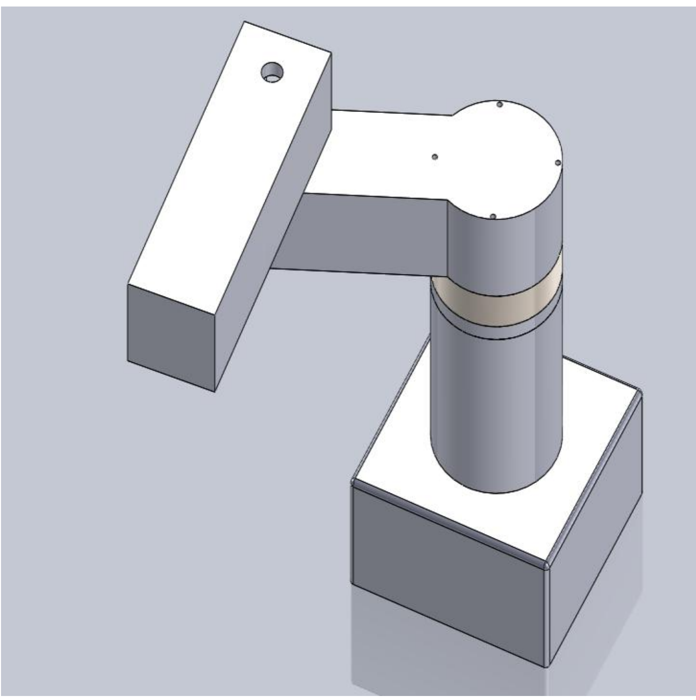

SCARA ROBOT

Final Report

ABSTRACT

Many manufacturing industries, such as electronics, automotive, and medical device production, face challenges in high-speed, ultra-precise assembly due to the limitations of manual labour which turns to be slow speed, prompt to human errors, and recently there is an increase in the cost of skilled labour. Companies often turn towards traditional industrial robots yet those are inflexibility, highly expensive, and require complex maintenance. As the market of such companies grows, there is a critical need for an affordable, precise, and fast automation solution to boost production rates while reducing costs and workplace strain placed on the employees.

To address this problem, we designed an affordable **SCARA (Selective Compliance Articulated Robot Arm) robot** optimized for repetitive tasks involving delicate, small-scale components. The SCARA's architecture combines high-speed operation that is rapid pick-and-place cycles, with millimeter precision, making it ideal for assembly lines. Its modular design reduces upfront costs, its user-friendly programming interface ensures adaptability across industries, and a simple circuit design to ease daily maintenance. By combining speed, accuracy, and affordability, this solution bridges the gap between manual labor and traditional robotics, offering manufacturers a scalable way to improve efficiency and competitiveness.

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ENGR 113 First Year Engineering Design

CONTENTS

2 Introduction....3
2.1 Problem Overview....3
2.2 Existing Solutions and Potential Market....4
2.3 Project Scope....5
3 Design Development....6
3.1 Concept generation....6
3.2 Concept Selection....8
4 Mechanical Design....9
4.1 Engineering drawings....11
4.2 CAD images....14
4.3 Technical Specifications....16
5 Electronics and Control Design....16
5.1 Components....16
5.2 Control logic....17
5.3 Wiring diagram....18
6 Prototyping and fabrication....18
7 Concept proof....19
8 Timeline....19
9 Impact Statement....20
10 Conclusions....21
10.1 Achievements....21
10.2 Lessons learned....22
10.3 Challenges and solutions....22
10.4 Future work....22
11 References....23
12 Appendices....24
12.1 Appendix A. Pictures of fabrication and testing process....24
12.2 Appendix B. Microcontroller code....25

ENGR 113 First Year Engineering Design – Section A
Drexel University
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2 INTRODUCTION

Through our project, we hope to develop a solution for manufacturing and assembly processes that would better optimize both productivity and overhead. We plan to help manufacturers increase their productivity and production on assembly lines, providing a great benefit to them. Not only that, but our solution will also provide economic advantages that will help us reduce costs for our clients and total overhead of production, giving customers another reason to partner with us.

