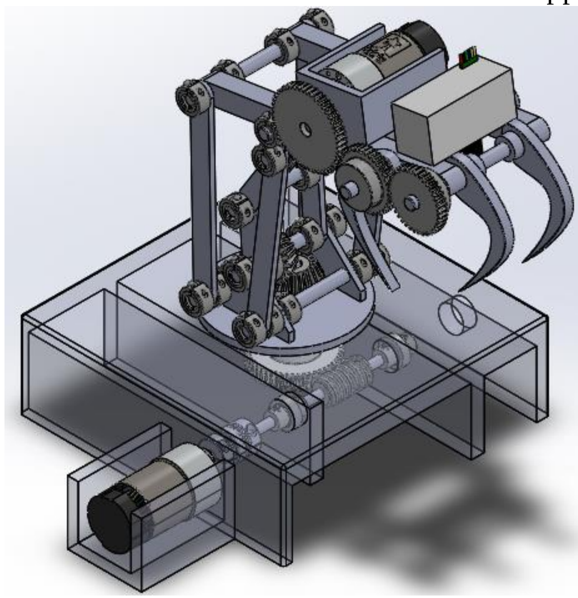
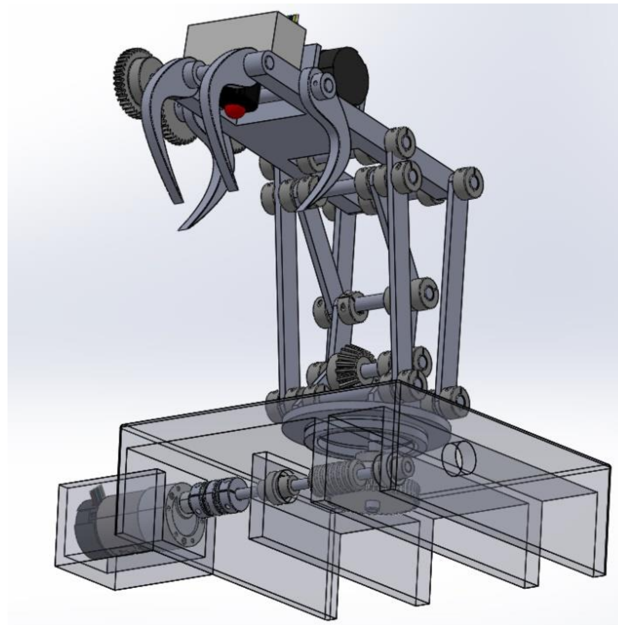
Alexander Yang 3032651143
ME 102B Final Project Report

Mechanical Gripper Arm with Touch Sensor

0. Description of the System

The mechanical system depicted above is the gripper robot. The idea behind the project was to create a design that could pick and place objects in a 3-D workspace. As currently designed, this arm can manipulate objects in the x-z plane along a fixed path. The key components of the design are a 6-bar linkage to establish the gripper arm's trajectory, a gear transmission system to facilitate the movement of the arm along its trajectory, and another gear transmission system to provide for the movement of the grippers themselves.

In this report, I will focus on ONE very important subassembly of this mechanical system: the bottom transmission system. This transmission system converts the torque from a motor through a set of worm gears and up through a set of miter gears to move the entire arm. The motor was chosen because this system requires a motor that can provide relatively high torque rather than high speed. The Pololu motor spins at 67 RPM without load, and the worm gear reduction of 50:1 ensures that the shafts in the 6-bar linkages will not be spinning much faster than 1 RPM. This is a reasonable operational speed for this application because the linkages are not rapidly spinning. Furthermore, the addition of worm gears ensures that the system is not back-drivable, which means that the forces due to the objects the arm picks up will not cause a backwards rotation on the links' shafts and will not damage the motor during operation. The additional benefit of two gear trains means that all four gears in this subassembly do not have to have the same module: only the respective pairs require the same module, with the worm gears having the extra constraint of having the same pitch angle. These design choices reduce the number of custom parts for this subassembly and satisfies the constraints for this arm to operate successfully.

