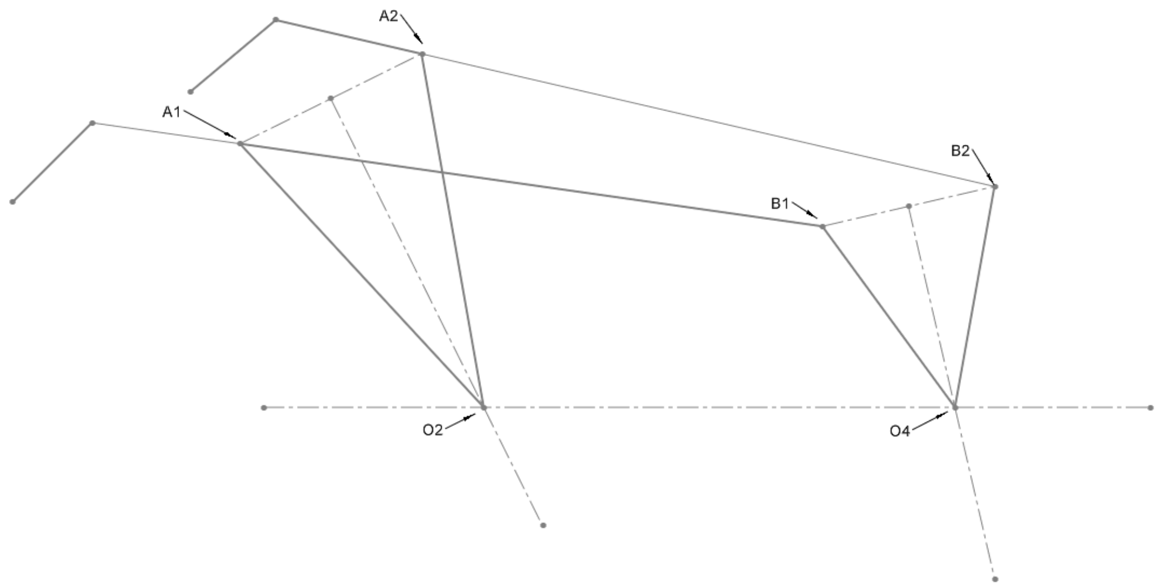


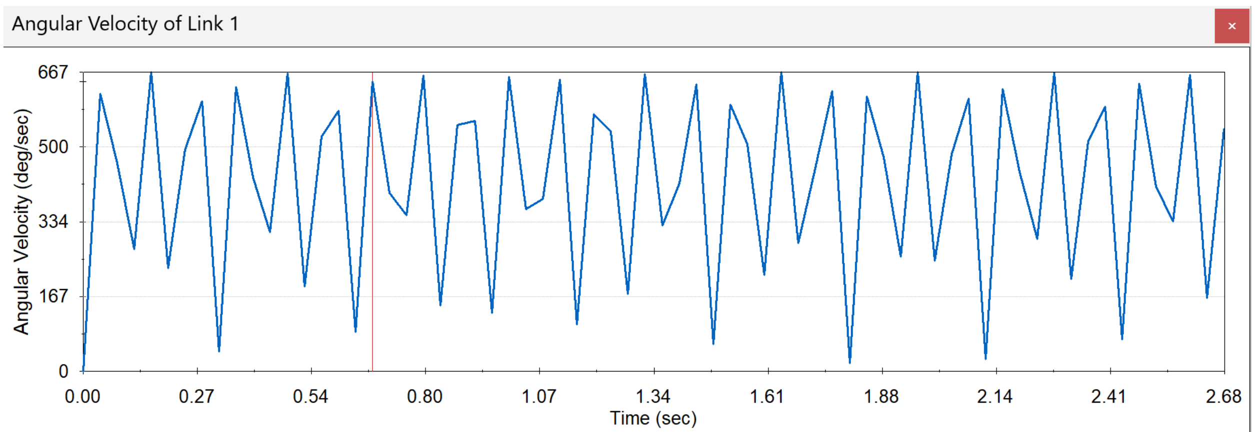
Figure 6. Graphical Analysis

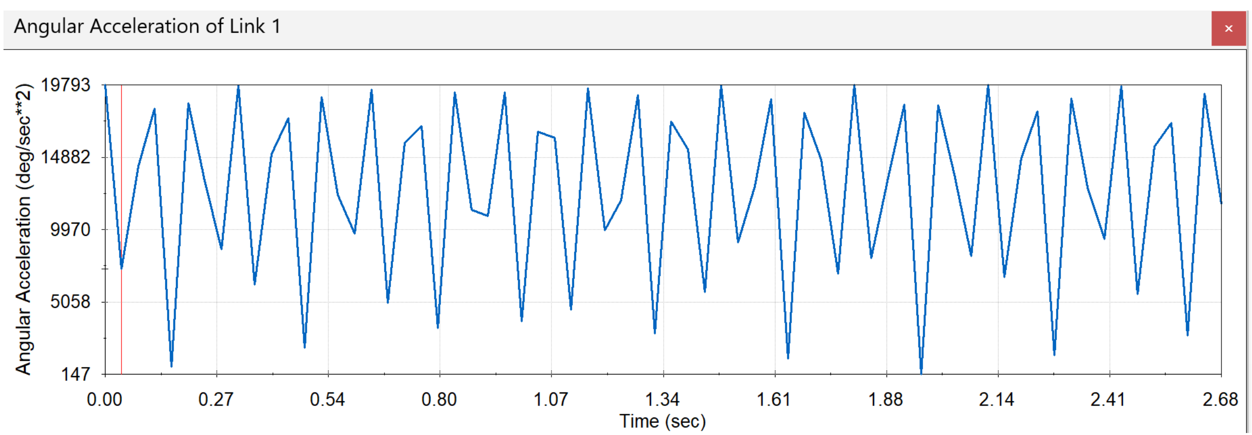
The figure above shows the graphical analysis of our robot. After deciding on two coupler output positions for the mechanism and determining an appropriate proportional length links 2 and 4, we scaled the robot up to fit our size constraints. Additionally, link 3 extends past point A. This extension acts as a mounting location for our suction device. This additional length provided by the suction device was considered in the graphical analysis and design of the ramps.