2.1 PROBLEM OVERVIEW

Manufacturing, in general, is quite similar across industries in modern days. Almost every product in the market is mass produced via assembly lines and factories. As technology advances, the demand for methods to cut costs and optimize production in these industries grows, and this has led companies to turn to robots such as SCARA models to automate tasks. The companies that design and produce the most accurate, reliable, and low-cost robots will be most successful in this sector, and we plan to capitalize on this opportunity. The following graph below from [1] is a great example of the profitability of solutions to this problem. The general upwards trend of the graph over time shows a growth in the manufacturing and sale of these robots in recent years, a trend which will likely continue now and in the future as technology can better advance models. Should we be able to produce a competitive SCARA robot in the market, sales and growth are almost guaranteed.

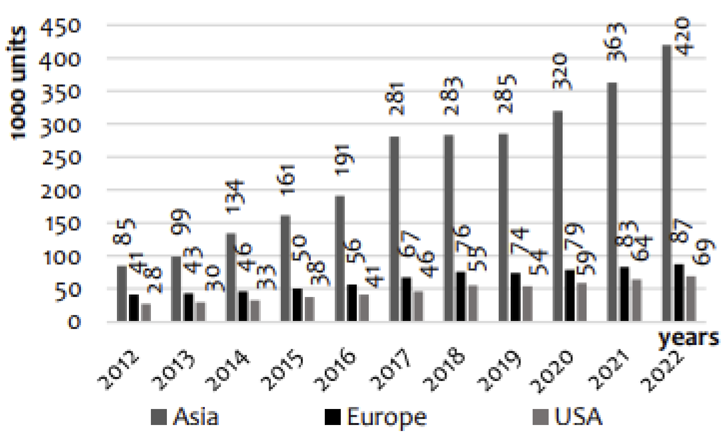


Figure 4: Sales of industrial robots in the world by region, 2012-2020 and forecast for 2021-2022

Source: *Research and Markets (2021)*

2.2 EXISTING SOLUTIONS AND POTENTIAL MARKET

As of now, there is much competition in this market. We are not the first ones to develop and implement this kind of technology, and in recent years SCARA robots have been increasingly used in many different industries. Below is a specification sheet for a model from Delta Electronics, one of the largest producers of SCARA robots and a multinational company, found from [2]. In the early stages of development for our SCARA robot, it will obviously be difficult to stay competitive with robots such as these. However, it is our hope that the later stages of our model will yield superior results and provide customers with a better option in the market. Some specific areas we would possibly like to target for improvement are body weight, maximum payload, and accuracy of repetition.

Table I Specification of Selective Compliance Articulated Robot Arm Scara[4]

SPECIFICATIONS OF SCARA		
ROBOT		***DELTA SCARA***
AXLE COUNT		4
ARM LENGTH (X + Y)		400mm
MAXIMUM PAYLOAD		3 Kg
MAXIMUM SPEED	X – Y(Q1 – Q2)	4710 mm/sec
	Z	666 mm/sec
	R	1875 */sec
RANGE OF MOTION	X (Q1)	±125°
	Y (Q2)	±140°
	Z	150 mm
	R	±360°
STANDARD TIME FOR A CYCLE	(PAYLOAD = 1 Kg)	0.42s
(25mm-300mm-25mm)		
ACCURACY OF REPETITION	X	± 0.010
	Y	±0.010
	Z	±0.010
	R	±0.005
BODY WEIGHT		16 Kg
DIMENSION OF BASE		290(mm) *170(mm) * 160(mm)

The size of our market, however, is not as much of a concern for us. Usage of SCARA robots in manufacturing has been on the rise in recent years as technology has developed. More and more are the production of things such as cars, electronics, and other products relying on the efficiency of these robots, and this will only become more evident in the future. Additionally, the applicability and versatility of SCARA robots makes it very flexible not just in our market, but in almost any market. For example, should we choose to expand apon our design in the future, we could specialize it for the medical industry, or many others. Below are two graphs from [1] which illustrate this. Not only do they show a general increase in the manufacture and sale of industrial robots (increased demand) in recent years, but they also demonstrate that industrial robots are tied to increases in the automotive and electronics industries which are booming fields and always relevant. For this reason, we are reassured that the size and demand of our market will not be an issue going forward and in the distant future.