I. Parts List (Bottom Transmission System)

- Pololu motor #2828, 67 RPM
- Plastic Worm Gear McMaster #4037N133
- Metal Worm Gear McMaster #57545K633
- Ball Bearings McMaster #6661K11
- Set Screw Shaft Collar McMaster #6056N14
- Shaft Coupling McMaster #2464K2
- Miter Gear McMaster #6529K57
- Belville disc spring McMaster #94065K24
- Shim McMaster #90214A111
- Ball Bearing McMaster #5972K91
- Belville disc spring McMaster #96445K35
- Shim McMaster #90214A115
- Stock aluminum bar 6 mm in diameter
- Stock aluminum bar 8 mm in diameter
- M3 screw
- Triangular Base Link (Custom)
- Bottom Motor Housing (Custom)

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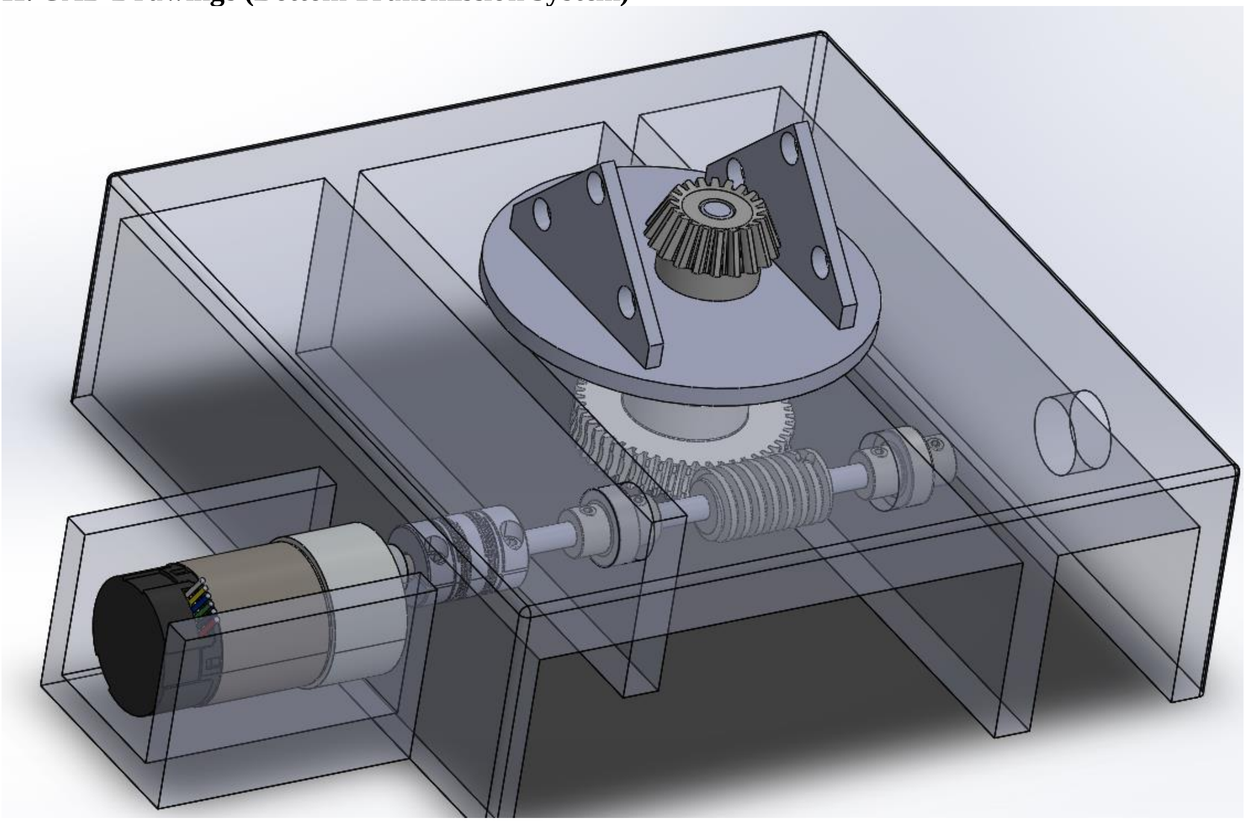
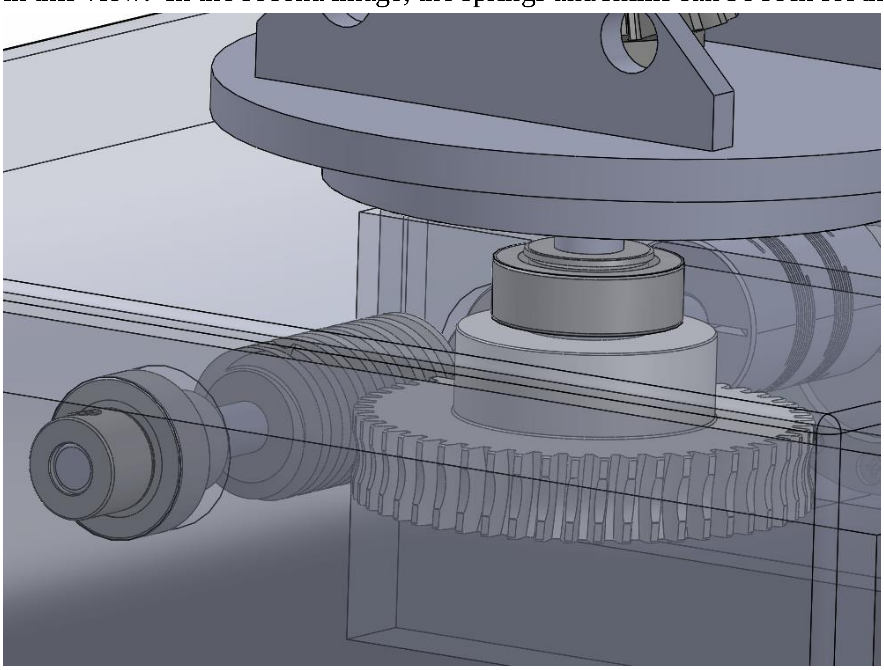
II. CAD Drawings (Bottom Transmission System)