Kinematics analysis (Motion analysis)

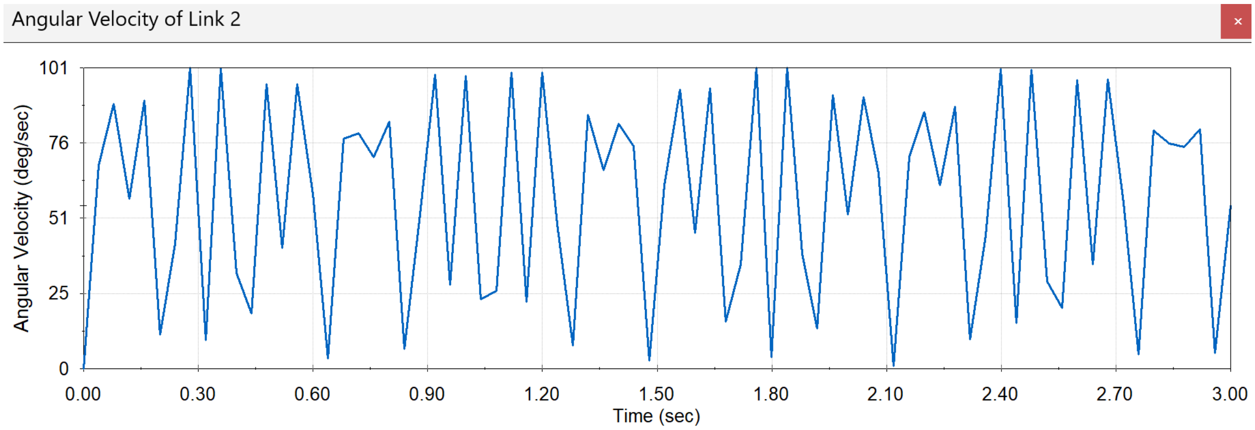
Frequency is set to 4.76Hz as it is what the operating frequency of the servo motor provided by the data sheet. The oscillation is between 45 degrees as we had calculated between our two positions. Duration is set for 3 seconds.

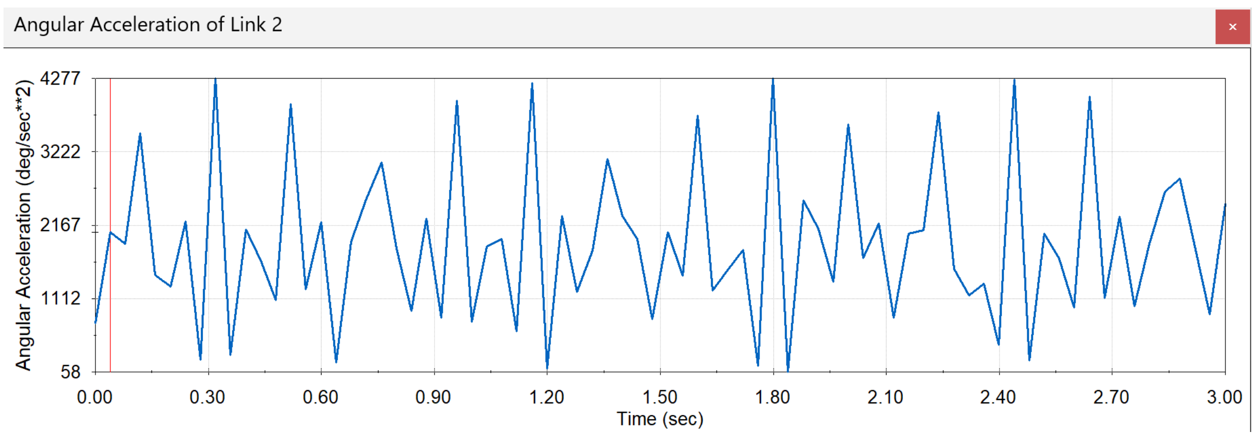
Link 1 (Crank):



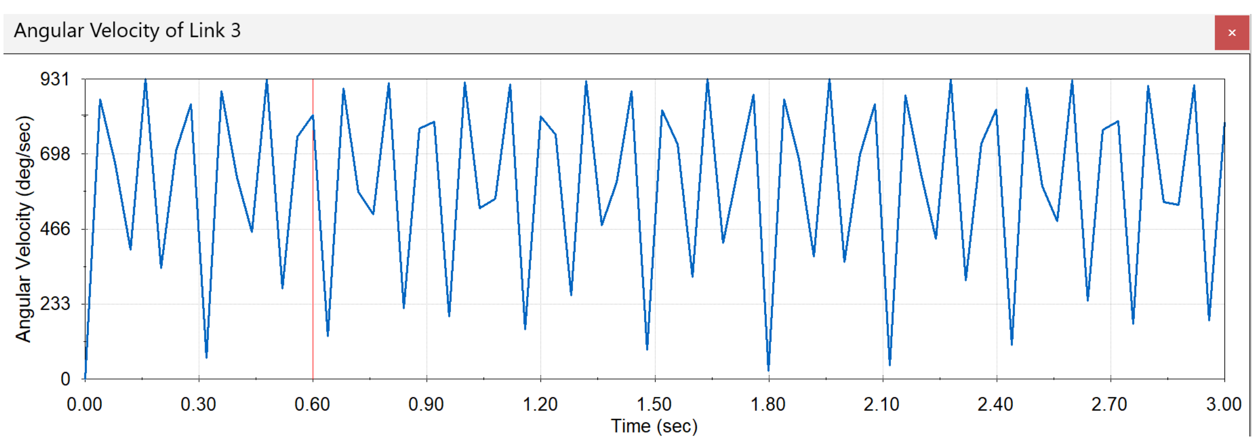


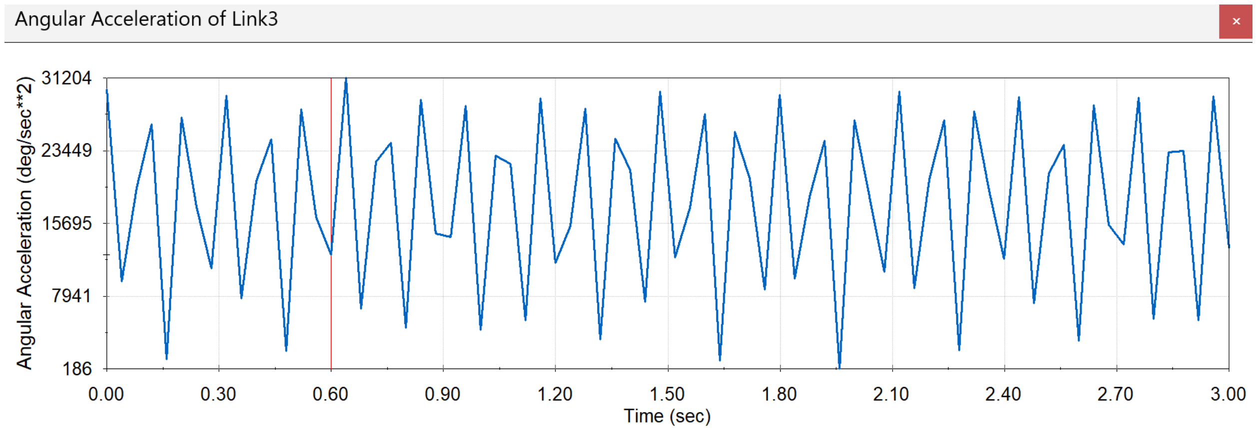
Link 2 (Coupler):





Link 3 (Output Link):





Kinetic Analysis (Analytical Force and Torque Analysis)

For the force analysis, we took the mass of the links and found their moments of inertia based on the geometry of the beam. Using those values and the numbers we got from our Solidworks Motion Analysis, we were able to calculate the inertia force, inertia torque, torque arm, and then the torque to move the link. Link 2 is the coupler link, attached to the suction, link 3 is the driver, and link 1 is the output link.

