Design and Development of a Planar Robot Arm

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Project Definition

The purpose of this project is to design and manufacture a planar robot arm. This project is done as a personal project to test and apply knowledge learned during university education. This project will utilize methods of robotics and automation, as well as control systems, actuators and power electronics, rapid prototyping, and mechatronics design.

The previous iteration of SARA left off with 4 motors controlled by a membrane switch, and an end effector designed to hold a marker to allow the arm to draw. This configuration came with many limitations that the next iteration seeks to improve on. These improvements include updated controls, and a replacement of the end effector.

Requirements

The robot arm must have at least 3 degrees of freedom, but may extend to 6 depending on the capabilities of the system. The arm is to utilize as many on-hand components as possible. The arm must be designed around the use of MG996R servo motors. The links of the arm are to be 3D printed as much as possible. The robot must be controlled using an arduino uno microcontroller or similar. The end effector is to be designed to be replaceable.

Additional requirements for the second iteration of the arm will be that the end effector must be capable of grabbing and letting go of small objects. The goal of the updated iteration of the arm is to be used for short range pick and place operations.

Test Results of Initial Design

The initial design of SARA consisted of 4 servo motors controlled by a membrane keypad switch. The switch was designed to move each motor a set amount in a specific direction depending on which button was pressed. For example, buttons 1 and 4 on the switch controlled the shoulder motor in the positive and negative direction respectively. This means that precise control of the arm is extremely difficult. The angle of change the motor undertakes must be determined in the code beforehand, making it impossible to move the arm large distances, while being precise at the same time. This is due in part to the membrane switch's inability to to move the arm by holding down the buttons. Each button press moves the arm a set amount, and must be released and pressed again to continue to move. For these reasons, The membrane switch is to be removed from the design, and replaced with a new method of control.

Weight is an issue when the arm is fully extended. The motor cage inside the base has a little bit of flexibility to it, and because of this, as the arm extends the end effector further away from the base, the shoulder joint begins to bend under the weight of the rest of the arm. It is recommended that the motor cage within the base be reinforced to mitigate the flexibility it has under the weight of the rest of the arm.

Engineering Specifications

The system needs to be able to be controlled by the user. The servo motors max speed should not exceed its maximum operating speed of 60 degrees per second. The arm should be capable of rotation of at or close to 360 degrees perpendicular to the ground plane of the arm. The additional links should have a degree of freedom to rotate at least 90 degrees in either direction from its zero position. The robot arm needs to be able to support the weight of the servo motors, which are 55 grams each. Any end effector designed for grabbing objects should be able to handle a minimum load of 55 grams as well.

Concept Generation

Body

The main design of the body remains the same as the previous iteration of the arm. The base allows the robot to be bolted securely to a desk for future testing to ensure that the arm does not tip over under its own weight.

End Effector

The main function of the redesigned end effector remains the same: a gripper for pick and place operations. With the weight issue being considered from the test results of the initial design, concepts were made to try and find a creative way to actuate a gripper without adding another servo motor to the end of the arm. These designs would be sacrificing the wrist joint at the end of the arm in favor of the reduced weight.

These designs revolved around a latch system that would clamp around the motor at the end of the arm. That motor, instead of being used for the wrist joint, would be used to actuate the grip itself. These designs and the notes on them can be seen in figures

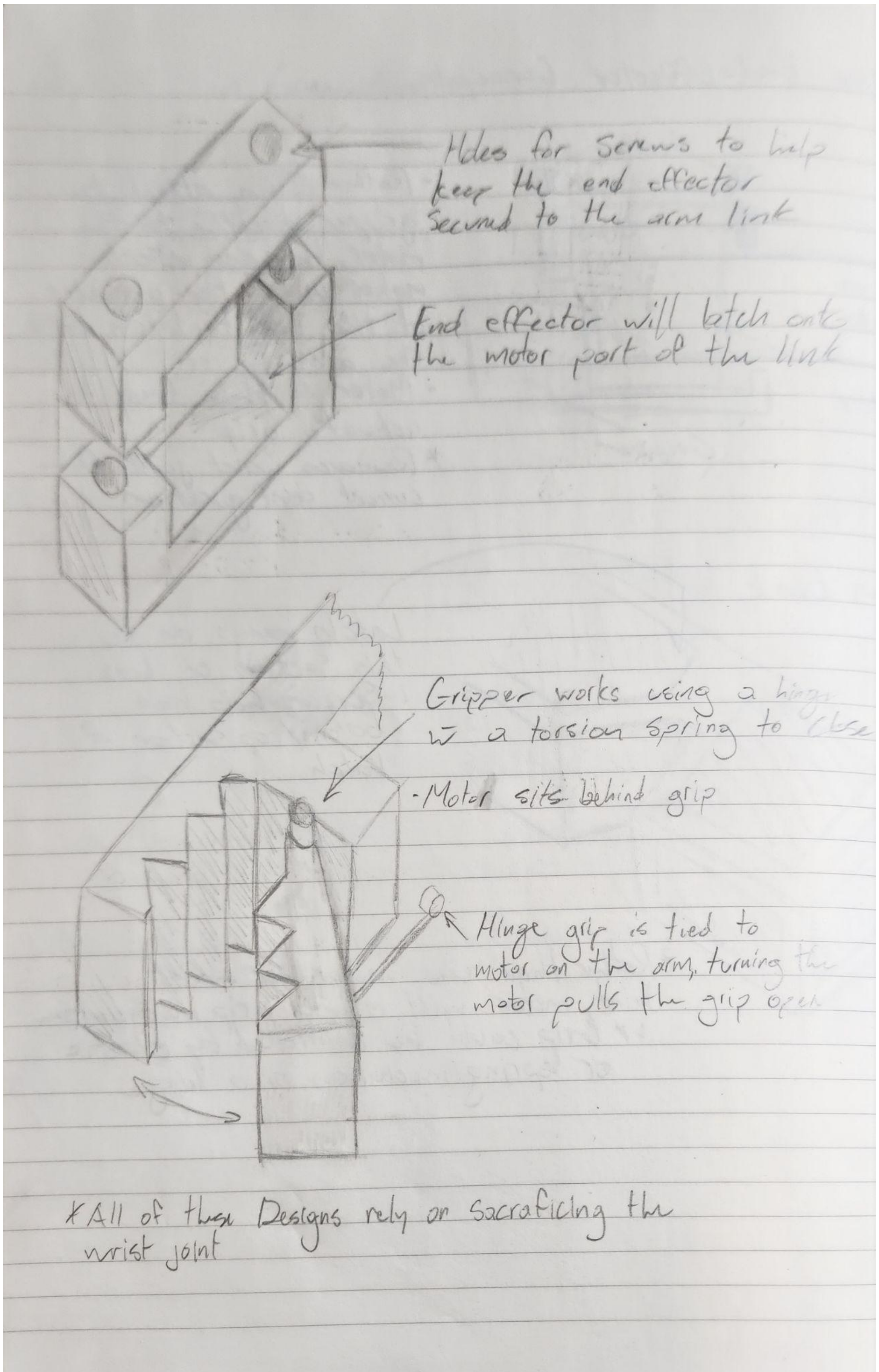

Holes for Screws to help keep the end effector Secured to the arm link
End effector will latch onto the motor port of the link
Gripper works using a hinge w/ a torsion Spring to close
·Motor sits behind grip
Hinge grip is tied to motor on the arm, turning the motor pulls the grip open
*All of these Designs rely on Sacraficing the wrist joint

