# 1. Finalized hardware design

I plan to build a 3-DOF robot arm for my output part. The 3D symbolic representation of the robot is shown as the figure as below.

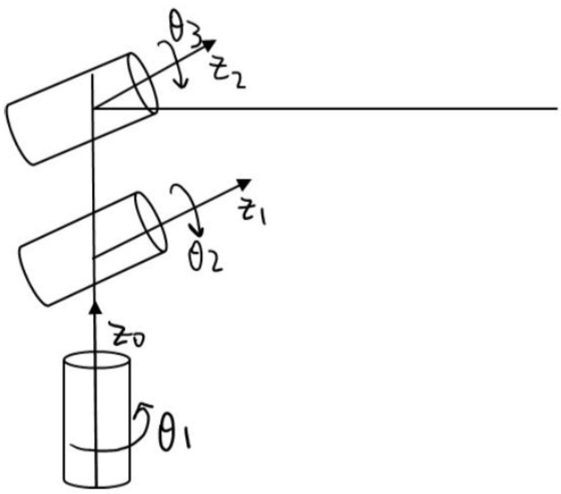


Figure 1 3D Representation

The arms of the robot rotate around $z_0$, $z_1$, $z_2$ respectively, with angle $\theta_1$, $\theta_2$ and $\theta_3$.

For the sensing part, each joint of the robot should be mounted with a potentiometer to 'know' exactly how many angles does the arm rotate. In this case, each arm should be designed to an appropriate size to fit the potentiometer. Meanwhile, the arm could not be too long. Otherwise, the torque rotating the potentiometer may be too large. Below is my design for the Waldo input side.

1. Bass
2. Potentiometer
3. Flange
4. Joint 1
5. Potentiometer
6. Flange
7. Link 1
8. Potentiometer
9. Link 2
10. Flange

Potentiometer acts like a joint for the input side. For each link/bass, there is a square hole that totally fits the size of potentiometer so that it could be fixed to the link. On the other side of the link, there is a hole that has the same shape as the potentiometer's shaft, as well as the hole on the flange, so that the potential meter could rotate with the link/bass. Since the requirement for assembly is not so high for the sensing part, I use superglue to attach each connection part.

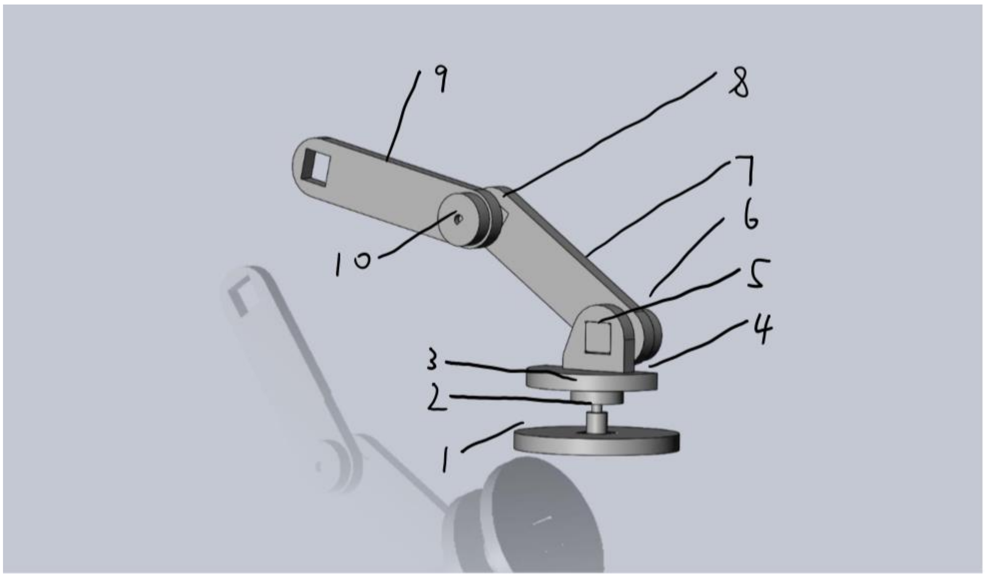


Figure 2 3D Assembly of Sensing Part 1

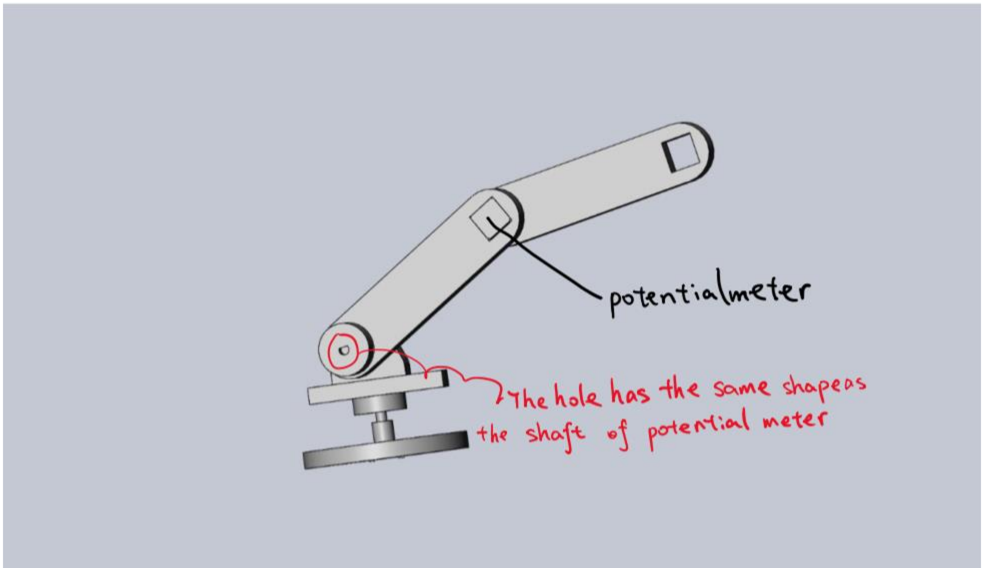


Figure 3 3D Assembly of Sensing Part 2

The dimensioned drawing for the assembly of sensing part is shown in the figure below, which shows the mounting details and the overall dimension of the input side. Considering the tolerance of laser cutting and 3D printing, I plan to use superglue and hot melt for mounting the potentiometer and links.

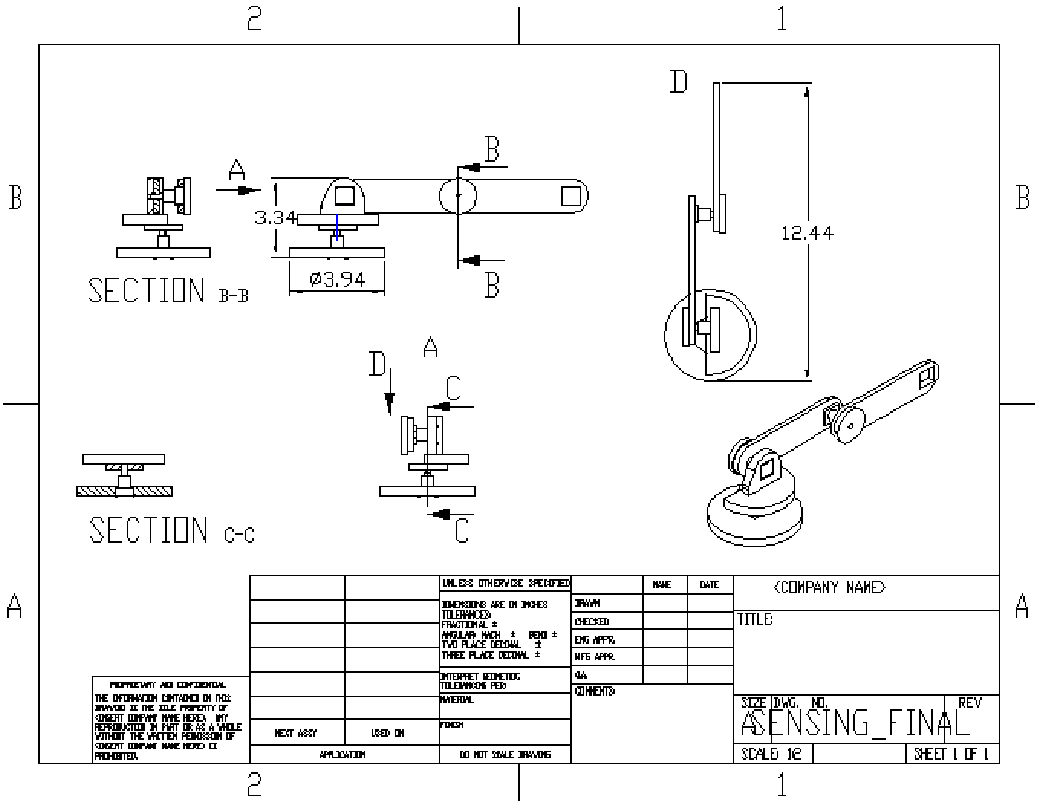


Figure 4 Assembling Drawing of Input Side

The detailed dimensions for each part are shown as below:

Noticed that for input side the 2 links are the same. And the dimensions are in **mm**.