Link	Mass (kg)	Linear Accel (m/s^2)	Moment of Inertia (kg*m^2)	Mass Moment of Inertia (kg^2*m^2)	Angular Accel (rad/s^2)
1	0.00276	17	1.82E-11	5.03E-14	351.26
2	0.00868	33	1.82E-11	1.58E-13	74.5
3	0.00419	16	1.82E-11	7.64E-14	532.7

Link	Inertia Force (N)	Inertia Torque (Nm)	Torque Arm	Internal Torque (kg*m)	torque (kg*mm)
1	0.04692	6.40E-09	1.36E-07	6.40E-09	6.40E-06
2	0.28644	1.36E-09	4.74E-09	1.36E-09	1.36E-06
3	0.06704	9.71E-09	1.45E-07	9.71E-09	9.71E-06

Link dimensions	meters
height	0.014
base	0.0025

Stress Analysis and Deflection:

For stress analysis, we have determined the following loadcase. This includes an external load of a 75 gram cube at the coupler. Furthermore, there is a required torque in order to overcome the mass moment of inertia. The required torque for this loadcase was 1.65 kg*cm at where link 2 coincides with the anodized COTS servo arm (front motor) in either direction (cw, ccw). The FEA was set with fixed geometry at the 4 bar's mockup base. Links are medium-high impact acrylic, the base is set with ABS plastic. The servo arm/adapters are made of 1060 alloy. The lowest FoS is at the edge nodes of the servo arm. The following diagrams (figures 7-9) show Von Mises stress, displacement in mm, and factor of safety respectively. Figure 10 shows the area of lowest factor of safety which is where the servo motor is mounted. The maximum displacement within the entire assembly is at the coupler because of the material. In real life, we found the acrylic to slightly bend while carrying the object.