Figure 1

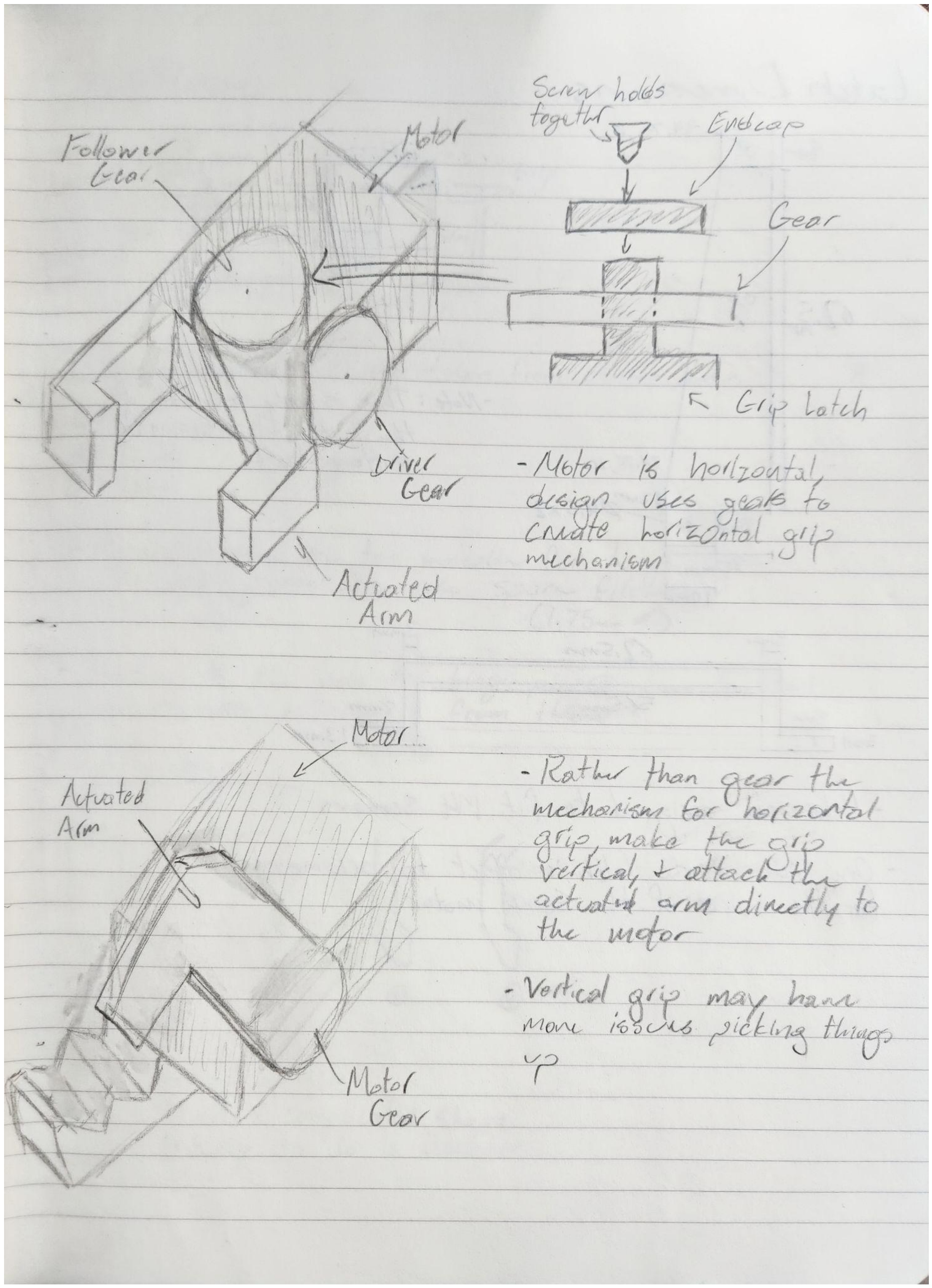


Figure 2

Ultimately, after testing of the latch design, it was determined that another motor would in fact be needed in order to reliably operate the gripper. The wrist joint was reintroduced in the design process, and the old end effector repurposed into a hybrid wrist-gripper mechanism. The concepts and their notes can be seen in figure 3.