The image above is the top view of the two transmission systems. The bottom motor housing has been rendered transparent to display the other components. Note how the second fin from the left is shorter than the other three fins. This choice was made to enable the use of tools such as a screwdriver to fix the motor to the housing. Due to the size of the materials, none of the shims and springs can be seen in this view. In the second image, the springs and shims can be seen for the second transmission system.



There were some additional tricks to shorten the height of the housing. Note that there does not appear to be collars on the second transmission system. The housing acts as the top collar, and due to the reduced contact area between the shim and the housing, there will be less friction. In addition, the bottom worm gear has a set screw and therefore, acts as the lower collar for the bearing. The triangular base helps reduce the load on the bearing.

III. Fabrication Process (Bottom Transmission System)

There are a few ways to fabricate the base motor housing. This part can be 3-D printed as there are minimal overhangs (with a particular orientation); furthermore, the actual piece that houses the motor can be 3-D printed separately and attached to the base, making sure it is centered horizontally with the holes along the side. If making this piece from metal, a CNC/milling machine can cut the deep groves, and the motor housing can be welded to the side.

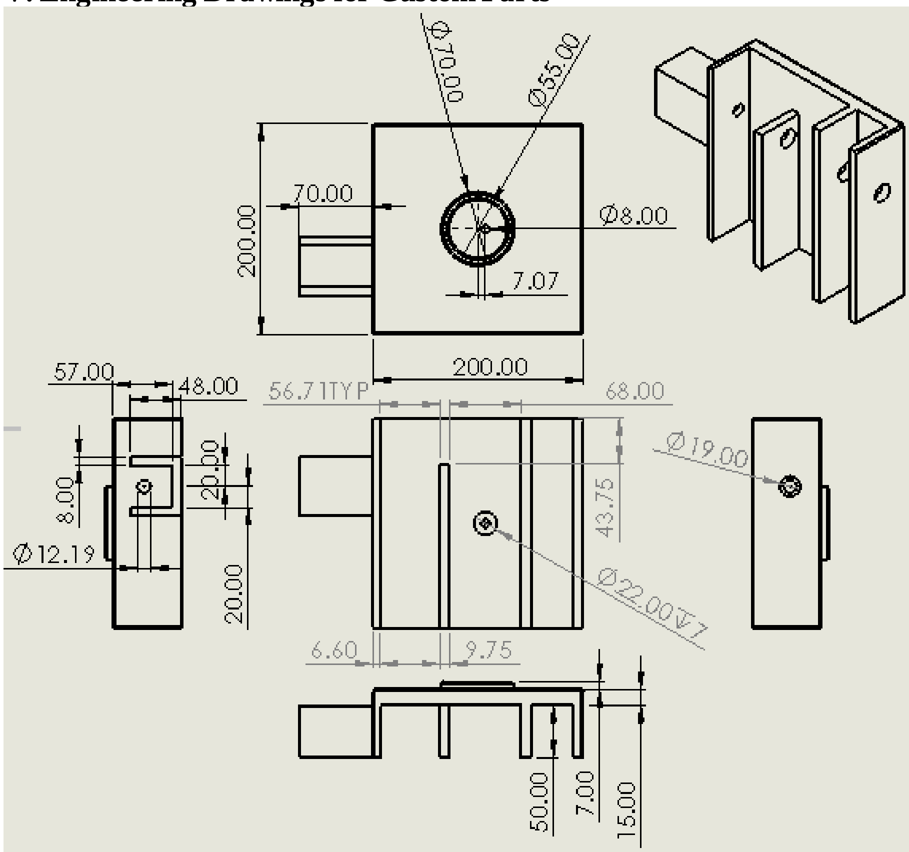
I recommend 3-D printing the triangular base link as well since the geometry would result in a large waste product if using a CNC to create the part. Welding two triangular pieces to the circular part could work, but there would be a lack of precision needed for a piece that regulates the motion of the claw arm.

Fabricating the transmission shaft is quite simple: take 6mm aluminum stock and cut it to 135 mm. The 8 mm aluminum stock can be fashioned into the second gear shaft by cutting it to 70 mm.

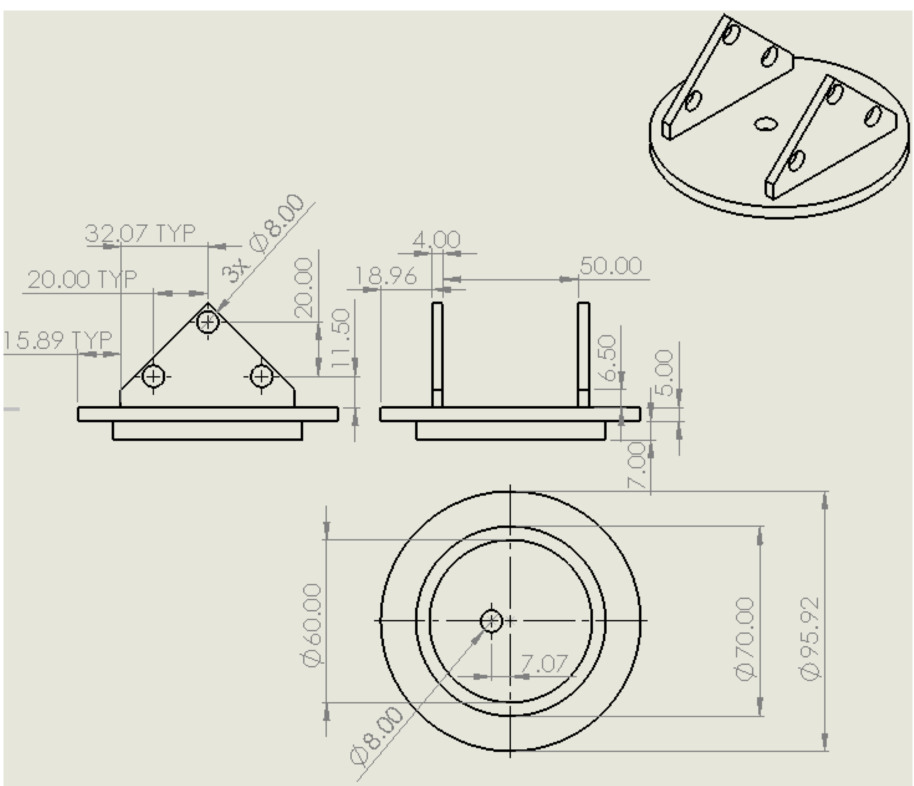
IV. Assembly Process (Bottom Transmission System)