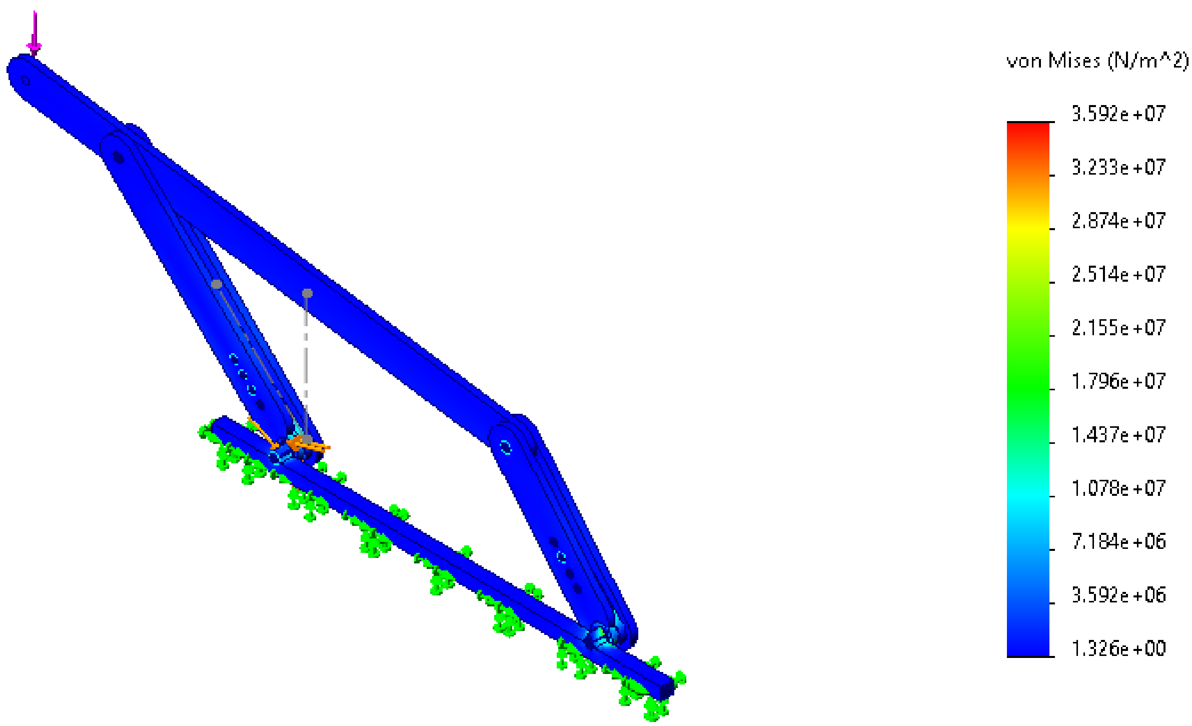


Figure 7. Von Mises Stress

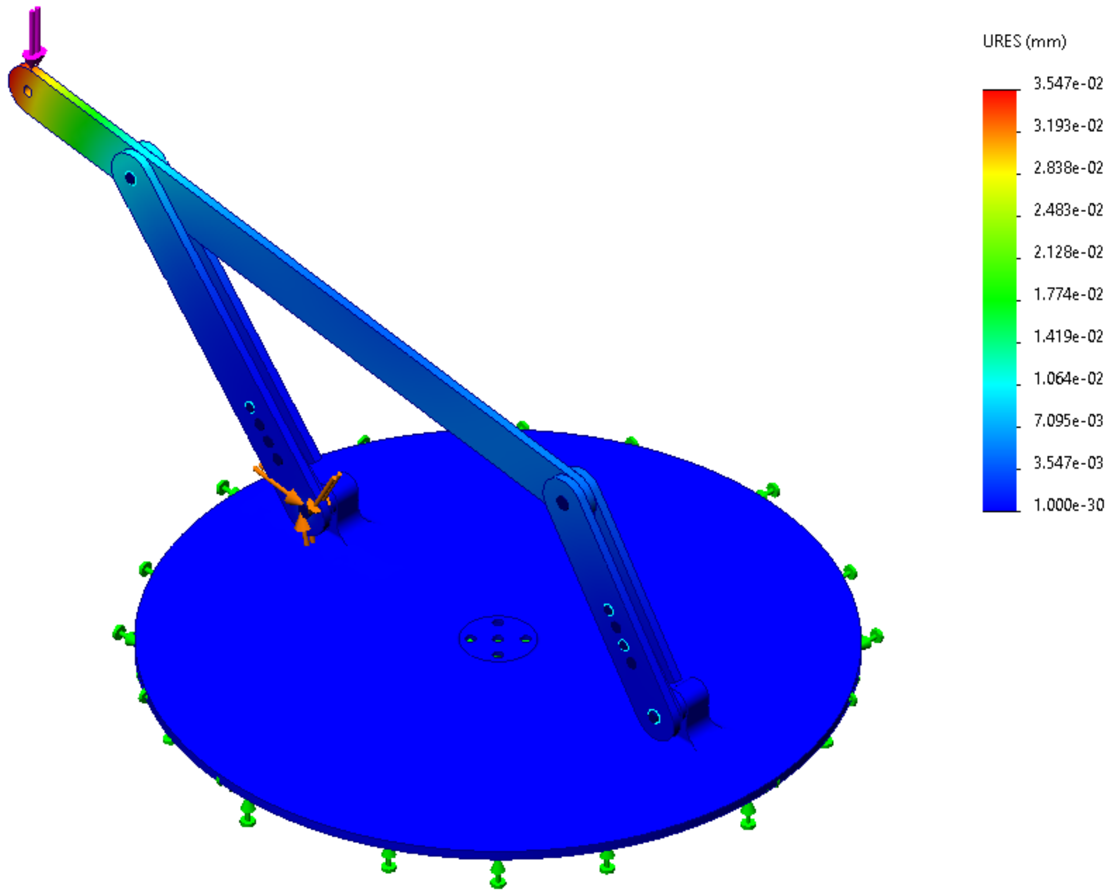


Figure 8. Displacement (deflection is peak at coupler)