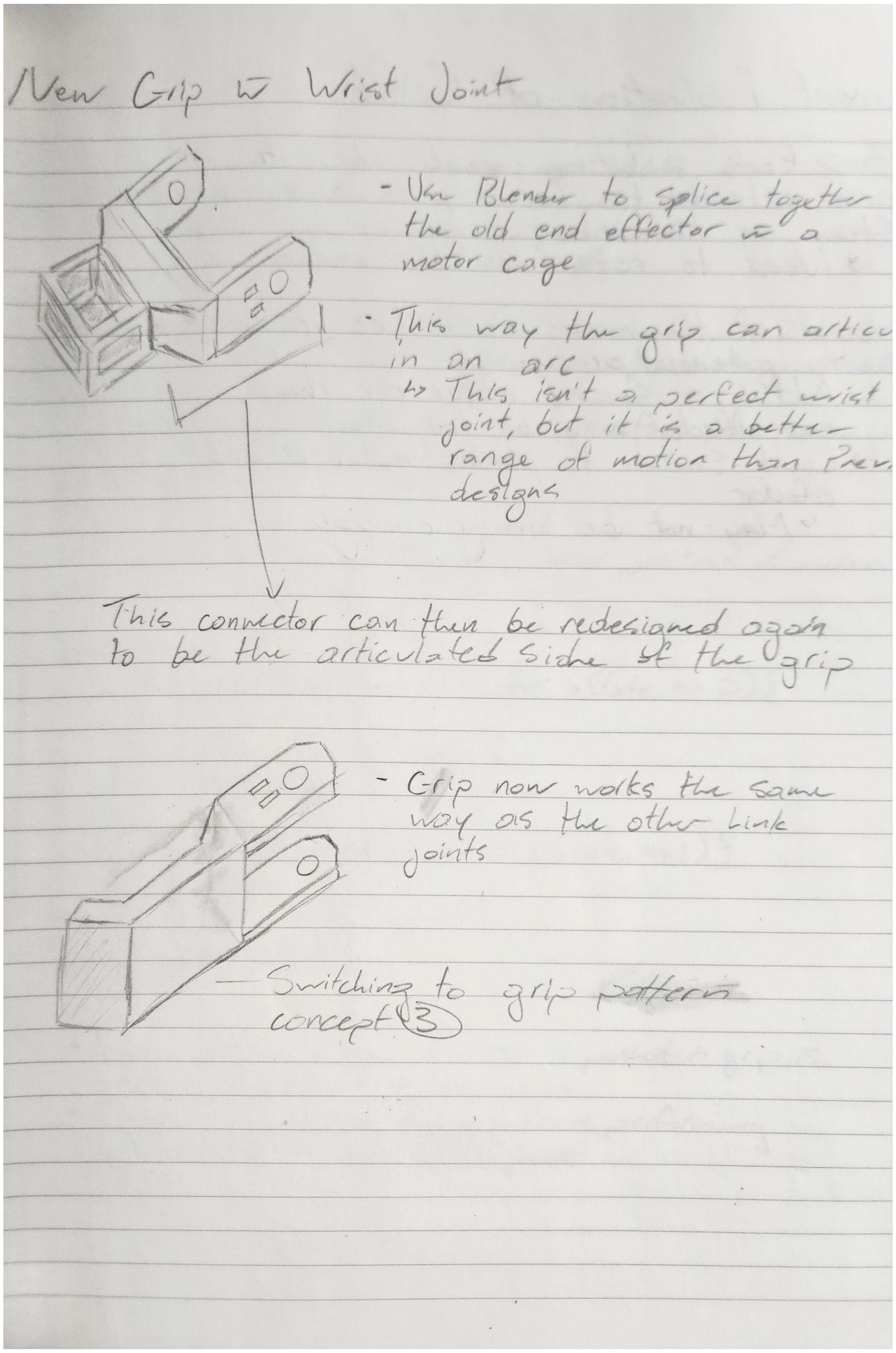


Figure 3

Controller

Control could be implemented using a few different modules. An IR remote with a receiver could be used to control the robot arm without wirelessly. The buttons on the remote could be rigged to control each motor separately. A similar setup could be used with a membrane switch, however this lacks the wireless capability. A joystick could be used similar to the design shown in figure 2, however this creates a problem with usability, and intuitive controls with the motors. The joystick would have limited capabilities with regards to how many motors it could control at a time.

Form Design and Engineering Analysis

Ultimately it was decided that for the first prototype of the robot arm, the second, more blockier concept for the body would be used along with the first concept for the end effector. Modeling and design started with taking the dimensions of the servo motor, and creating a cage that will be present in all of the links for the arm. The 3D model was then loaded onto the printer, and dimensions were tuned until the test print was capable of holding the motor firmly in the cage. The 3D model and final test print of the motor cage can be seen in figure 4 and figure 5. The slot in the motor cage is to allow the wires that come off of the side of the motor to be accessible without interfering with the cages ability to hold the motor.

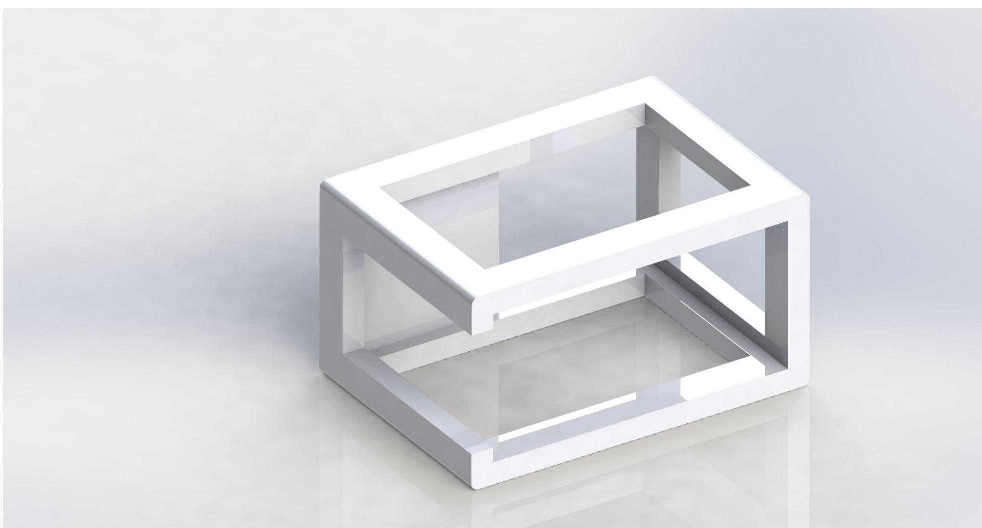


Figure 4

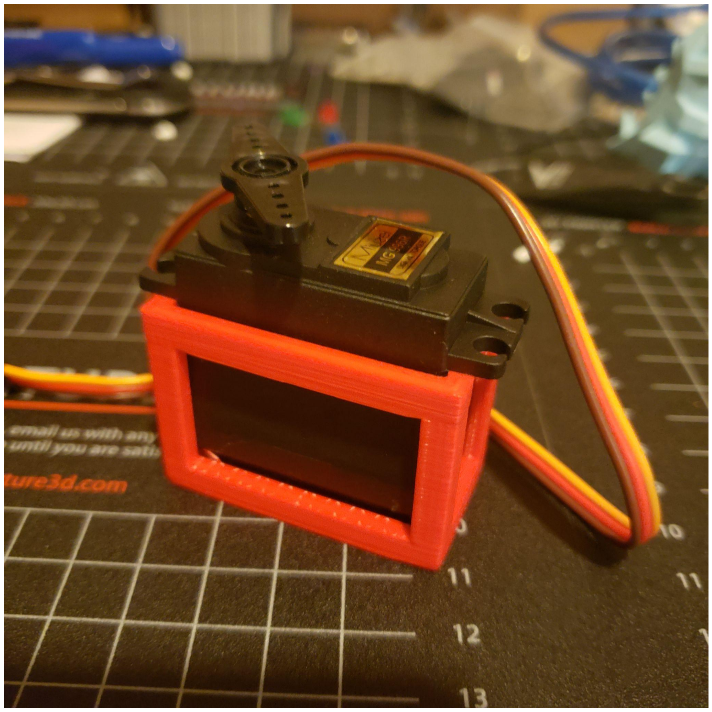


Figure 5

Once the dimensions of the motor cage were finalized, the cage was used as a starting point for the links and base of the robot. The links were designed with a more blocky structure and an exposed motor cage. One end of the link is designed to receive the motor, and has holes cut out and notches extruded to allow the plastic propeller piece that comes with the motor to be attached to the motor to control the link. The opposite end of the link has the motor cage, designed with an additional support pin extruded from the opposite side of the motor cage in line with where the gear of the motor is. The 3D model of the links can be seen in figures 6 and 7. These links were designed with minimal support material in mind for 3D printing, as well as a hollowed out middle section to reduce the amount of material needed to manufacture the parts. The links were also designed so that any number of them could be connected in series without the need to design entirely new parts.