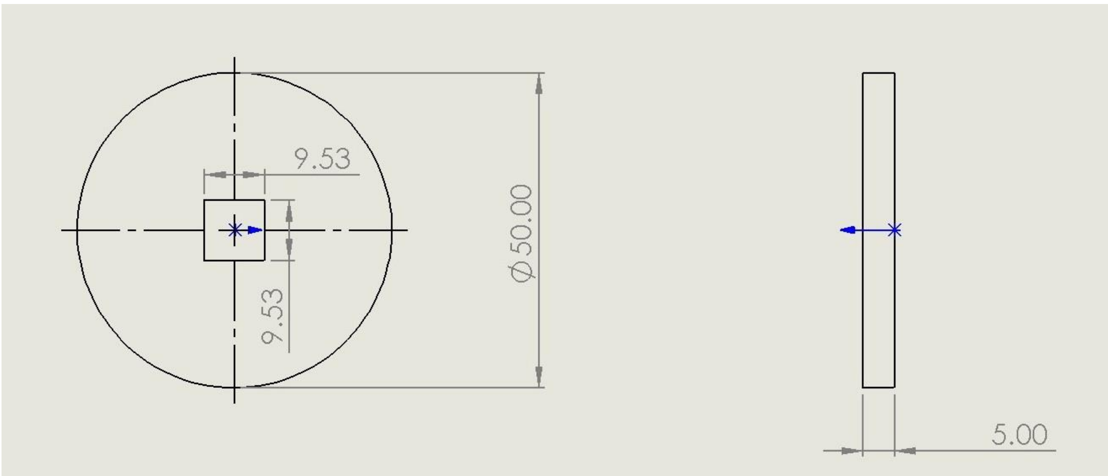


Figure 5 Input Bass

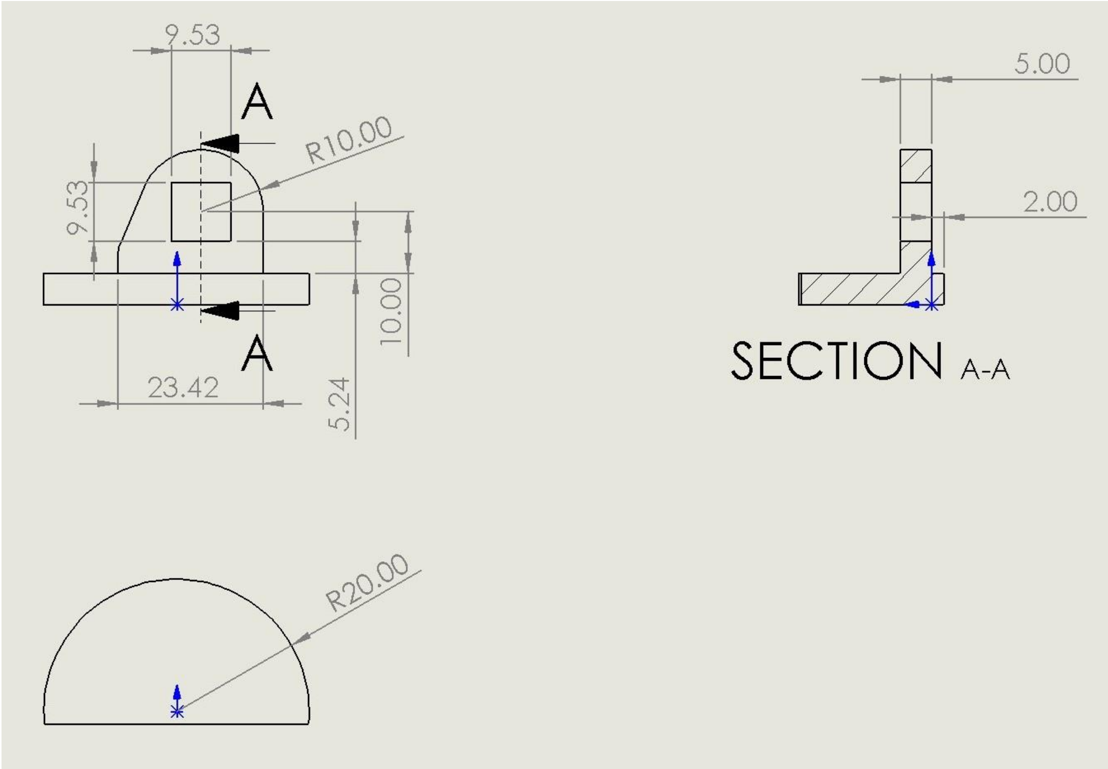


Figure 6 Input Joint 1

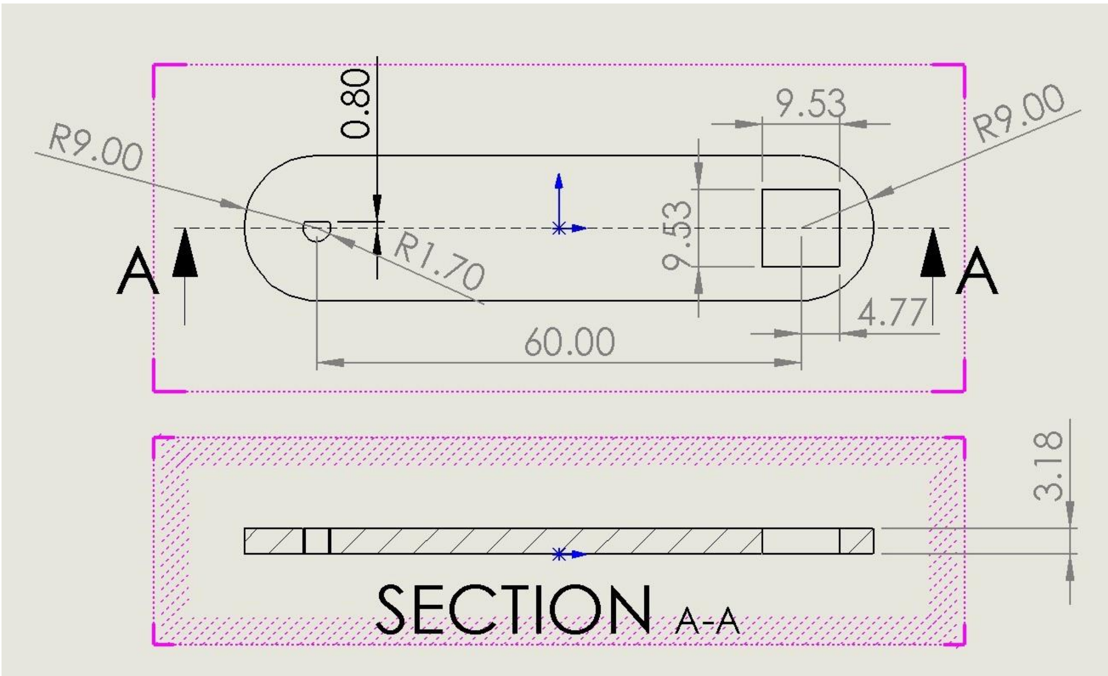


Figure 7 Input Link 1 & 2

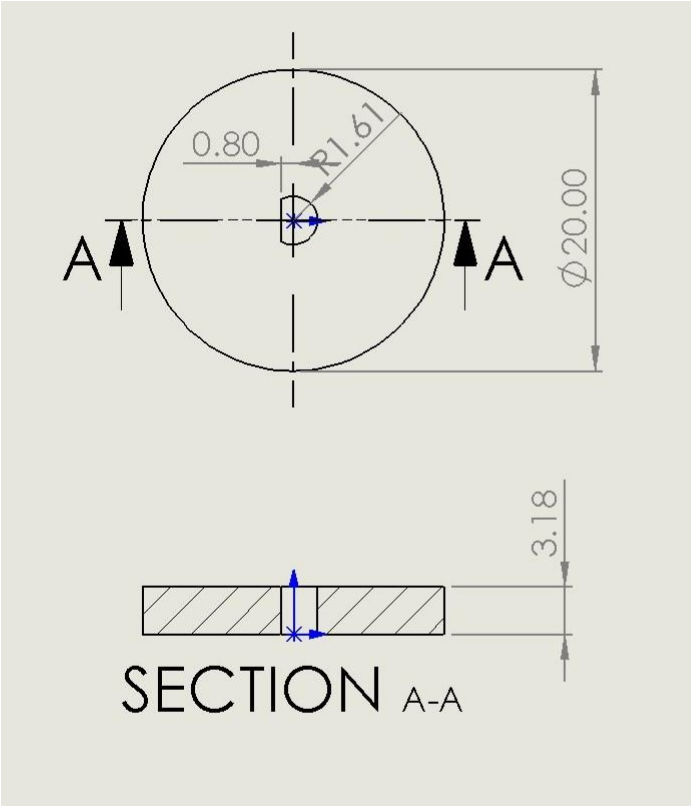


Figure 8 Flange

For the output part, I adjust the dimension of input side. Most of the design part of the output side is quite similar to the sensing part. However, I replace the potentiometer with servo motor. To make sure that the motor could be places strength to each link, I enlarge the end of the link, and dig a hole that fix the size of motor so that the motor could be fully embedded into link. To fasten the motor to the link, I use screws for connections. To connect the link to shaft, I use a long flange, which is shown as the picture below, connected both to the shaft (there is a hub inside the flange in order to connect the motor and the flange itself) and the link (use superglue). The 3D representation is showed as below.