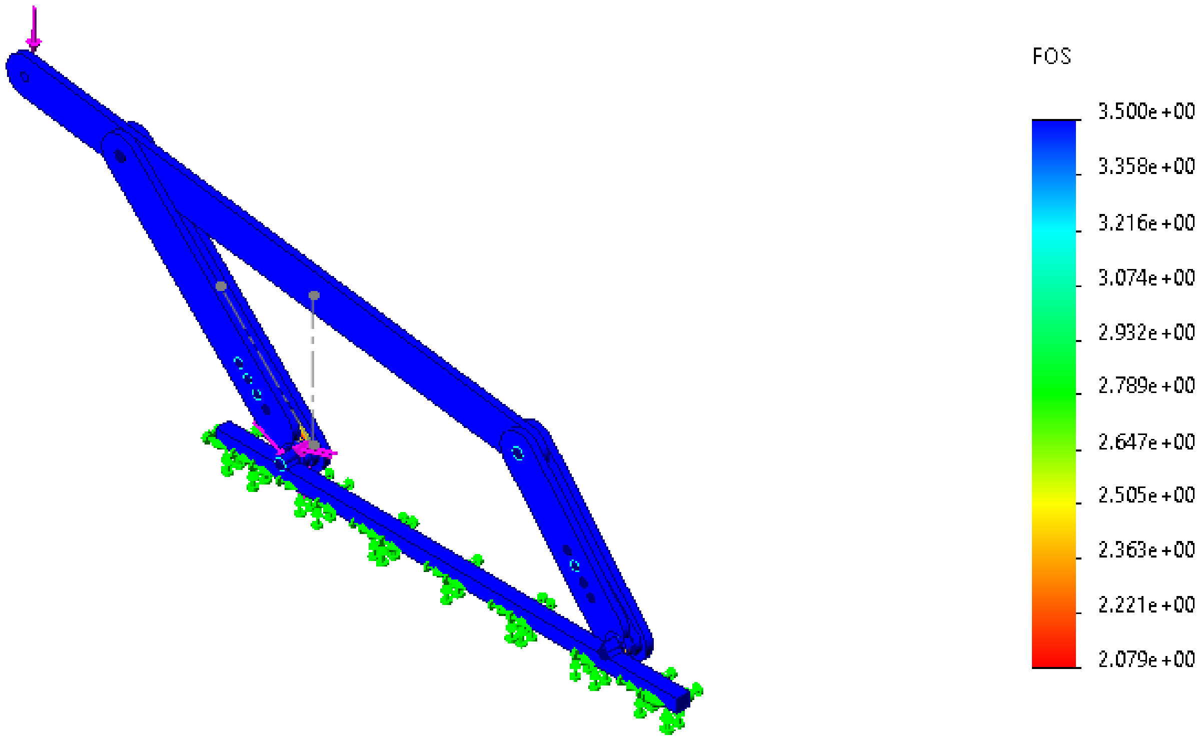


Figure 9. Factor of Safety

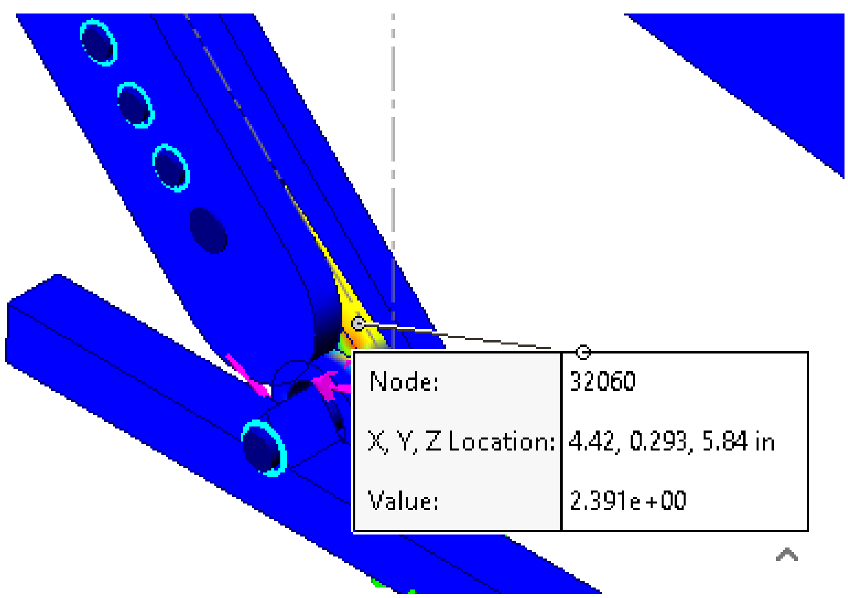
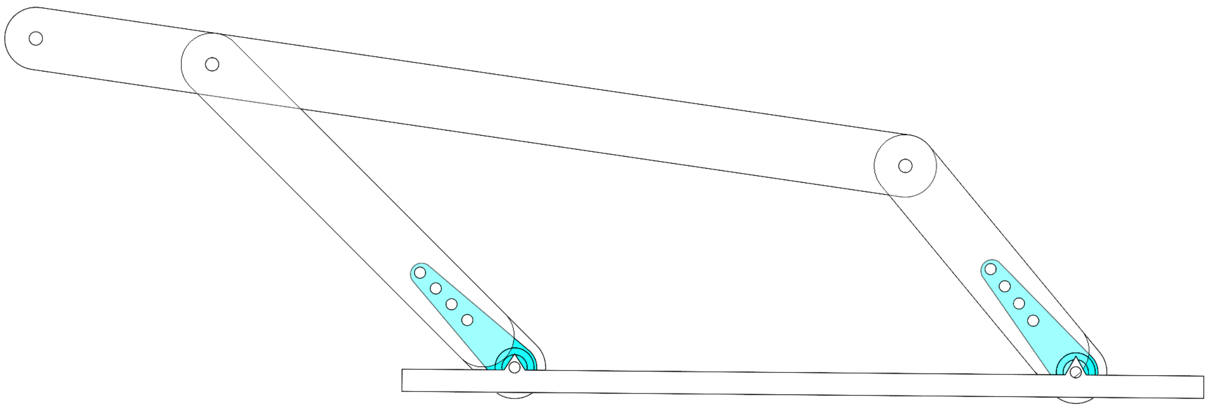


Figure 10. Area of Lowest FoS

Animation of the Mechanism



Four-Bar In Motion

Models & Drawings

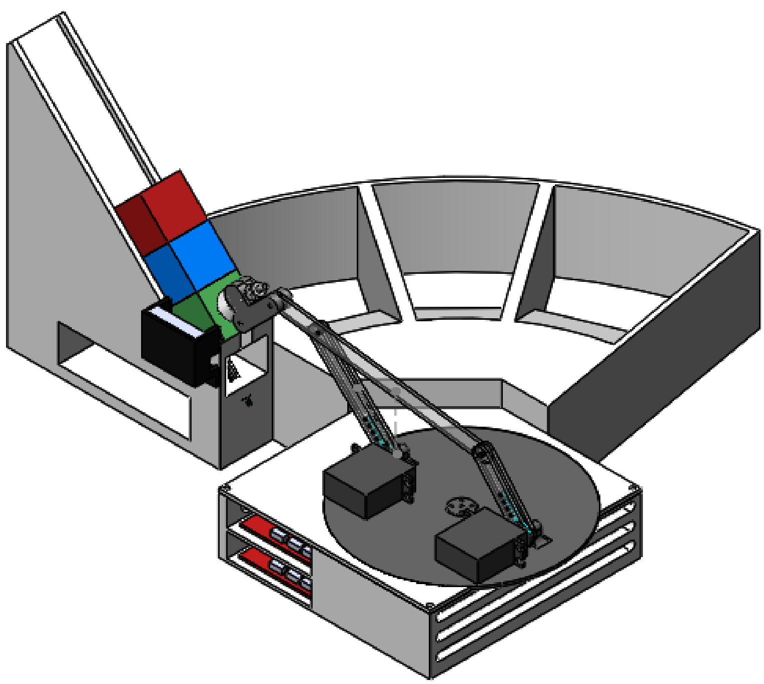


Figure 11.3D Full Assembly

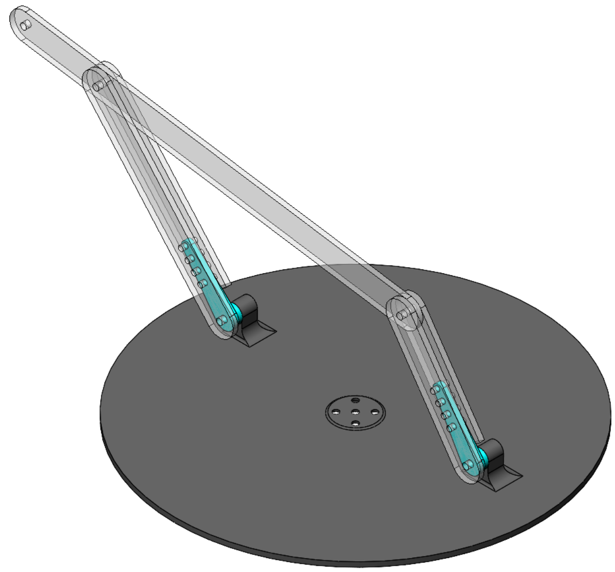
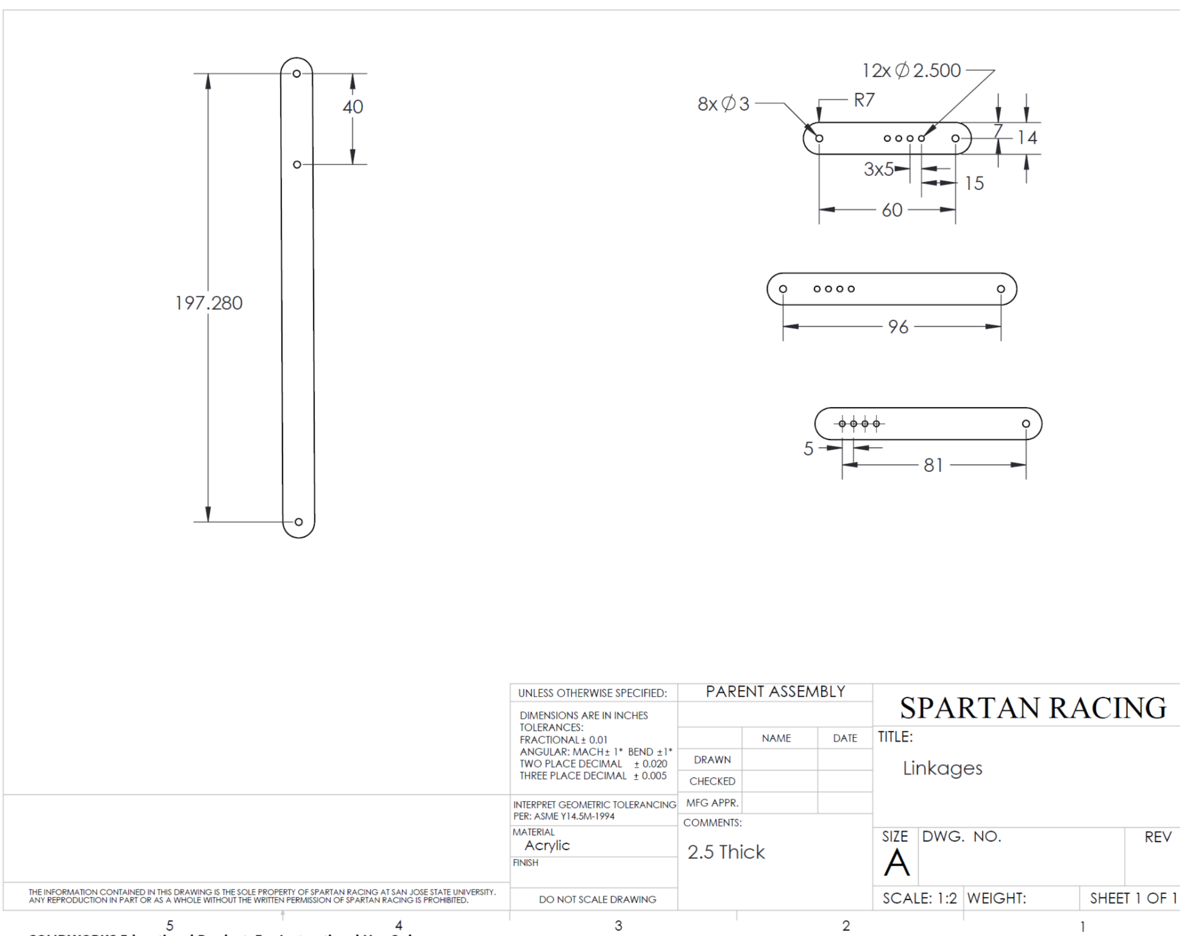