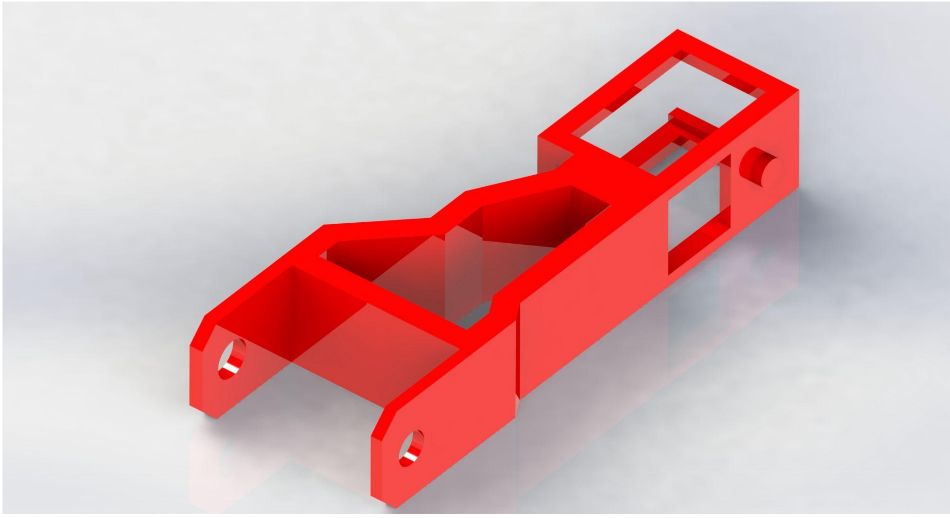


Figure 6

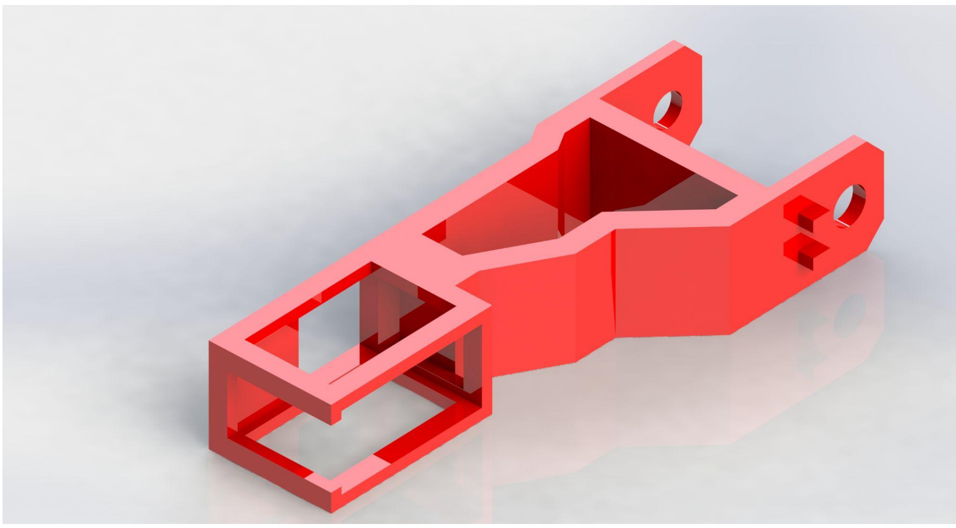


Figure 7

The platform and base of the robot arm were designed together. The base is a large cylindrical container with a motor cage in the center. The top of the cylinder contains a counterbore to allow the platform to sit on top, making it flush with the top of the base. The platform also contains a small ring around the bottom that will allow it to be screwed into a table to fix it to a surface. The bottom of the base contains a through hole directly underneath the motor cage, to allow the entire motor and platform to be removed safely from the base without pulling on the top of the robot. Just punching the motor through the hole should lift the assembly out of the base. Another through hole is cut out from the side of the base to allow the wires for the motor inside the base to be accessible. The platform contains a motor cage in a horizontal position to act as a shoulder joint. The platform also has 4 holes in a circular pattern that line up with one of the propeller pieces from the servo motors. The propeller can be screwed into the platform, and then the platform attached to the motor to allow it to rotate perpendicular to the ground. The platform and base can be seen in figures 8 and 9.

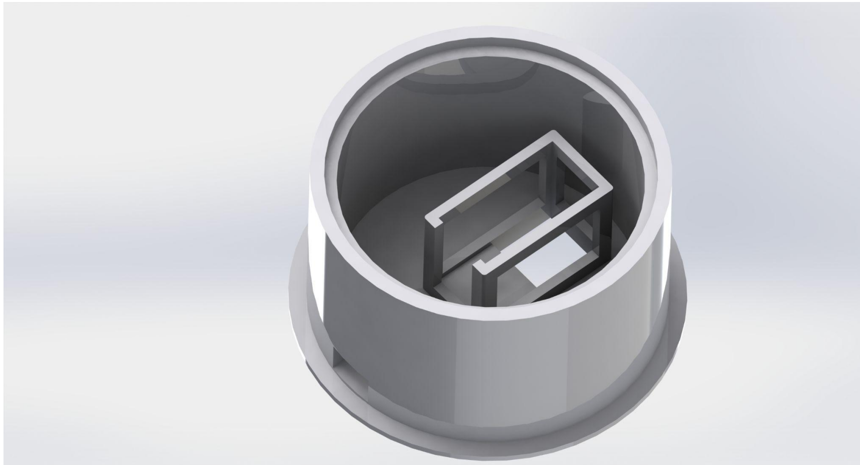


Figure 8

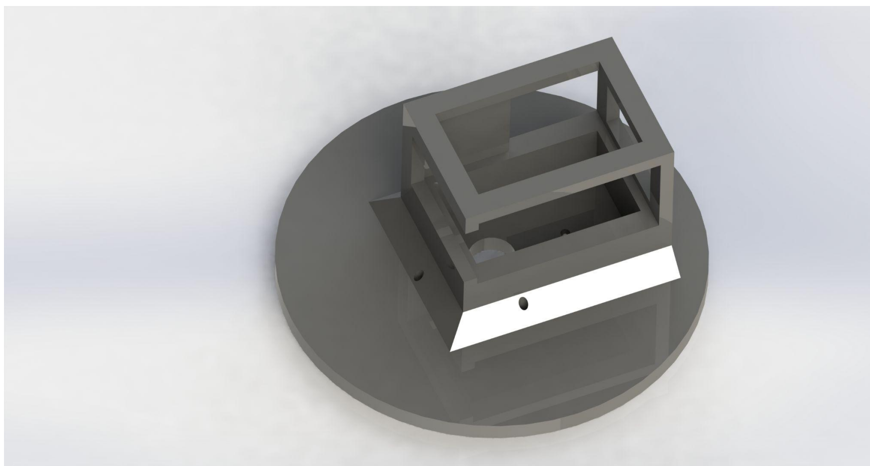


Figure 9

The end effector of the robot was designed to hold a sharpie, and connects to the motor cage of the end link. The full assembly of the robot can be seen in figure 10

Figure 10

The end effector for the wrist joint and gripper was made using the same joint system as the other links, just without the length of the arm. The motor cage attaches directly to the hinge where the link meets the motor. The same principle was then applied to the actuated half of the gripper mechanism. The full design for the arm can be seen in figures 11 and 12.