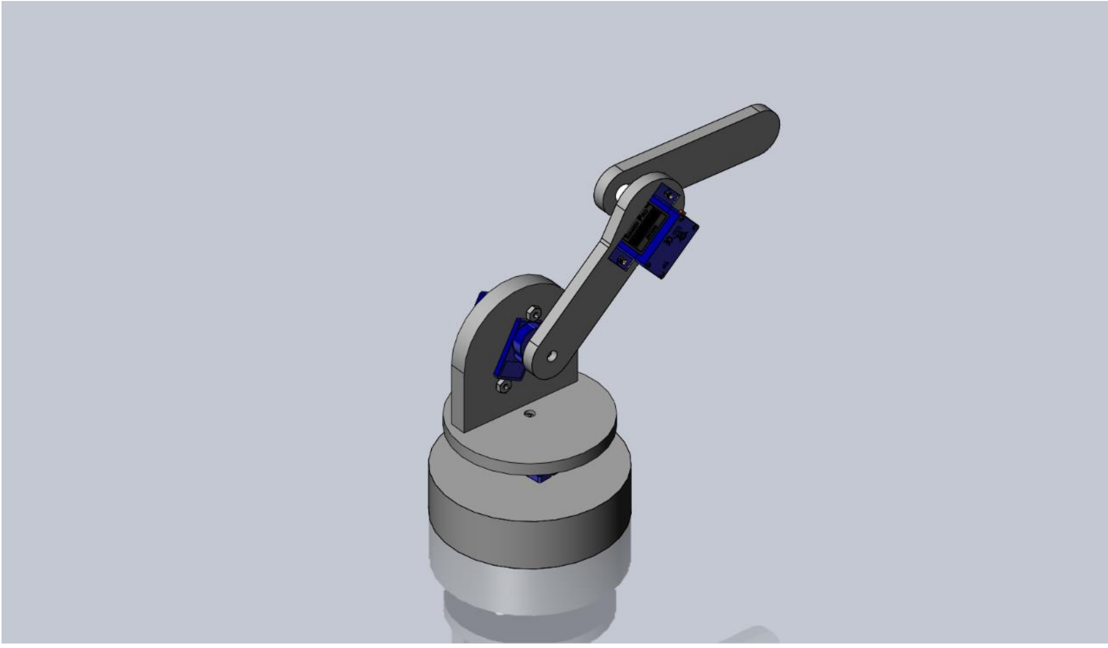

Figure 9 3D Sketch of Output

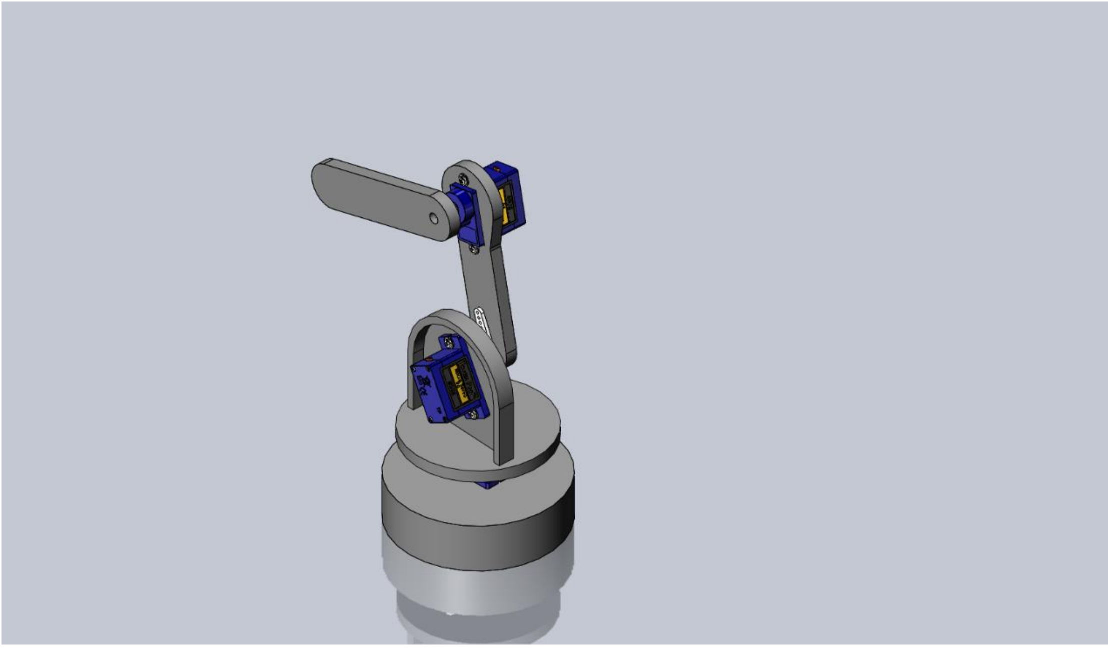

Figure 10 3D Sketch of Output

Below are the mounting details of the output part.

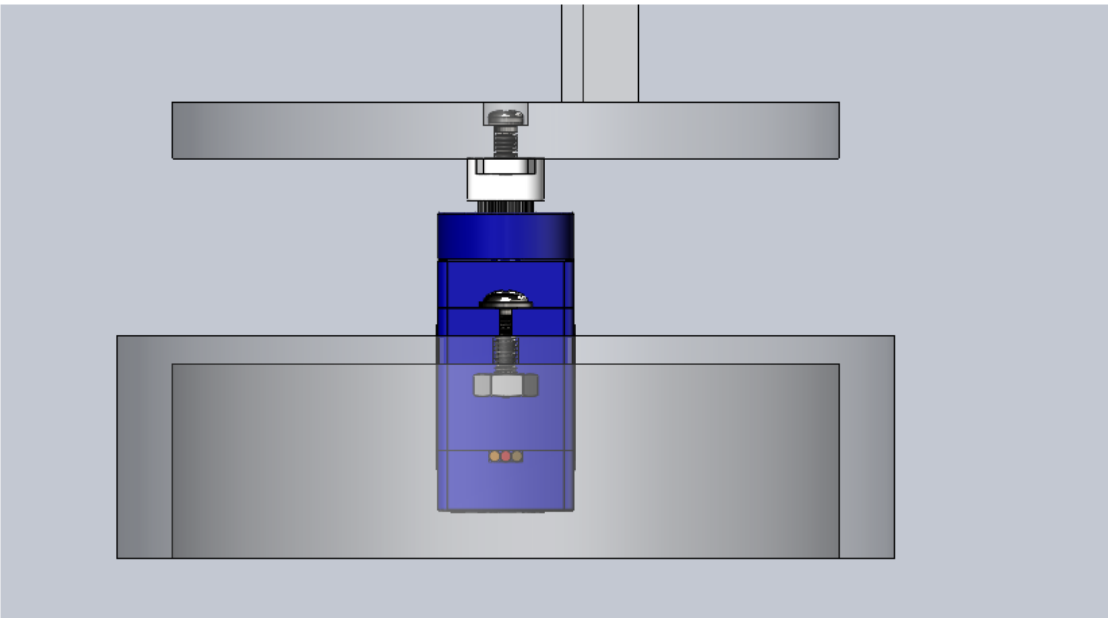

Figure 11 Mounting Details of Joint 1

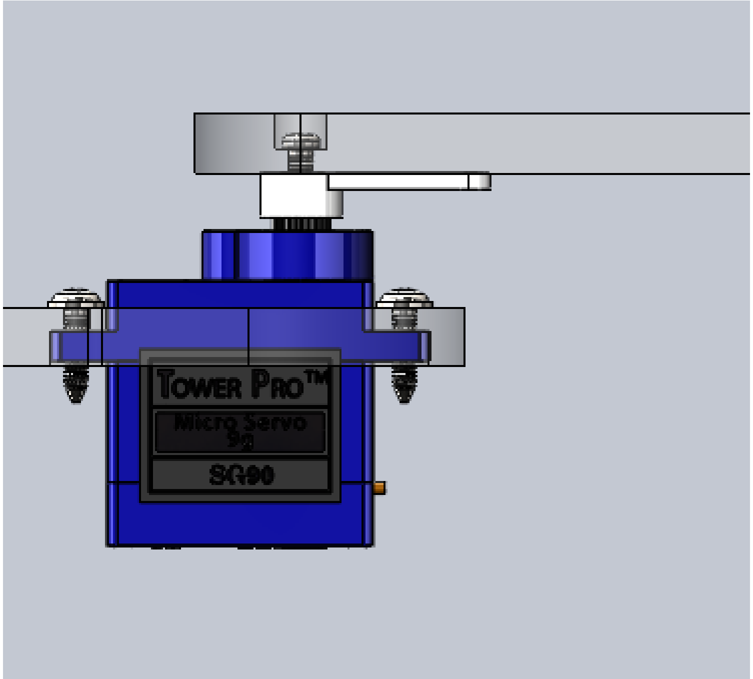


Figure 12 Mounting Details of Joint 3 (from the back)

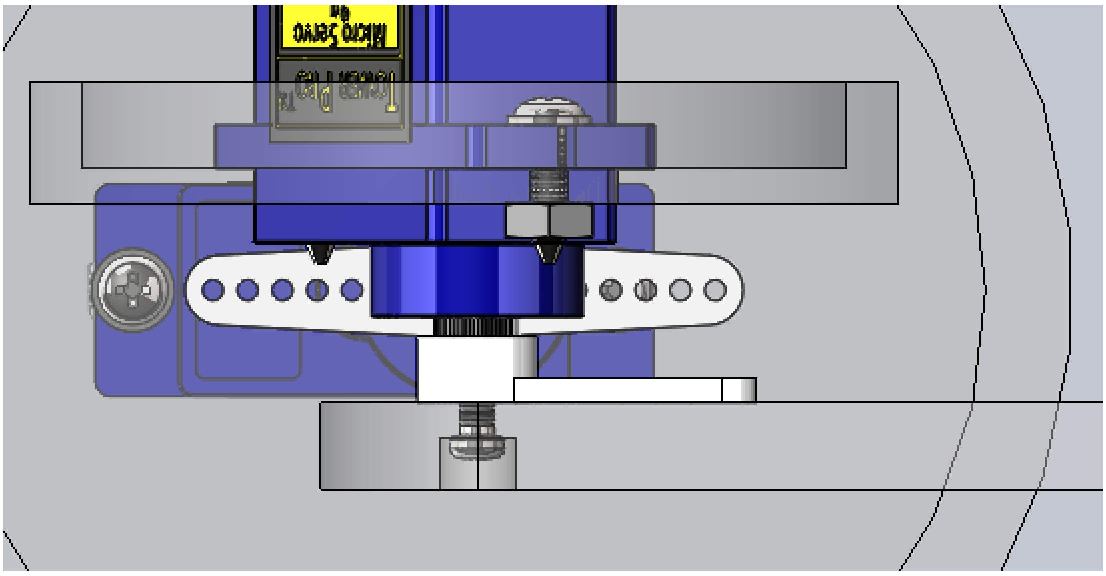

Figure 13 Mounting Details of Joint 2 (from the top)