1. Start with the Pololu Motor #2828 and fit it to the motor housing, making sure the motor shaft pokes through the corresponding hole. Fix the motor to the housing by using 3 M3 screws into the housing. Notice that the gap in the second fin of the housing allows the use of a screwdriver to fix the motor.
2. Attach the shaft coupling to the motor, and use an Allen key to secure the coupling to the motor shaft.
3. Take the aluminum transmission shaft (6mm diameter) and attach the following pieces to the shaft in order (WITHOUT fixing their positions via set screws): shaft collar (McMaster #6056N14), shim (McMaster #90214A111), spring (McMaster #94065K24), ball bearing (McMaster #6661K11), spring (McMaster #94065K24), shim (McMaster #90214A111), shaft collar (McMaster #6056N14).
4. Attach the metal worm gear on the shaft to the right of this assembly.
5. Attach another copy of the two shaft collars, two shims, two springs, and ball bearing in the same order as the previous assortment, but on the right side of the metal worm gear.
6. Feed the aluminum transmission shaft through the corresponding holes of the bottom motor housing, making sure to insert one end into the shaft coupling. Tighten the set screw on the right side of the shaft coupling to fix the position of the aluminum transmission shaft.
7. Ensure that each bearing is inserted into the corresponding holes in the second and third fins.
8. Consider the left ball bearing. Take the left shaft collar and make sure that the ball bearing is firmly secured on one side by the shim and the spring. Secure this shaft collar by screwing in the set screw. Repeat for the other shaft collar on the left ball bearing. The ball bearing should be snug between a pair of springs and shims, with positions fixed by the pair of shaft collars.
9. Repeat the previous step with the right ball bearing. At this point, the motor should be fixed to the housing, the coupling to both the motor shaft and the transmission shaft, and all four ball bearings should be fixed to the transmission shaft. The worm gear should not be fixed to the transmission shaft at this point (to ensure alignment between the two worm gears.
10. Attach the triangle base link above the bottom motor housing by aligning the corresponding holes and slide them together.
11. Attach the miter gear to the top of the corresponding hole of the triangular link, and slide the second gear shaft (8mm diameter) through all three holes. Make sure the shaft is flush to the top face of the miter gear, and secure it via set screw on the miter gear.
12. Place in this order onto the 8mm shaft below the bottom housing: shim (McMaster #90214A115), spring (McMaster #96445K35), ball bearing (McMaster #5972K91), spring (McMaster #96445K35), shim (McMaster #90214A115), worm gear (McMaster #4037N133). Make sure the TOP face of the gear is flush to the bearing. Secure this piece to the shaft via set screw.
13. At this point, the two worm gears should have interlocking teeth. Secure the position of the first worm gear via the two set screws.

V. Engineering Drawings for Custom Parts



This drawing to the left depicts the bottom motor housing part.



This drawing to the left depicts the triangular base link.