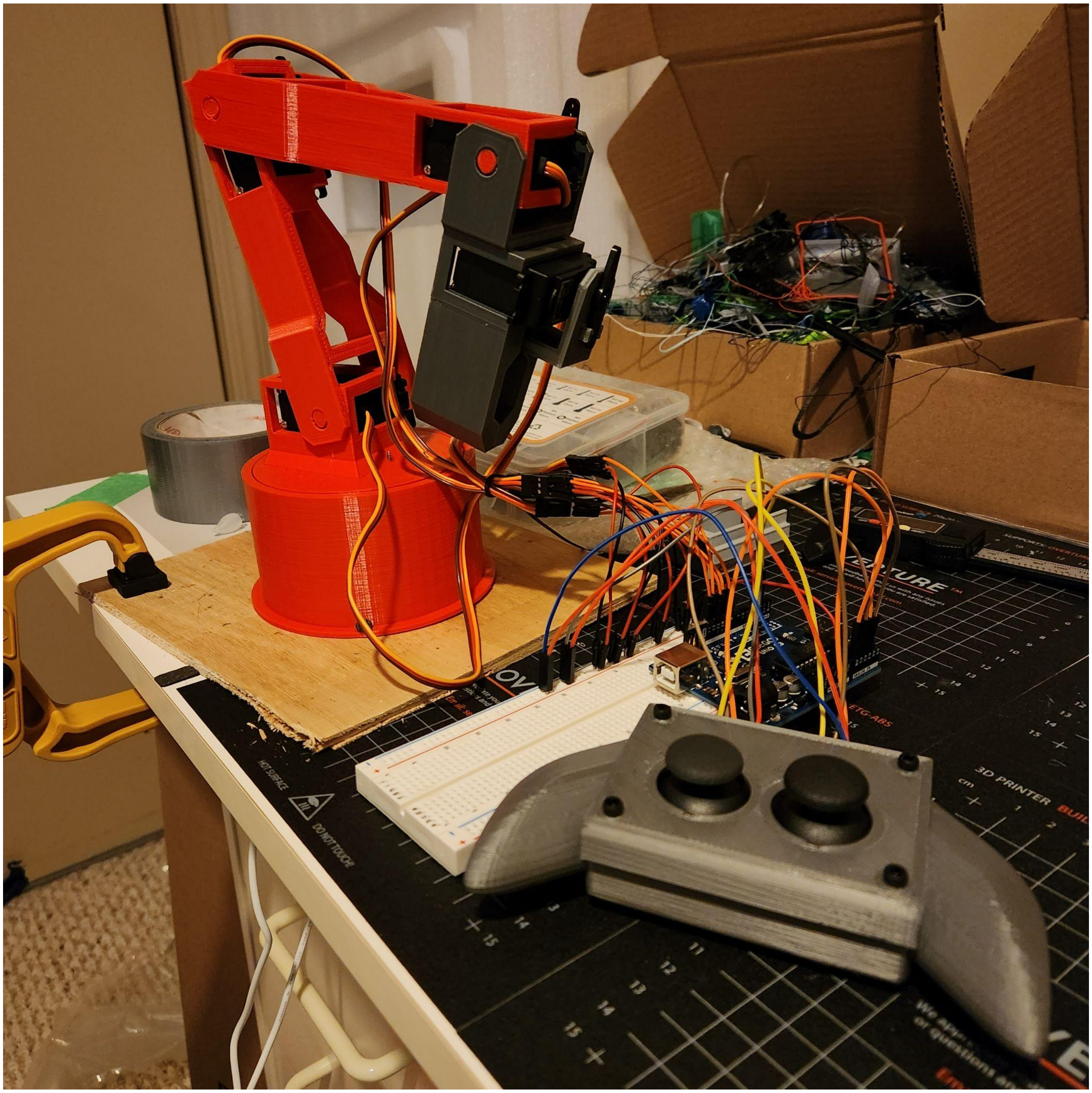


Figure 11

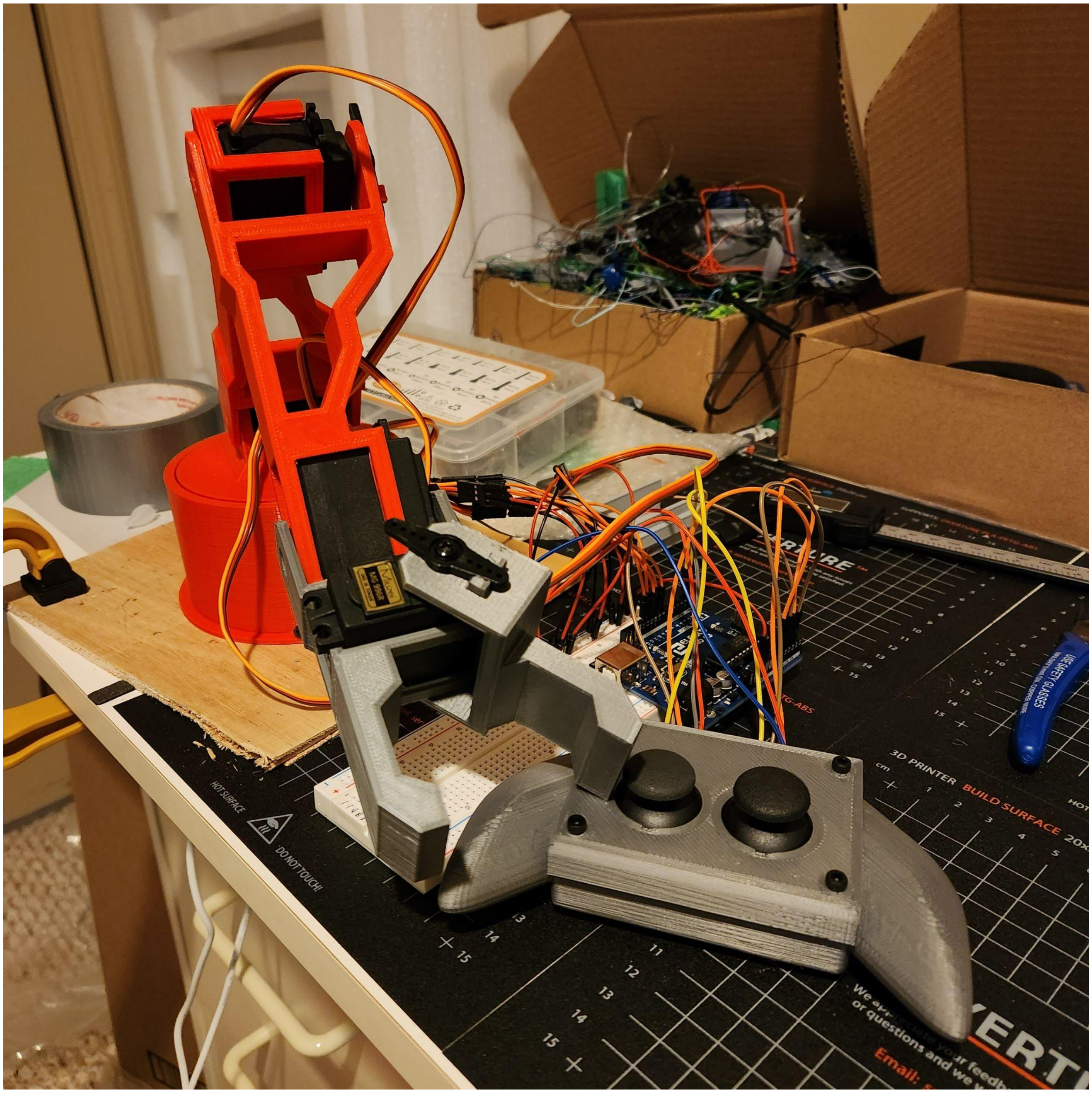


Figure 12

The method of control for this design of the arm was changed from the membrane switch to the joystick control. This version of the arm utilizes 2 joysticks, each using the x and y axis control to move a different motor on the arm, and the switch button on the joystick to actuate the open/close operation of the grip. A basic controller was modeled and 3d printed to house the joystick modules. This design is similar to that of a game console controller. The controller consists of 2 parts, the main body, and the lid that covers the electronics. The main body was designed to hold the joysticks in place using 4 m3 screws using m3 nuts on the underside of the body. The lid attaches using the same type of screws and a captive nut mechanism in the body to hold the threads. The controller can be seen in figures 11 and 12 as well.