Figure 12.Main mock-up of the four-bar design



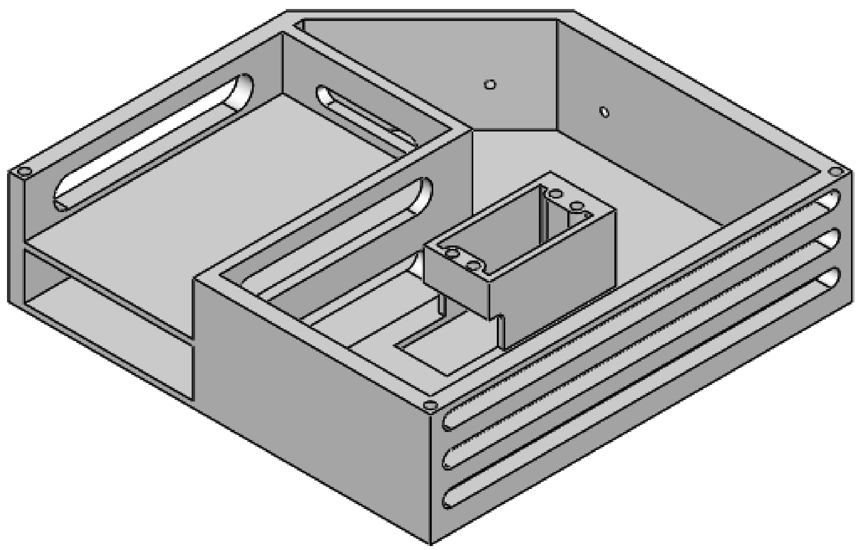
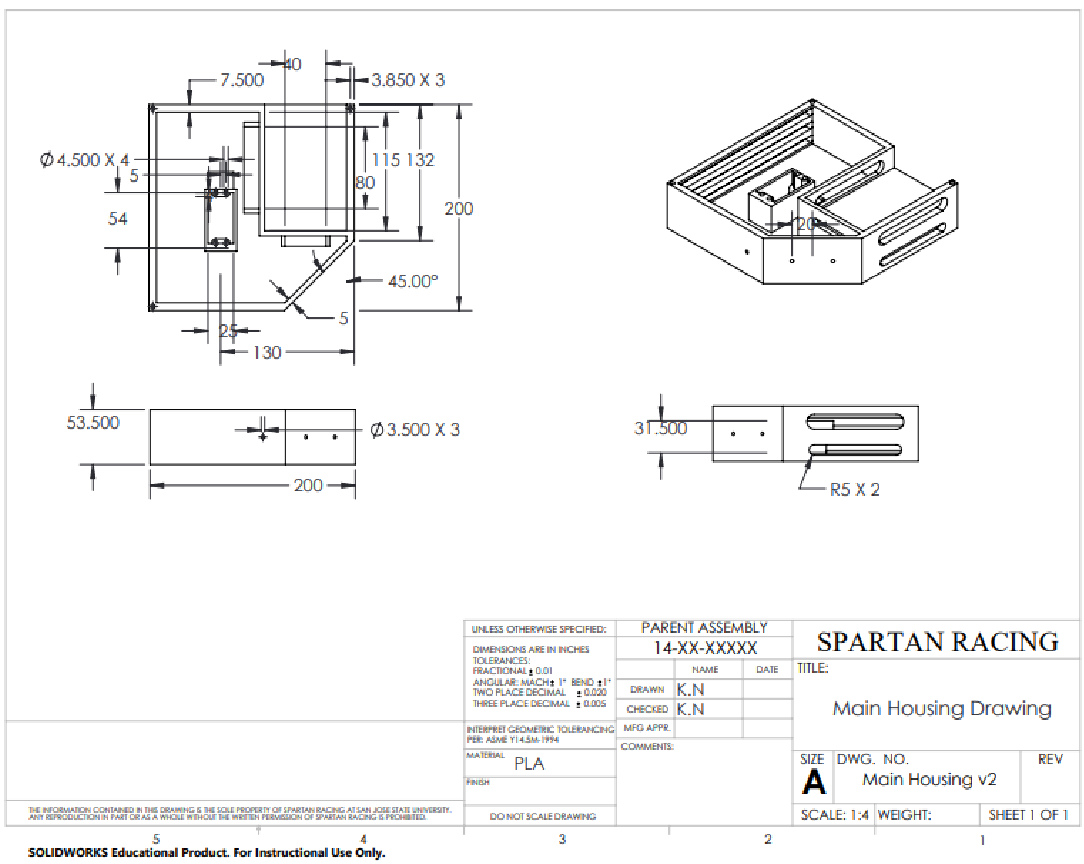