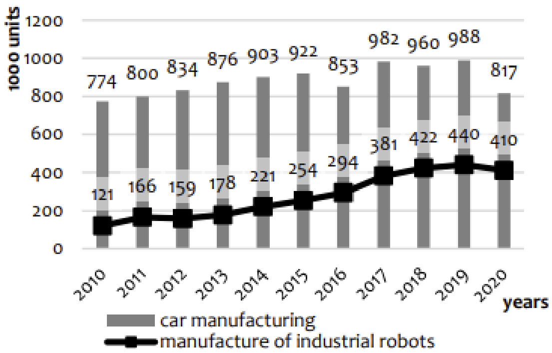


Figure 2: Production of industrial robots versus vehicle production 2010-2020

Source: *IFR (2020a); International Organization of Motor Vehicle Manufacturers (2021)*

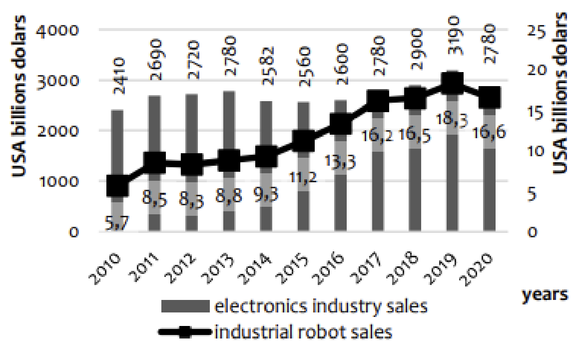


Figure 3: Sales of industrial robots versus sales of electrical / electronic products 2010-2020

Source: *IFR (2020a); Statista Research Department (2021)*

2.3 Project Scope

Through the completion of this project, we will fully go through the steps of product development, including the design, prototyping, and technical documentation of our SCARA robot. The design of the robot focuses on two main rotating joints and one prismatic joint, as that is what most SCARA robots have. Following our design, our team began with physical/mechanical design using SolidWorks and continued through with 3D printing and assembly. Additionally, we will integrate electrical components such as stepper motors, DC motor, and a microcontroller to control the functions of the robot. For these components, we have written and will test code that provides functionality for the robot and allows it to perform pick-and-place tasks. Of the 10 weeks we were given to produce a functional prototype, 2 are left, leaving us with plenty of time remaining for testing and revisions once assembly is finished. The final stretch of this project will include a concept selection document with specifications, a presentational poster, a final version of a report to be given, and a presentation on our SCARA robot.

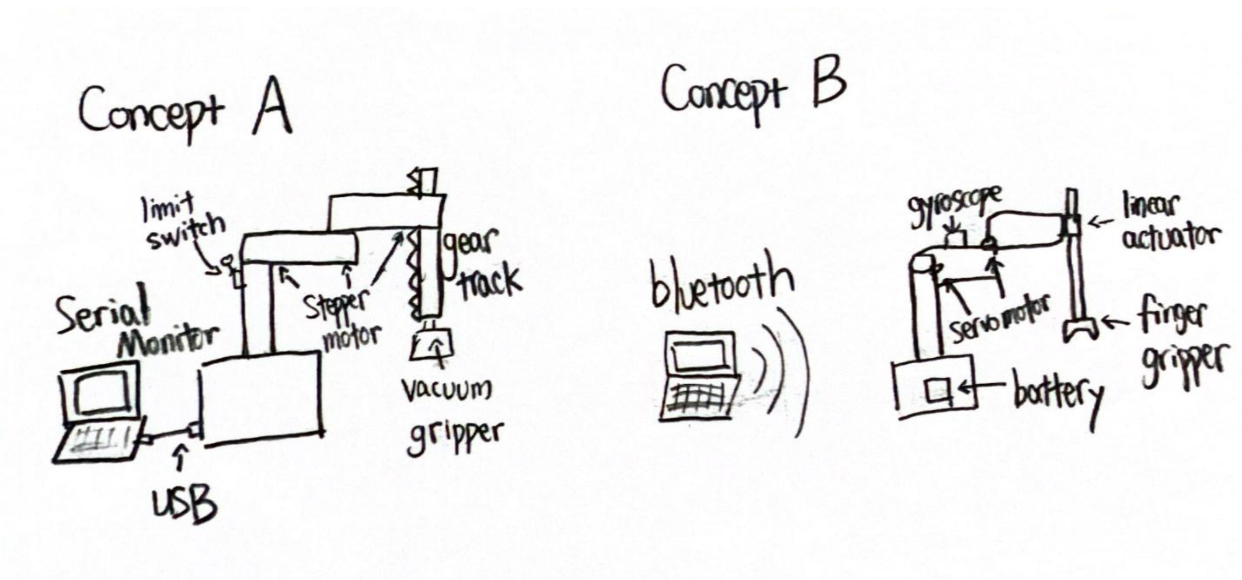
3 Design Development

3.1 Concept generation

Design Problem: SCARA Robot to Move 1-inch Cubes

FUNCTION	SOLUTIONS		
Power	USB	Battery	
Move joint	Servo Motor	Stepper Mottor	
Z motion	Lead Screw	Rack and Pinion	Linear Actuator
End Effector	Finger Gripper	Vaccum Gripper	
User Interface	Serial Monitor	key pad	Web Interface (buetooth)
Control Logic	typed input	hard written program	button sequence
Home Position	Limit Switch	Gyroscope	