*Note: Any of the new parts of the robot arm from the previous design were made in blender rather than Solidworks, and as such there are no nice renders of the 3D models.

Design For Manufacturing

The robot arm was designed with 3D printing in mind as the method of manufacturing parts. Because of this, all parts were designed with minimal overhang to reduce the amount of support material needed during printing. The parts were printed with a 0.2mm layer height and an infill density of 15%. This ensures that the parts are decently strong, but still reducing the amount of time the parts will take to actually print. The expected load on the parts is not high, so the structural integrity of the parts is not the largest concern.

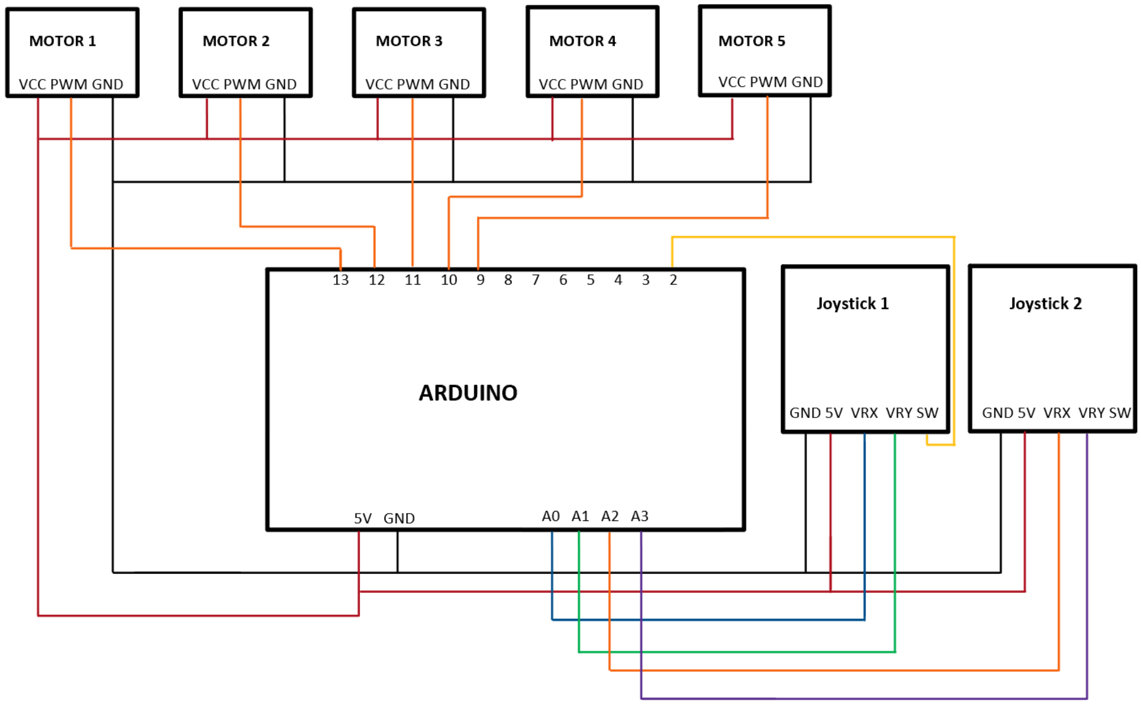
Any holes where a screw would need to be threaded into were made slightly smaller than the diameter of the screw to ensure that the threads had a solid wall to grip onto when they were put in place. Any holes requiring a bolt/nut to fit through them were made slightly bigger so as not to interfere with the bolt going through the hole.

Control Algorithm Design

The control for the arm is updated from the membrane switch to two joystick modules connected to the arduino. The joystick modules work by outputting a value between 0 and 1023 for both the x and y axis directions, with 512 being the neutral position for the joystick. Similar to the previous control code, each motor starts with an initial position. There are ‘if’ statements in place to move each motor individually. If the motor returns a number greater than 600, increase the angle by a set change amount, and if less than 400, decrease the angle value. Using this the joysticks function more as binary switches as opposed to something you might see on a video game controller, but for this iteration of the arm it is acceptable. The speed of the robot can be controlled by changing the distance the angle changes each loop, or by changing the delay in between each loop. The left joystick controls two motors in the shoulder joint, and the right joystick controls the elbow and wrist motors.

Each joystick also has a momentary pushbutton on its board activated by pushing the joystick down. This is used to activate the fifth motor that activates the grip. If the grip is closed when the button is pressed, open it, and vice versa.

Wiring Diagram



Testing and Test Results

Initial designs for the latch style end effector concepts shown in figures 1 and 2 were manufactured and tested with the joystick control. These designs did not function as well as intended, and were determined to be unsuitable for further testing. Spring mechanisms did not function as intended. It was also determined that the toothed grip pattern was not ideal, and that items kept slipping out of the gripper. Ultimately it was decided that the partial wrist joint would need to be a part of the mechanism.

For the grip designs shown in figure 3, the tests were much more successful. The grip could open and close freely without issues. The grip was also able to grab, hold, and let go of the test block. Weight still seems to be an issue, when the grip is holding something, the arm struggles to lift upwards. This is also thought to be a power issue. Currently, all of the motors are connected to a common power. With the way that the grip is controlled, if there is something in the grip, the arm is constantly fighting to reach the closed position angle. If something is blocking the motor from doing so, it could be attempting to draw more current from the power supply to compensate, and the reduced current to the other motors makes them struggle to lift the weight of the robot.

Improvements for Future Prototypes

The issues regarding the flexibility and stability of the motor cage within the base of the arm were not addressed for this design, and will still need to be updated. It is recommended that the motor that actuates the gripper be connected to a separate power supply from the rest of the motors, to see if that helps the robot function better when picking things up.

It is also desired to create a housing for the electronics. The arduino and all the wires are still exposed, it would be nice to have connectors set up to be able to plug in/out the motors and controller from a central box that holds the microcontroller and circuit. A PCB is desired to replace the breadboard for the electronics. Longer wires are also needed to improve the versatility of the controls. Currently the controller must be within a few inches of the arm in order to operate, this needs to be improved.