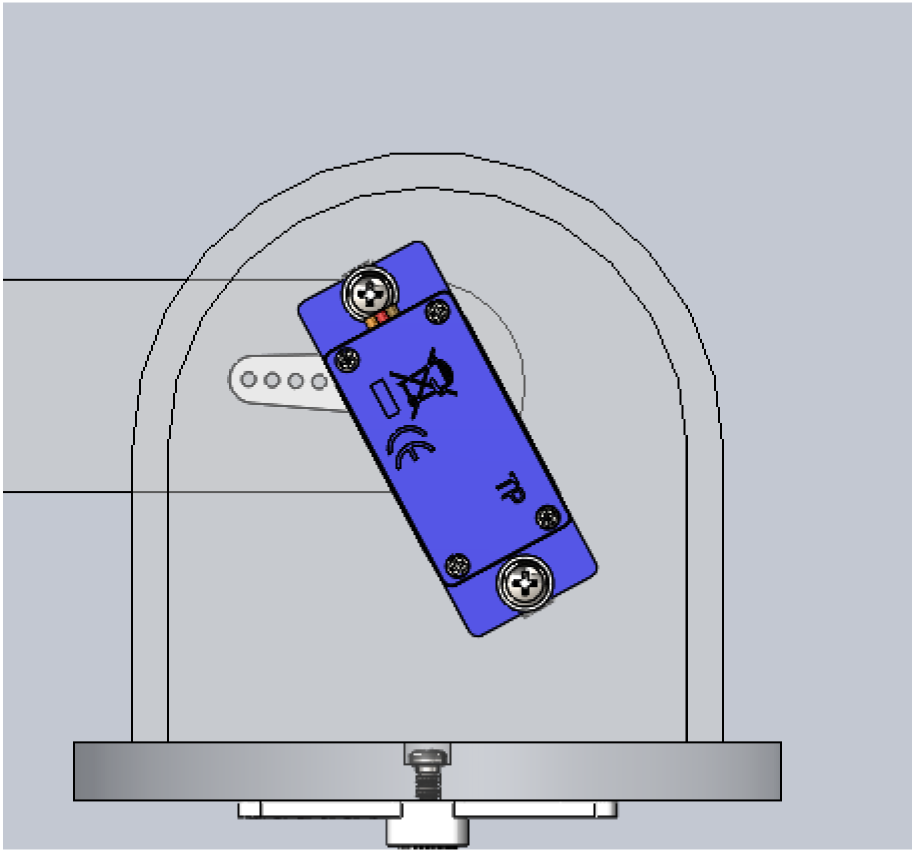

Figure 14 Mounting Details of Joint 2

Also, the dimensioned drawing below shows the overall and important dimensions of the output part.

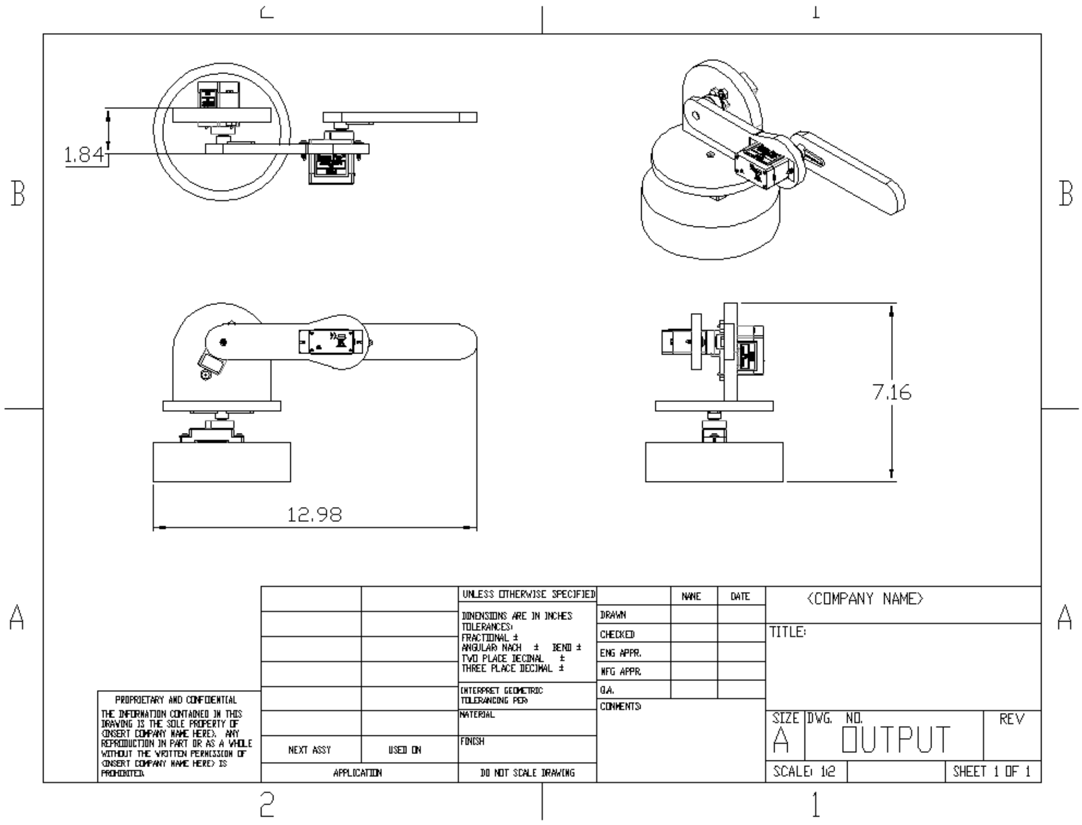


Figure 15 Assembling drawing of Output Side

The detailed dimensions of each part is shown as below.