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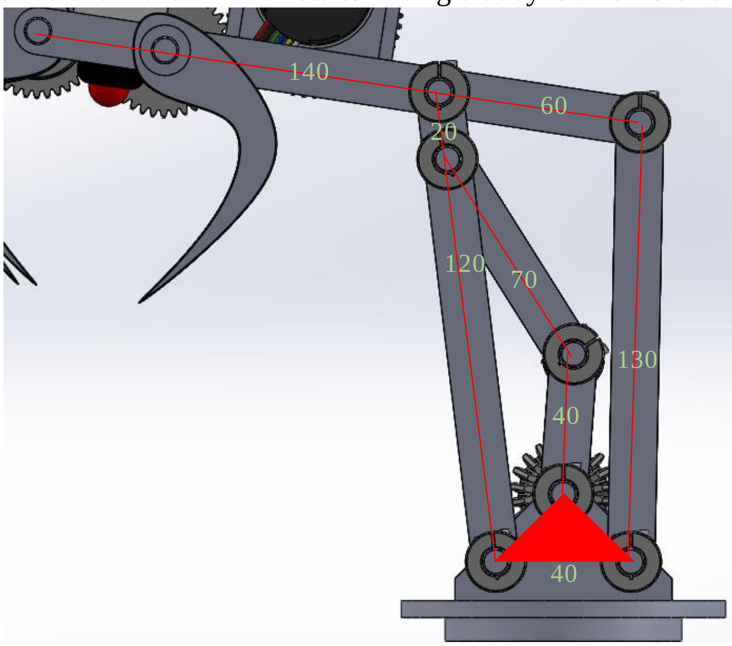
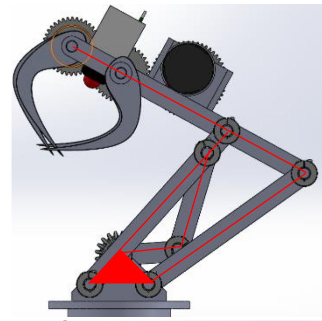
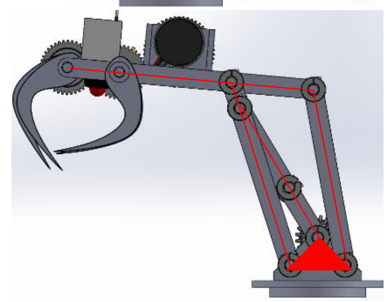
V. Appendix: Analysis of the 6-Bar Linkage

The key to reducing the degrees of freedom of the arm is the 6-bar linkage. The 6-bar is essentially two nested 4-bar linkages, both sharing one pivot of the ground link. The key dimensions for the 6-bar are shown below, along with the maximum and minimum positions along its trajectory. All dimensions are in millimeters. The rigid body is a 45-45-90 triangle with hypotenuse 40 mm.







The lengths in millimeters of the legs of the two 4-bars are then (starting from the ground link): $20\sqrt{2}, 40, 70, 120$ and $40, 140, 60, 130$. By applying Grashof's criterion to both 4-bars, we find that they are a double rocker and a crank rocker, respectively. Using Greubler's equation, with $n = 6, J_1 = 7$, and $J_2 = 0$, we find that $\text{DOF} = 3(n-1) - 2J_1 - J_2 = 1$, which means that this 6-bar has one degree of freedom. This is also supported by the fact that both 4 bars have one degree of freedom, with the double rocker's impact only being to impose limits on the crank rocker. The link of length 200 was only considered as length of 60 since the 140-length determined the position of the end effector along the trajectory. These lengths of the 6-bar were chosen to specifically create the two sub-linkages because the main goal was to have an overall path of a crank-rocker, but to reduce the amount of actuation required by imposing the limits of motion from a double rocker. Looking at this claw assembly alone, we see that it can pick objects far from the root base and move it towards the origin frame of the base.

V.A Parts List from Vendor for one 6-bar Linkage

- Miter Gear: McMaster #6529K57
- Shaft collar: McMaster #57445K442
- Gripper gears: McMaster #2664N503 and McMaster #2664N501
- Pololu motor #2828, 67 RPM
- Stock aluminum bar 8mm diameter

V.B Custom Parts List

- Upper Motor Housing
- 120 mm Link
- 130 mm Link
- 140 mm Link
- 40 mm Link
- Triangular Base Link