Appendix

Source Code

```
#include <Servo.h>

//Set up servos
Servo sev1;
Servo sev2;
Servo sev3;
Servo sev4;
Servo sev5;
//Initial angle for motors
int angle1 = 115;
int angle2 = 10;
int angle3 = 90;
int angle4 = 90;
int change = 5; //change in angle for movement

//define joystick pins
const int sw1 = 2;
const int sw2 = 3;
const int joyX1 = 0;
const int joyY1 = 1;
const int joyX2 = 2;
const int joyY2 = 3;

//define variable for opening/closing the grip
int gState = 0;

//variable to read analogue input
int joyValX1;
int joyValY1;
int joyValX2;
int joyValY2;

//Open and Close andgles for the grip motor
int angleC = 60;
int angleO = 100;

void setup()
{
  pinMode(sw1, INPUT);
  digitalWrite(sw1, HIGH);
  Serial.begin(9600);
  sev1.attach(10);
  sev2.attach(11);
```

```
  sev3.attach(12);
  sev4.attach(13);
  sev5.attach(9);
}

void loop()
{
  sev1.write(angle1);
  sev2.write(angle2);
  sev3.write(angle3);
  sev4.write(angle4);

  //X and Y value reads for the left joystick. Moves the motors based on returned
value
  joyValX1 = analogRead(joyX1);
  if(joyValX1 > 600){
    angle2 = angle2 + change;
    sev2.write(angle2);
  }
  if(joyValX1 < 400){
    angle2 = angle2 - change;
    sev2.write(angle2);
  }

  joyValY1 = analogRead(joyY1);
  if(joyValY1 > 600){
    angle3 = angle3 - change;
    sev3.write(angle3);
  }
  if(joyValY1 < 400){
    angle3 = angle3 + change;
    sev3.write(angle3);
  }


  //X and Y value reads for right motor. Moves motors based on returned values
  joyValX2 = analogRead(joyX2);
  // joyValX = map(joyValX, 0, 1023, 0, 180);
  if(joyValX2 > 600){
    angle1 = angle1 + change;
    sev1.write(angle1);
  }
  if(joyValX2 < 400){
    angle1 = angle1 - change;
    sev1.write(angle1);
  }
```

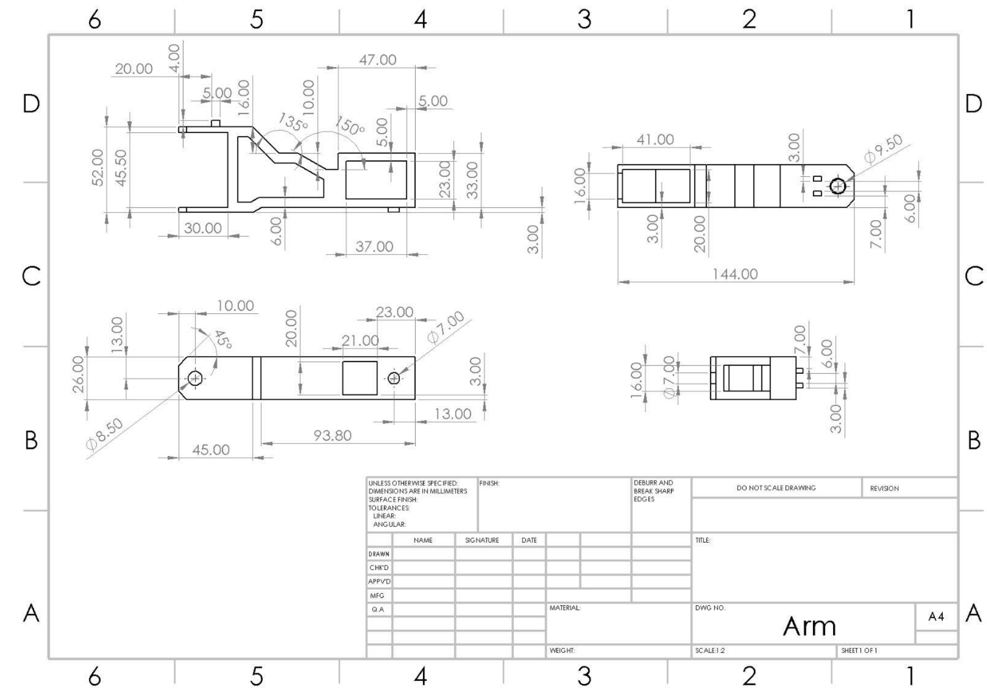
```
  joyValY2 = analogRead(joyY2);
  //joyValY = map(joyValY, 0, 1023, 0, 180);
  if(joyValY2 > 600){
    angle4 = angle4 - change;
    sev4.write(angle4);
  }
  if(joyValY2 < 400){
    angle4 = angle4 + change;
    sev4.write(angle4);
  }


  //Gripper control
  if(digitalRead(sw1) == 0 && gState == 0){
    gState = 1;
    sev5.write(angleC);
    delay(200);
  }

  if(digitalRead(sw1) == 0 && gState == 1){
    gState = 0;
    sev5.write(angleO);
    delay(200);
  }
  delay(70);
}
```