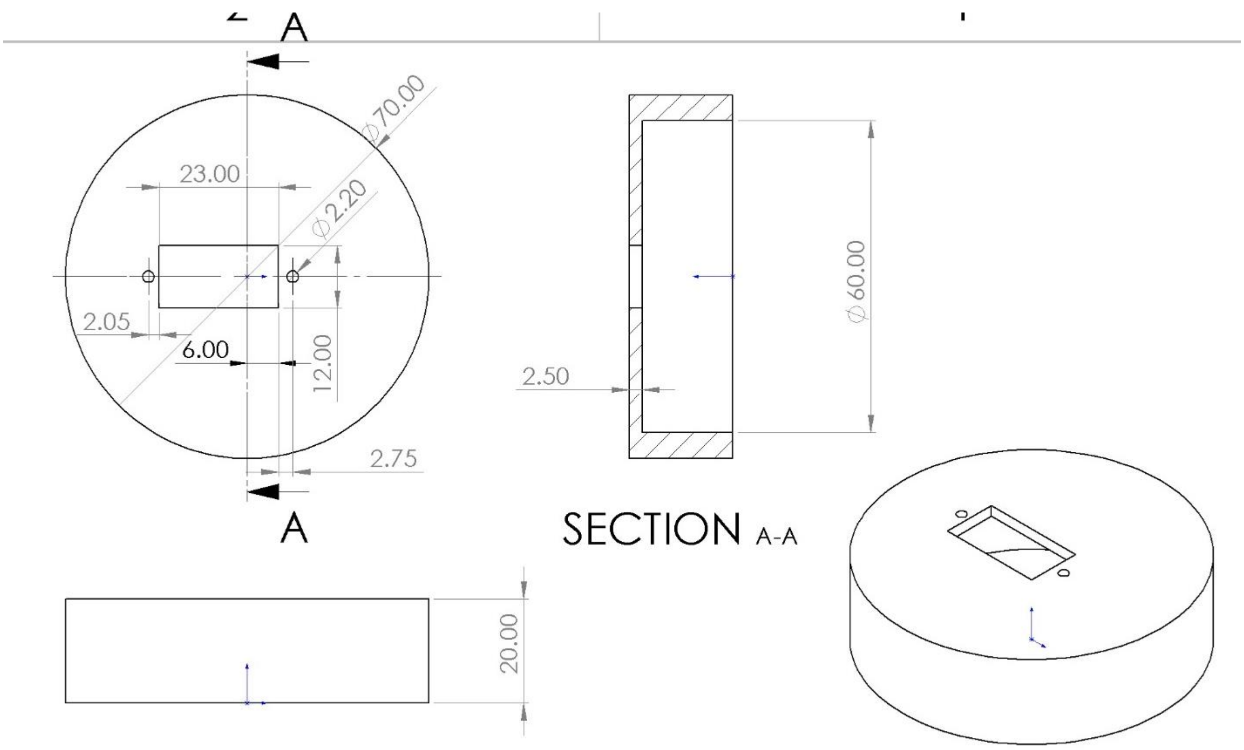


Figure 16 Dimension of Output Bass

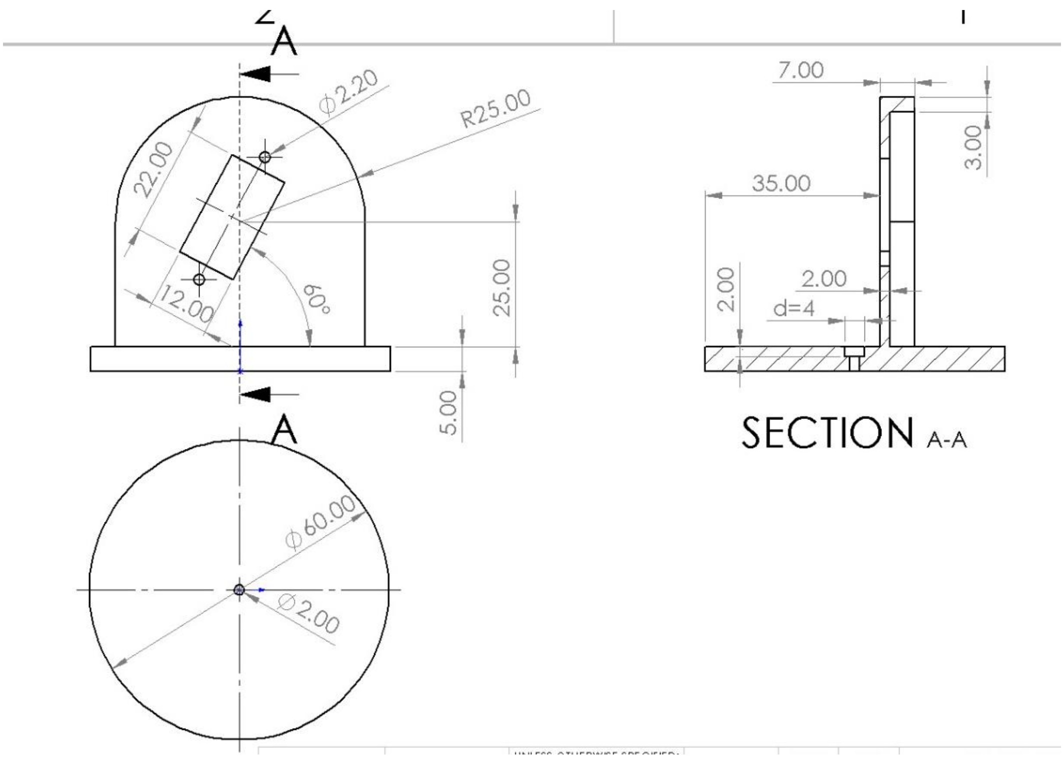


Figure 17 Dimension of Output Bass 2

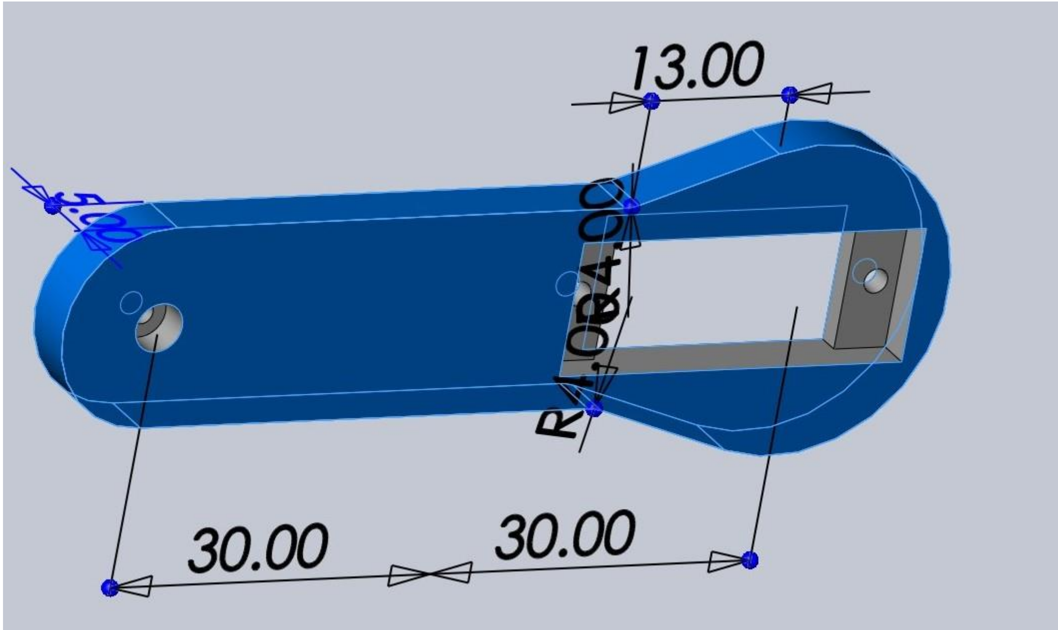


Figure 18 Dimension of Output Link 1

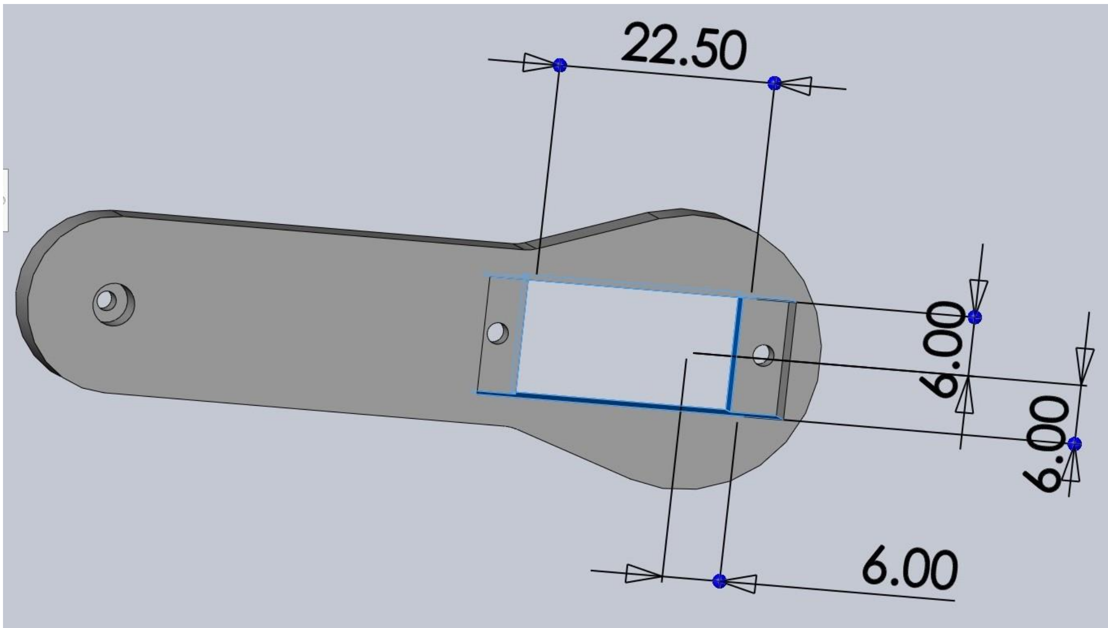


Figure 19 Dimension of Output Link 1

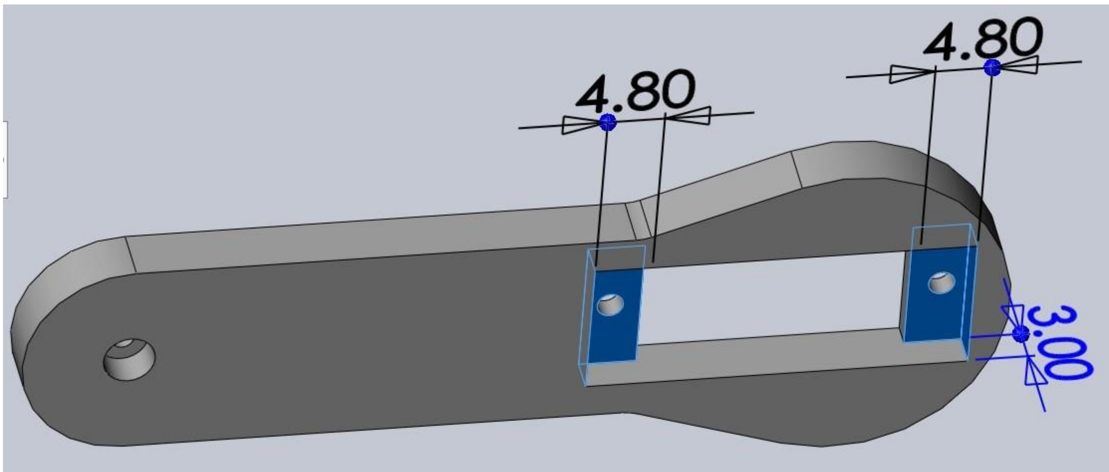


Figure 20 Dimension of Output Link 1

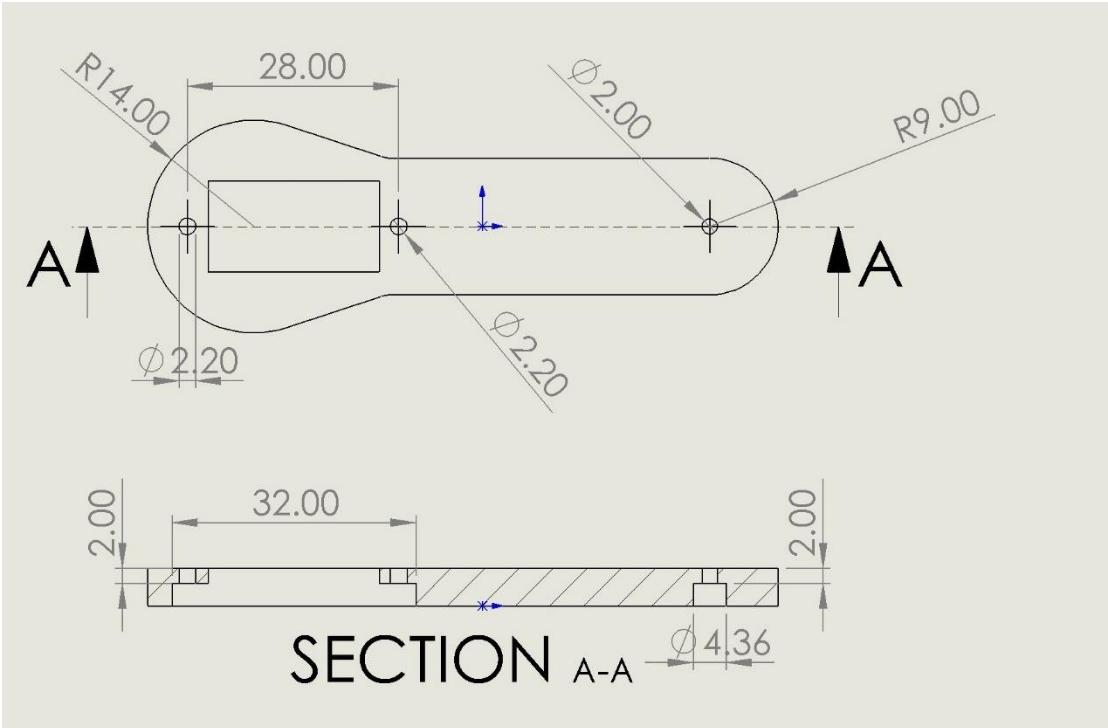


Figure 21 Dimension of Output Link 1

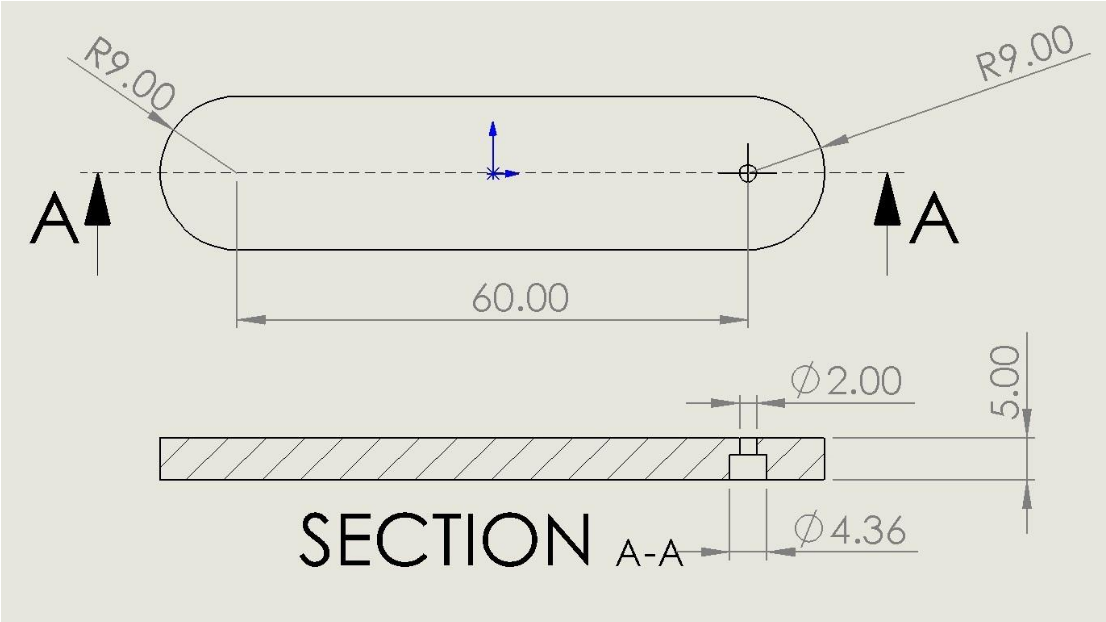


Figure 22 Dimension of Output Link 2

## 2. Hardware fabrication and analysis

I use SG 90 servo motor mounted on my output part. From the lecture slide #L10 Page 39, we know that the free-run current at 6 V is 120mA, the stall current at 6V is 800mA. It means that the current needed to draw the motor moving is 120mA. And when the motor applies its maximum amount of torque that is being produce, the current drawn is 800mA.


| | |
|---|---|
| Digital?: | N |
| Free-run current @ 6V: | 120 mA |
| Stall current @ 6V: | 800 mA |
| Speed @ 6V: | 0.10 sec/60° |
| Stall torque @ 6V: | 1.5 kg·cm |
| Speed @ 4.8V: | 0.12 sec/60° |
| Stall torque @ 4.8V: | 1.3 kg·cm |
| Lead length: | 10 in |

Figure 23 Screenshot from Slides

However, I use 5V from the power supply to draw my motor because the datasheet mention that the operating voltage should be at around +5V. Referring from the datasheet on the Internet,

( https://www.addicore.com/FS90-Mini-Servo-p/113.html) I should ensure that the torque of the motion should not be too large. Otherwise, the motor will work at the stall current. In this case the motor won't work and will be very hot, which is bad for the motor.

| | **Operating Voltage** | |
|---|---|---|
| | **4.8V** | **6.0V** |
| **Stall Torque** | 1.3 kg/cm (18.09 oz/in) | 1.5 kg/cm (20.86 oz/in) |
| **Max Speed** | 0.12sec/60° | 0.12sec/60° |
| **Idle Current** | 5 mA | 6 mA |