Figure 13.Main Housing



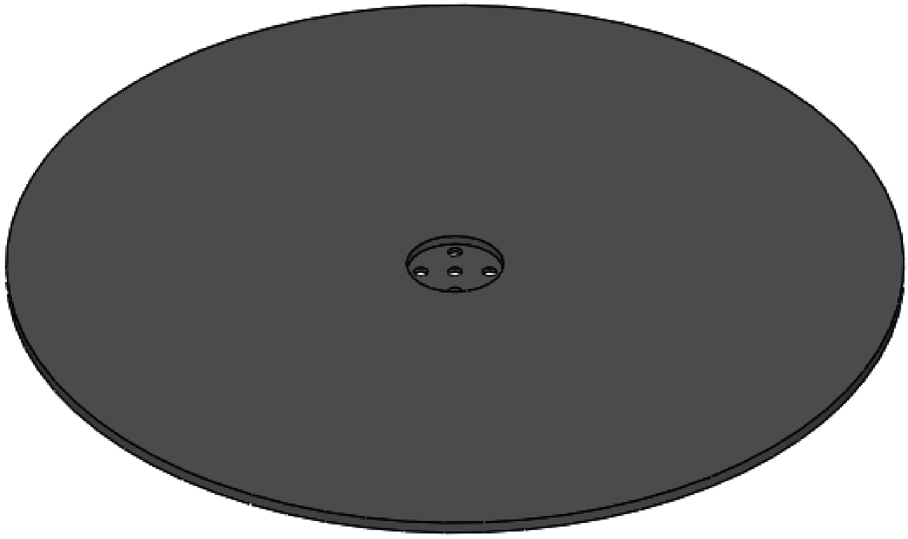
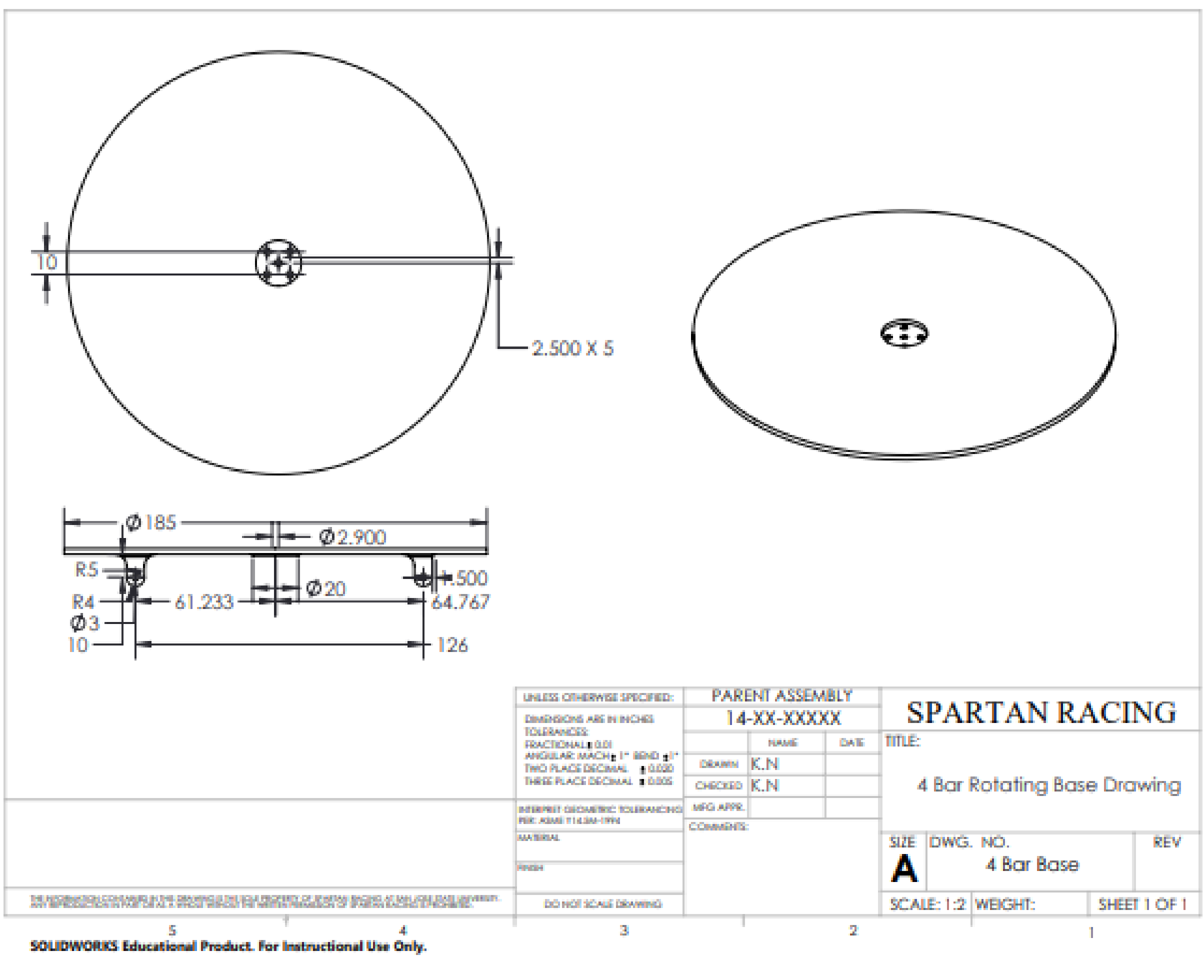