Part Drawings

**Note: Any new parts that were not from the previous design were made using blender instead of solidworks, and as such, there are no engineering drawings for these parts. This will be updated when I can regain access to a software that is capable of doing so.*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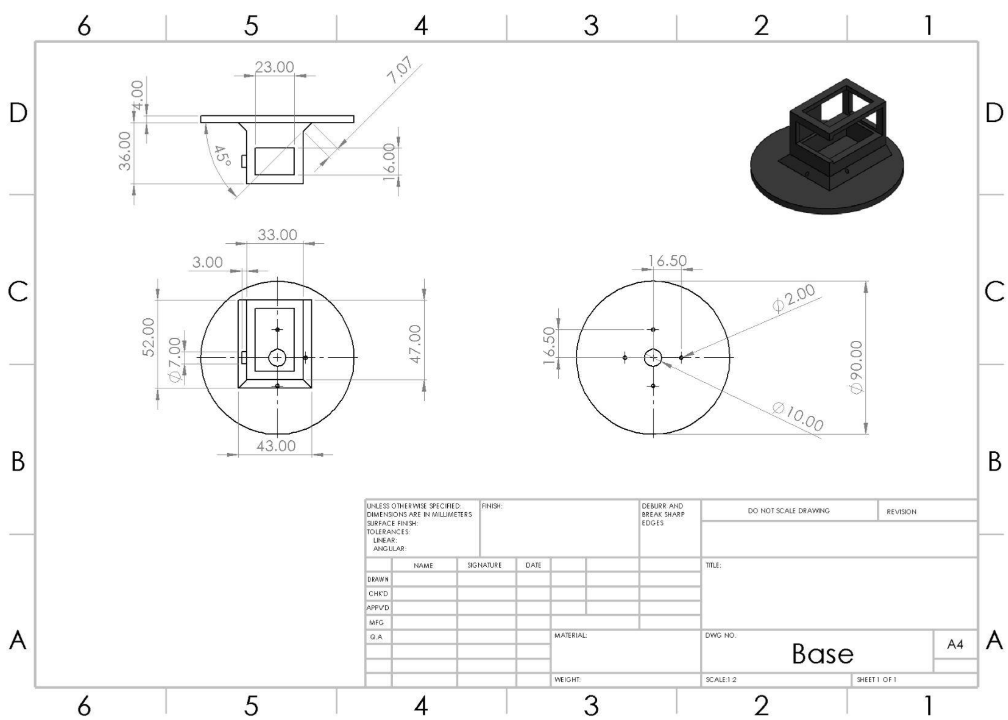
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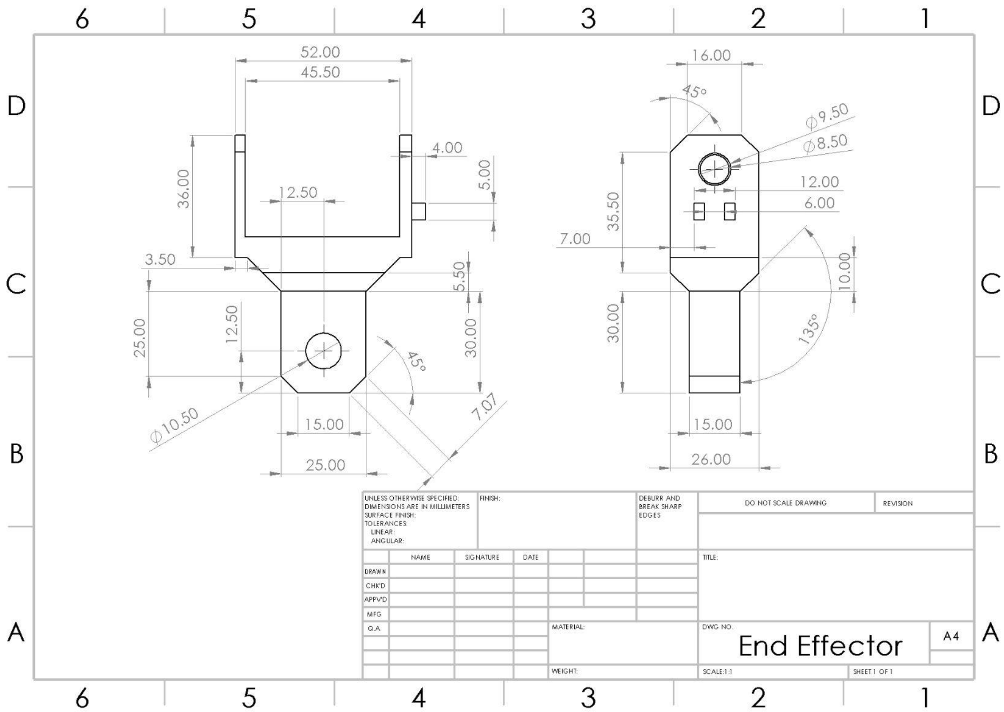
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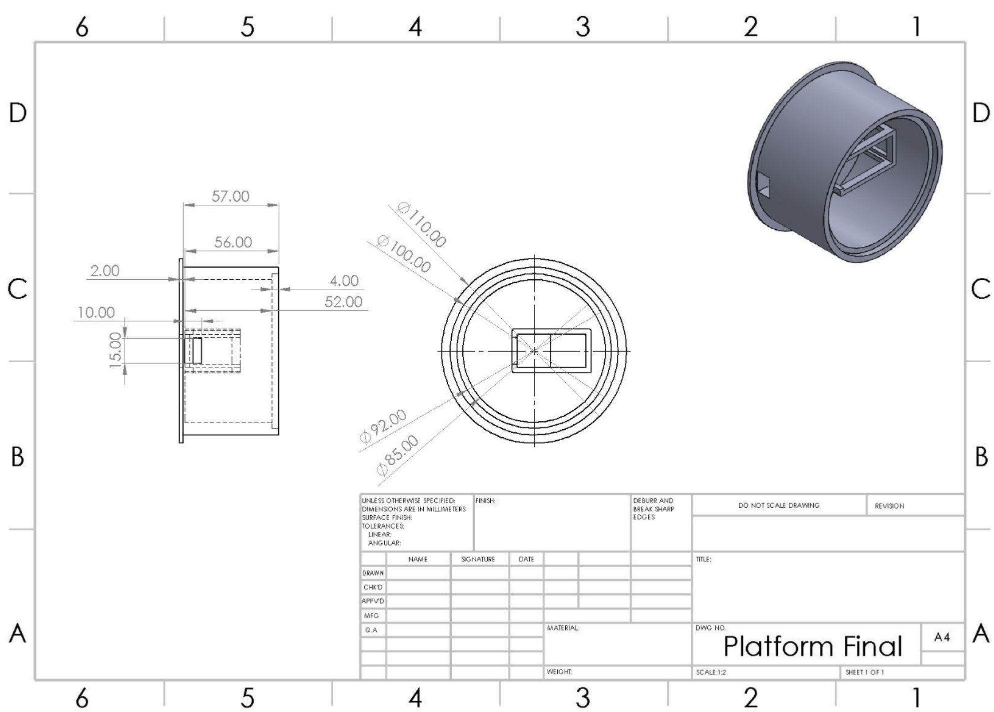
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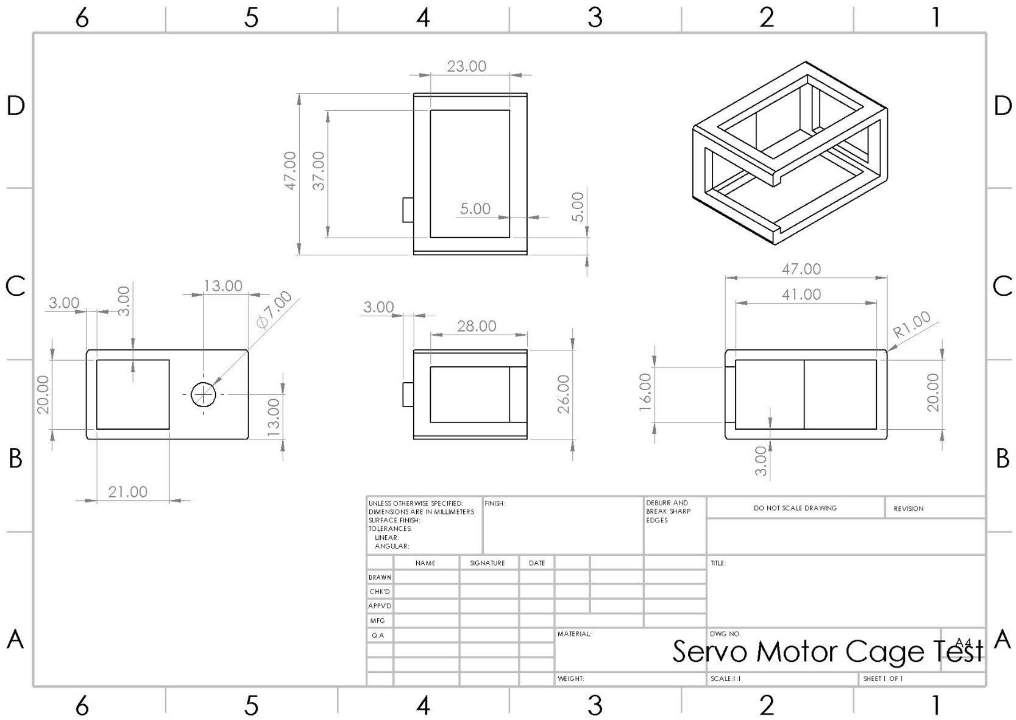

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