| **No Load Running Current** | 100 mA | 120 mA |
| **Stall Current** | 700 mA | 800 mA |

Figure 24 Current Usage of the Servo Motor

The circuit diagram of the whole system is shown as below:

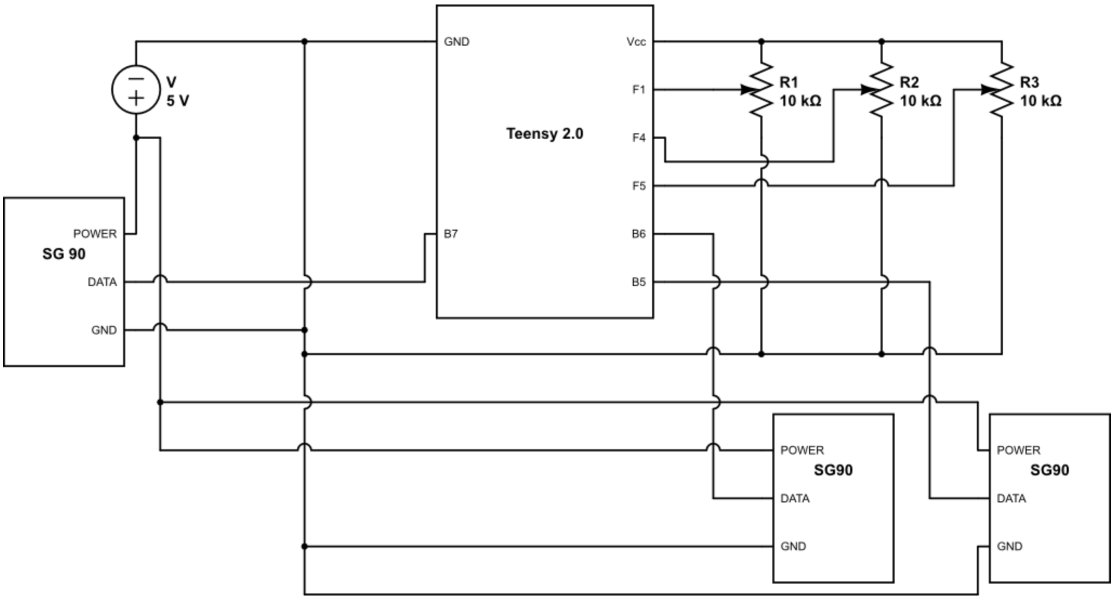


Figure 25 Circuit Diagram

From the circuit diagram above, we know that the motors are in parallel with each other, connected to the power supply and the shared ground. The idle current for each motor is 5mA. If all the motors works in idle status, the whole current drawn should be at around $3 \times 5 = 15mA$. When the motors are in free run, i.e. all the motor are working in a gentle way, the whole current drawn is at around $3 \times 100mA = 300mA$. In the worst case, all the motors stall. In this case, each motor could draw

700mA, and therefore, the whole current drawn is $3 \times 716mA = 2.148A$. By inspection, since my output side is quite light and the motor do not need to draw too much torque, in the worst case, the current draw of my circuit is 0.690A (inspected from the power supply).

My potentiometer is 3310Y-001-103L. Therefore, the maximum value of the potentiometer is $10K\Omega$. The current drawn from the teensy is $3 \times \frac{5V}{10K\Omega} = 1.5mA$, which is below the teensy's safe current 20mA(https://www.pjrc.com/teensy/techspecs.html). Also, there are current drawn from the teensy to send signal to 3 of the motors.

Therefore, I set the maximum current of the power supply to more than $2.1 + 0.0015 + 3 \times 0.02 = 2.2615A$ So I set the maximum current of the power supply to 2.4 A, including the stall, teensy and potentiometer's current. As long as the current of the circuit is below 2.4A, the circuit will work quite well.

## 3. Software Integration and demonstration

The code is submitted separately on Canvas. Figures below show the full range of motion of each degree of freedom.

Joint 1's limitation:

The joint 1's limitation is almost at around 180°, which is shown as below.