Figure 14.4 Bar Base



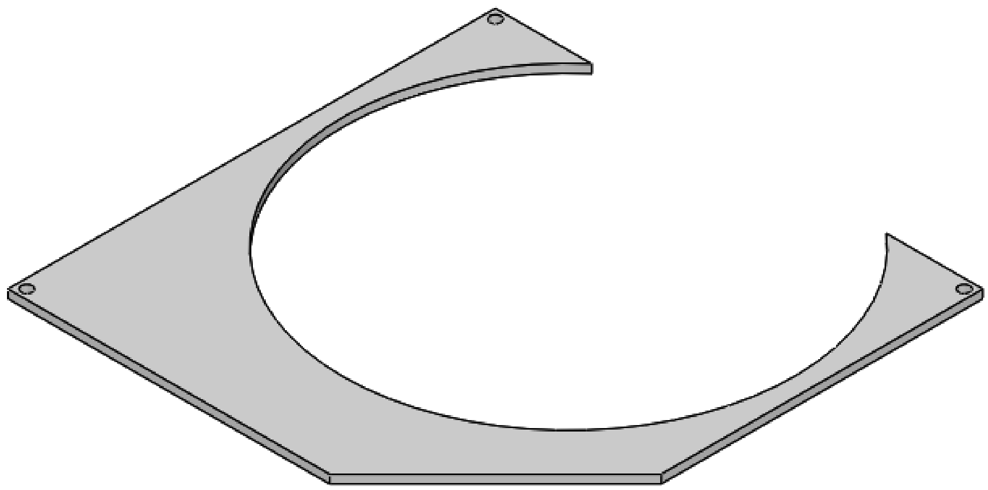
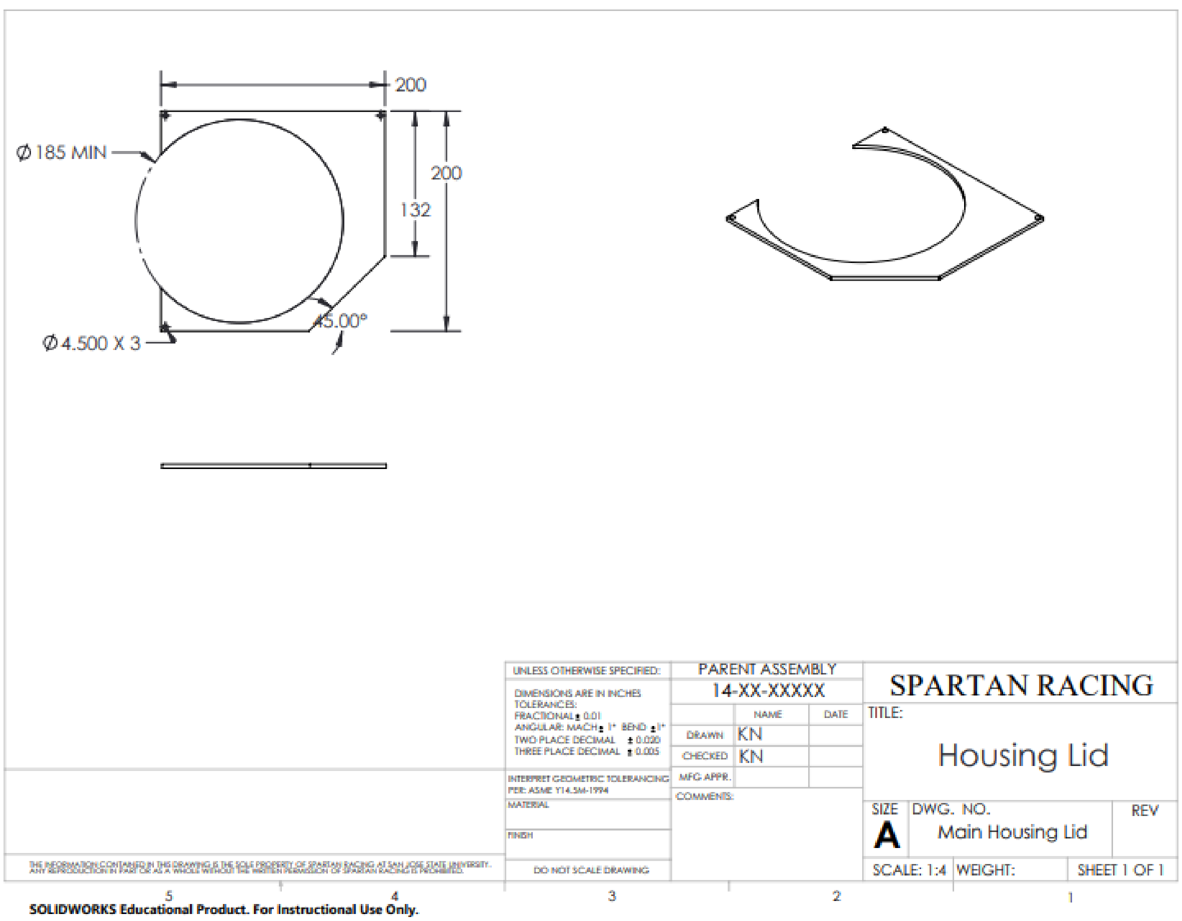


Figure 15.Housing Lid



Discussion and Future modifications

Major issues for future design would be setting up the 3D printer's temperature characteristics correctly as many of the parts were warped to some degree. We would've also liked to simplify our designs as print times for certain parts came around to ~32 hours. In addition, we can take the time to scale everything up. With that in mind, we would likely need to change the material for the four-bar as with increased loads we would need stronger materials for the links.

One modification that we would like to make in the future would be to use a camera or optical sensor to detect the objects rather than using an RGB color sensor, especially since there is a module available to use with the Raspberry Pi Pico. While we lacked the time to incorporate this feature, it would be highly beneficial to the robot's object recognition capabilities and make it more relevant to implement in other real-world fields. This is because the camera is able to gather more information about the object than the color sensor, such as size, shape, texture, and depth. They are also more reliable in low-light conditions, where the color sensor may face difficulties in detection. This would also allow us to sort by other variables aside from weight and color, increasing the applicability exponentially.

Regarding applications in varying fields, one future modification would be producing a modular sorting head that allows the user to change the sorting head based on their needs. Suction may not be applicable for some niche items, so it would be convenient to have a charge that is compatible with different attachments. For example, if the robot were to be used to sort recyclables from mixed waste, a claw head may be more desirable than a suction head.

We would also like to make the four-bar base more robust. Due to the four-bar repeatedly picking up weights on one side of the base, it started to sag in towards the housing and run into interference with the housing lid. We would like to counteract the weight or at least account for it while designing the four-bar base. This would improve the stability of the four-bar when it's sorting into a bin and returning back to the unsorted ramp.

Lastly, we'd consider better hardware for fastening the links to each other. With repeated movement, couple screws would unthread themselves, which demands for repeated, unnecessary servicing.

References

Norton, R. L. (2019). *Machine Design: An Integrated Approach*. Pearson.

Appendix

Data Sheets

- Air Pump Datasheet
  - https://www.adafruit.com/product/4700#technical-details
- M45CHW Coreless Servo
  - https://www.flashhobby.com/m45chw-coreless-servo.html
- MG996R High Torque
  - https://www.electronicoscaldas.com/datasheet/MG996R_Tower-Pro.pdf
- Color Sensor
  - https://cdn-shop.adafruit.com/datasheets/TCS34725.pdf
- Pressure Pad
  - https://cdn2.hubspot.net/hubfs/3899023/Interlinkelectronics%20November2017/Docs/Datasheet_FSR.pdf