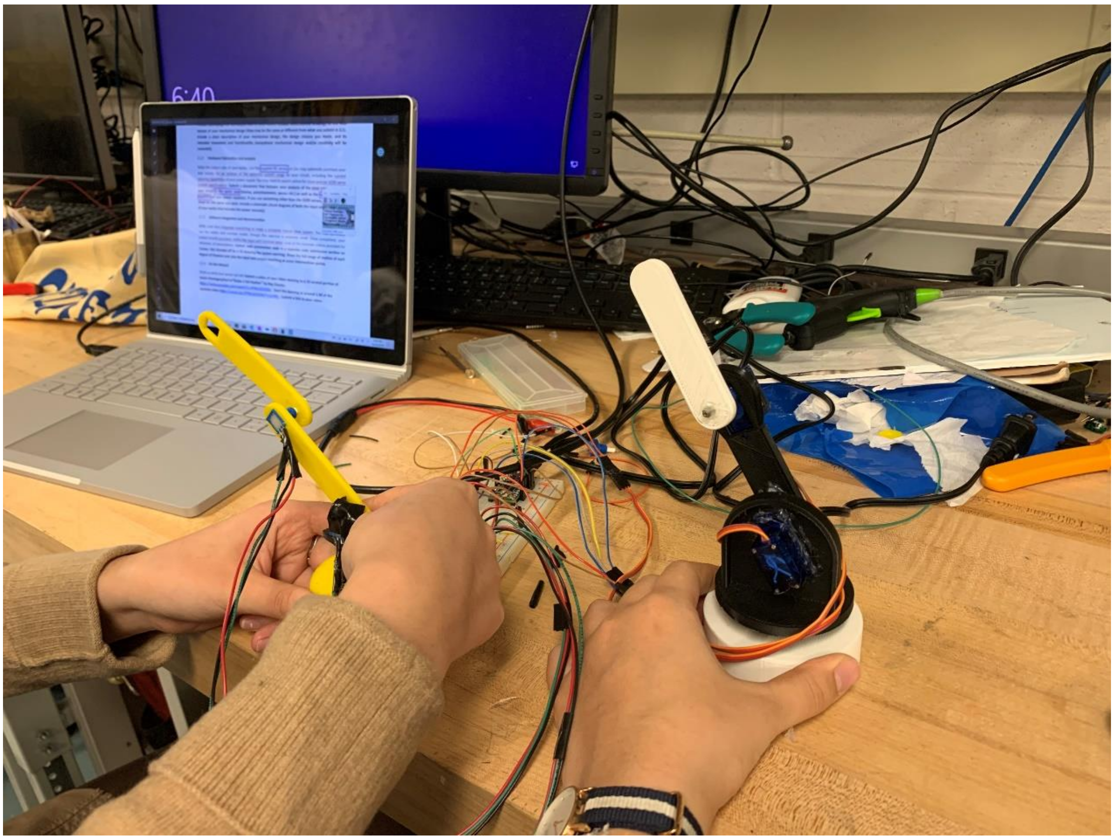

Figure 26 Joint 1 Limitation

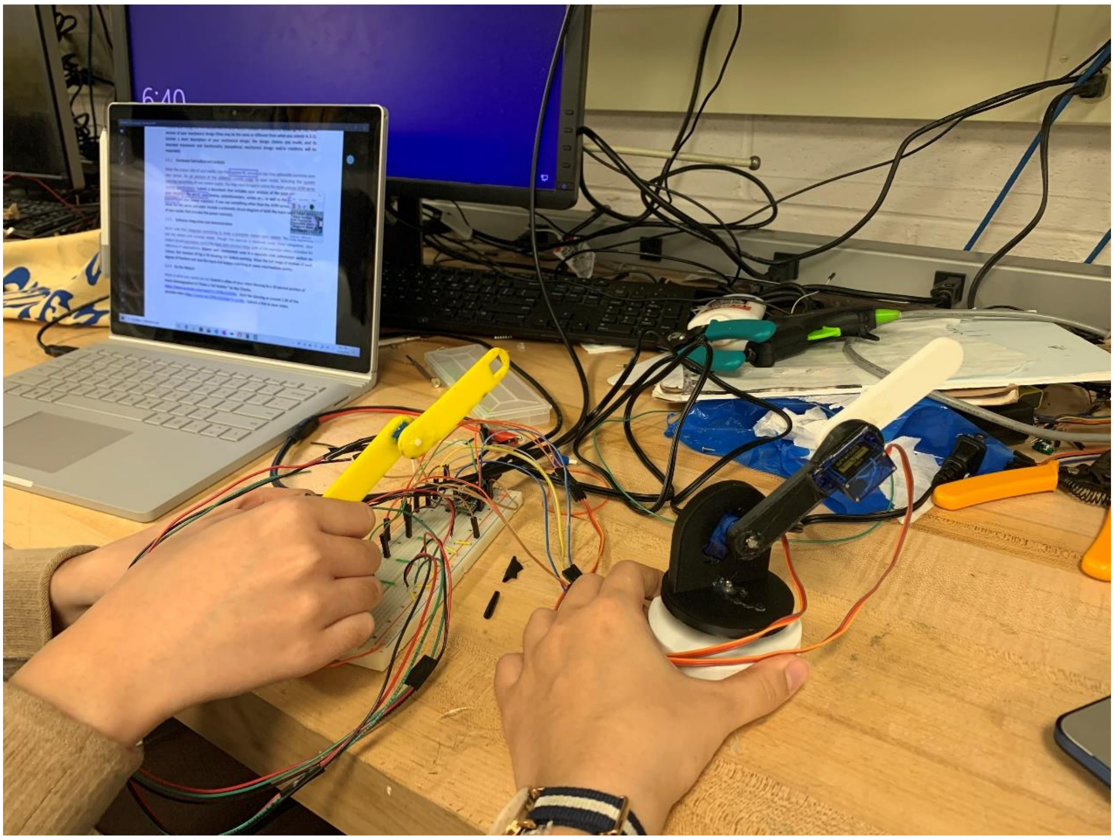

Figure 27 Joint 1 Limitation

Joint 2 Limitation

At first I plan to design a link that could rotates along its axis at around 180°. However, in the real mounting, there are some self-collisions of this link and the desk/ bass.

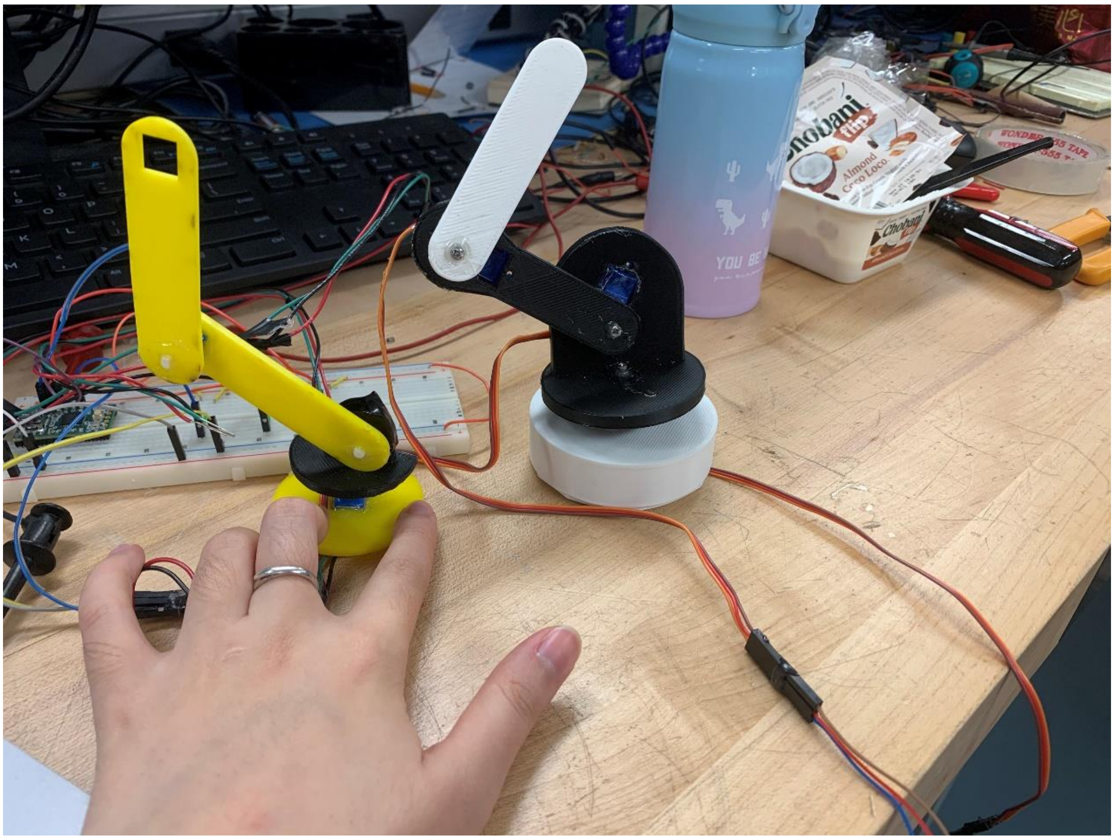

Figure 28 Joint 2 Limitation(both potentiometer and motor reach their limits)

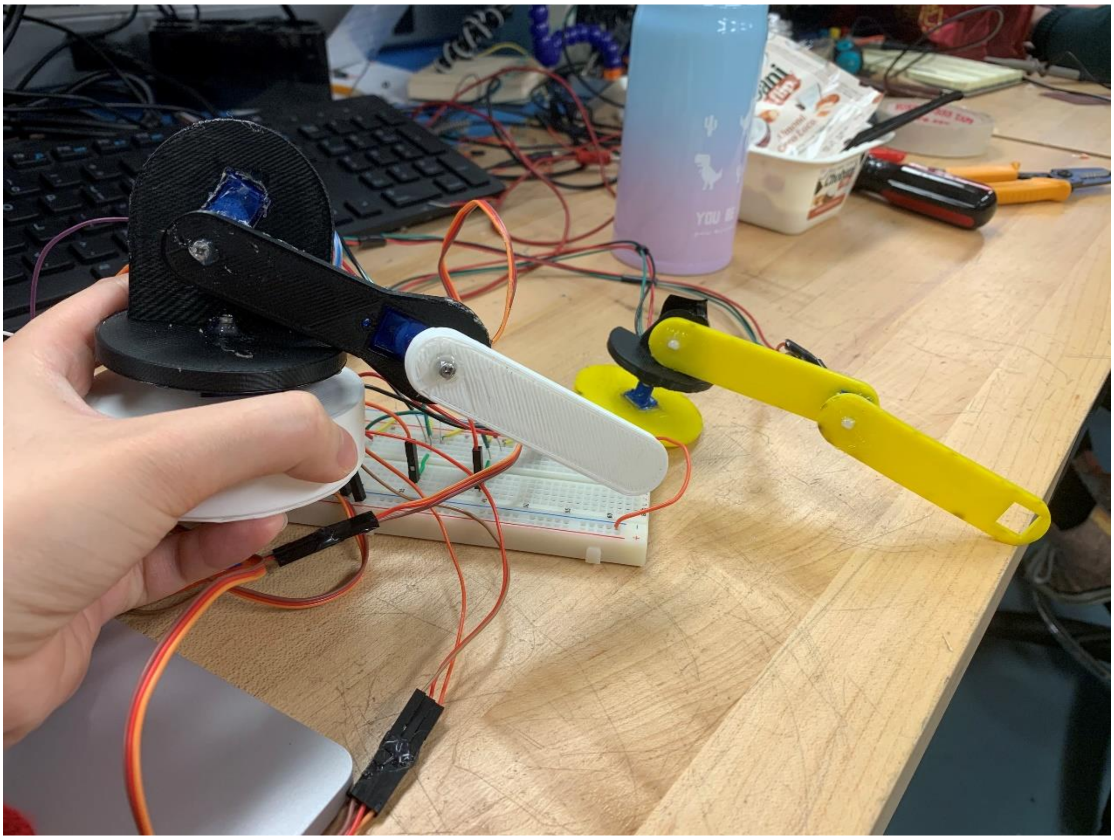

Figure 29 Joint 2 Limitation (because of self-collision)

Joint 3 Limitation:

Joint 3’ s limitation is set to around 180°.

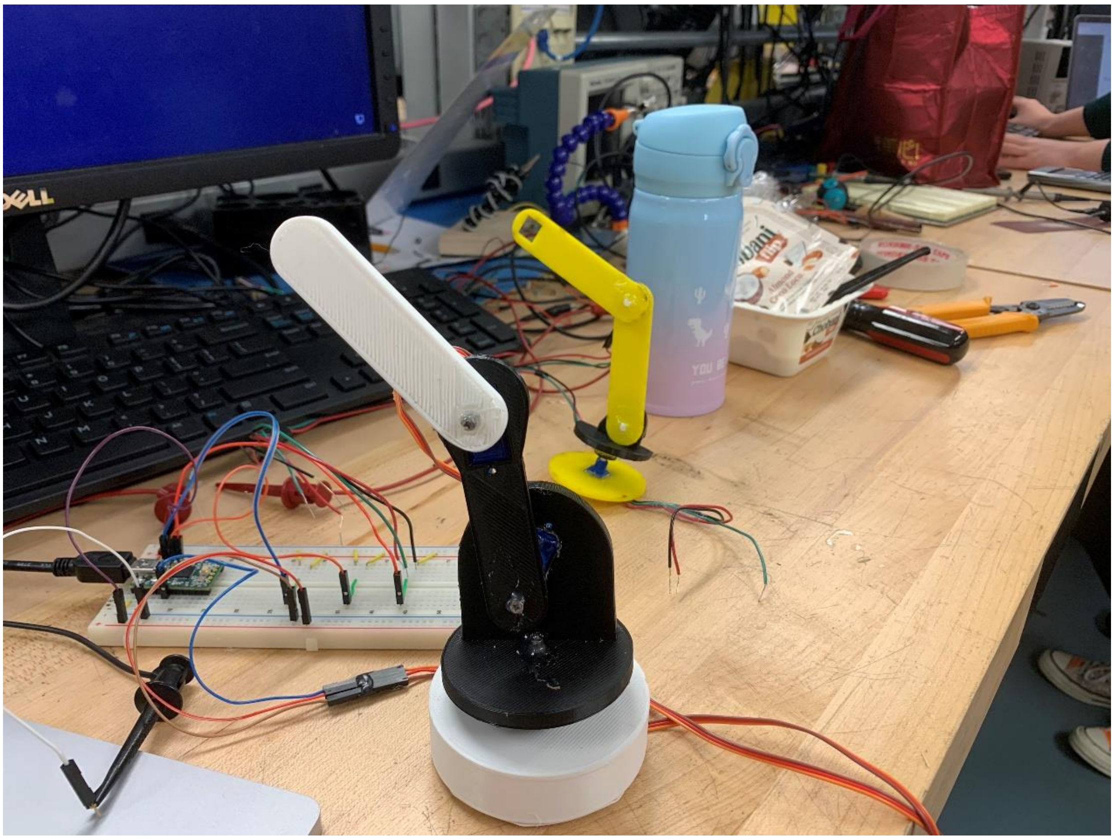

Figure 30 Joint 3 Limitation (both potentiometer and motor reach their limits)

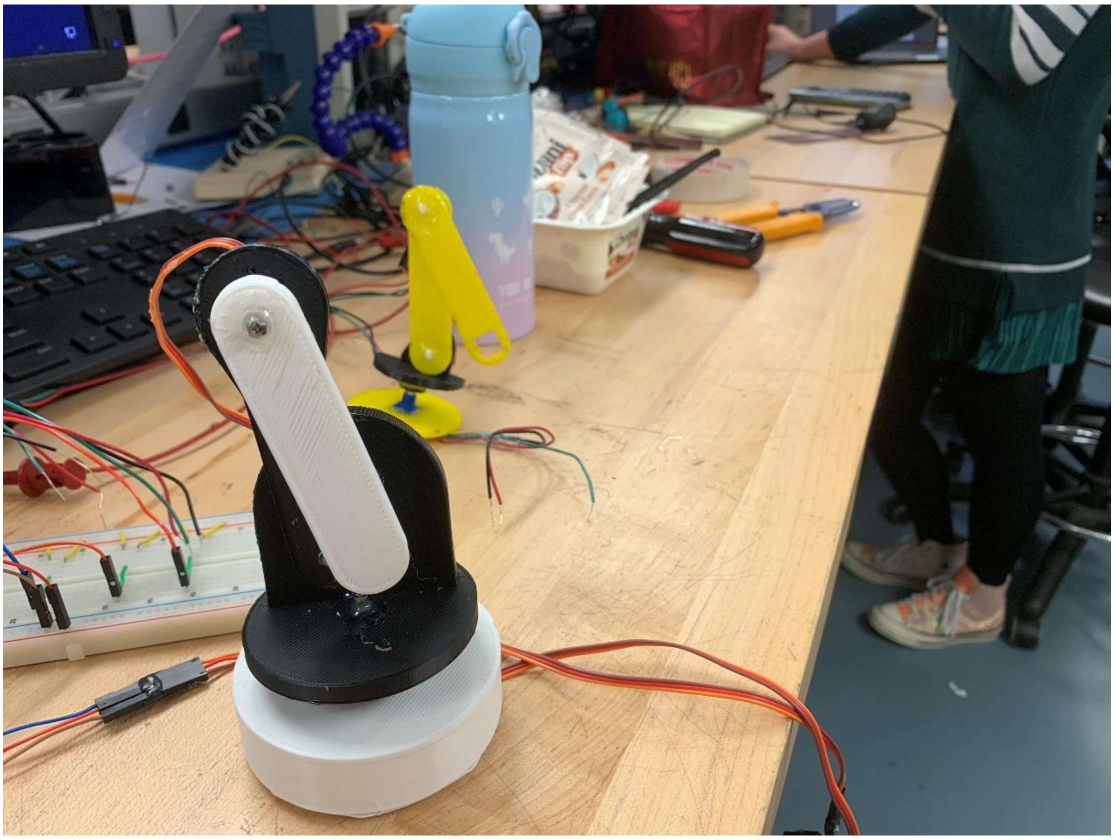

Figure 31 Joint 3 Limitation (the motor reach its limit)

Intermediate Points:

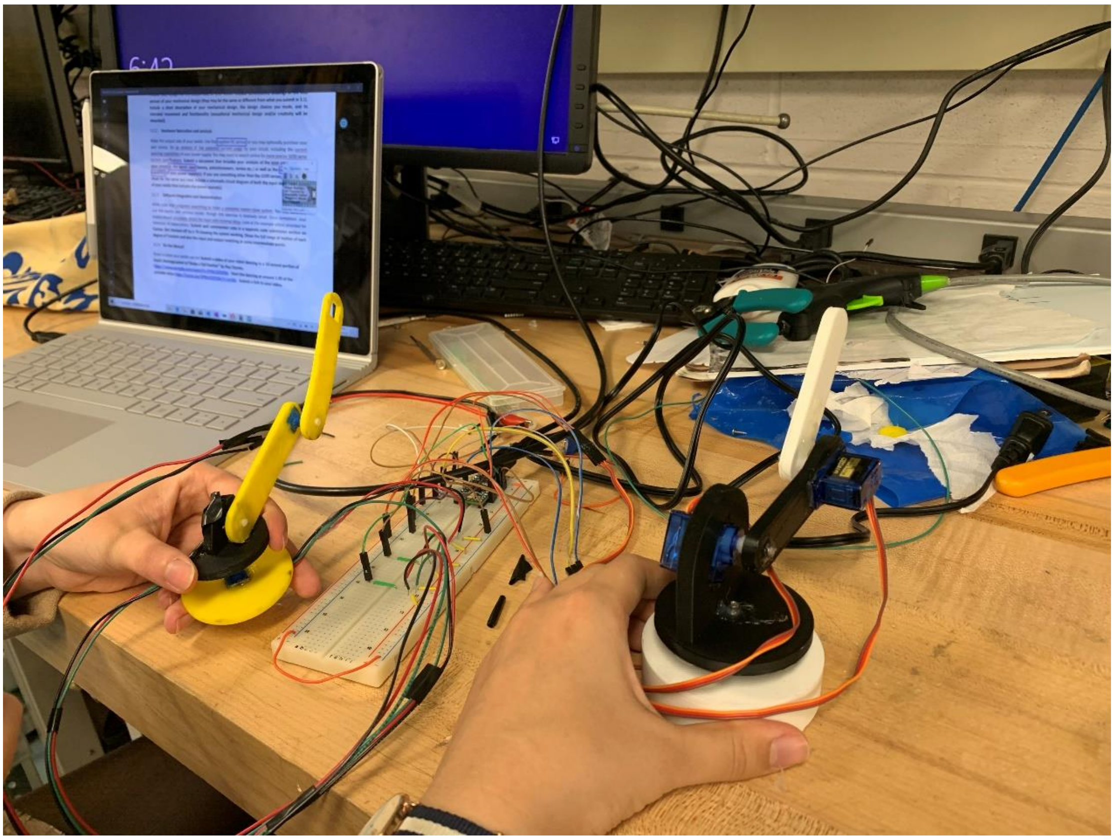

Figure 32 Intermediate Points

By adjusting the angle read by teensy in the code, the input side totally matches the output side in its full range.

## 4. Do the Watus.

The video is in the link below:

https://drive.google.com/file/d/1uZyIOPrHcd2vpPz_YNgULEIHckDRJUuq/view?usp=sharing