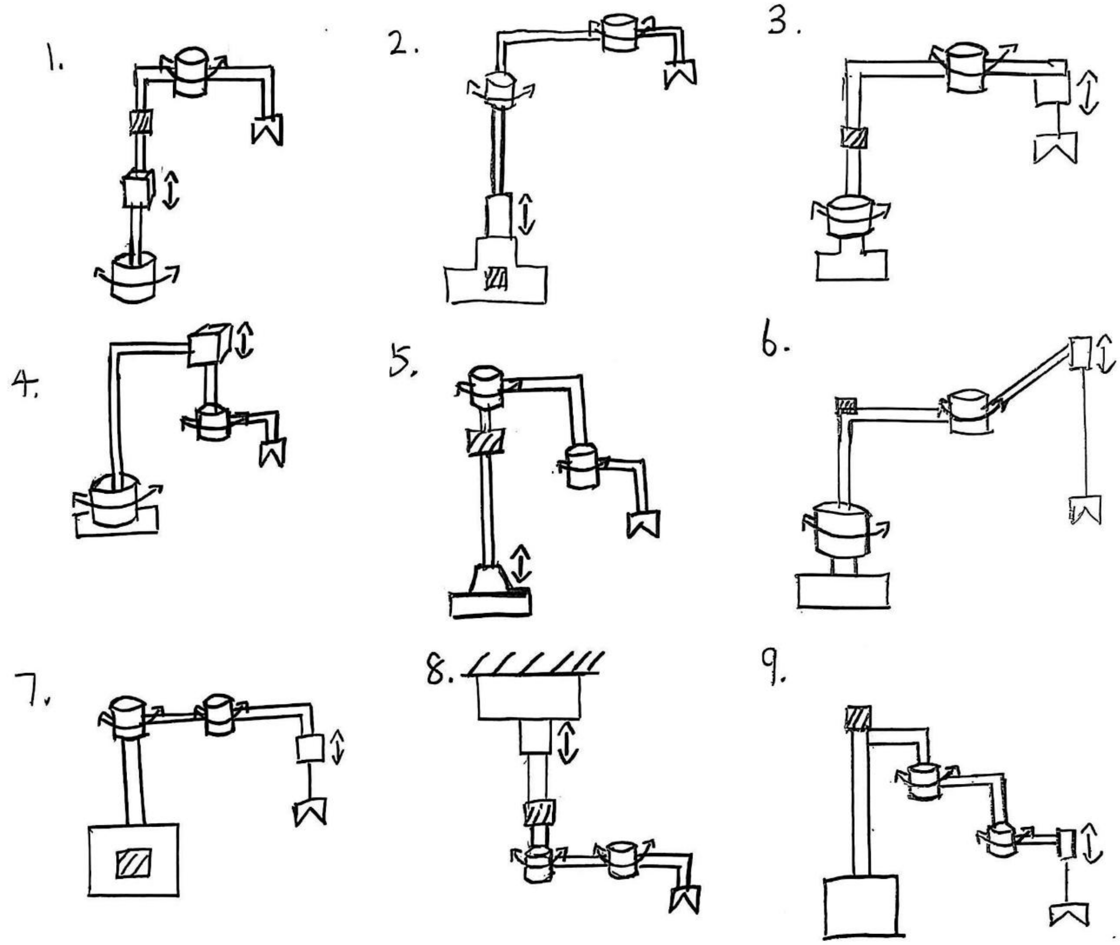
The engineering task is to use a SCARA robot to move 1-inch wooden cubes. The power can be from a computer using USB, or a battery. To move the joint, stepper motors can be more precise while servo motors can detect their own position without a limit switch. For z axis motion, there would be a conversion from rotational motion to linear motion. The Rack and Pinion design uses a gear track to do so, a lead screw design uses threads, and a linear actuator uses electric power to create linear motion. To pick up the block, a vacuum gripper would use air compression while finger gripper would grip the block mechanically. For user interface, the Arduino IDE would be used, and the input would come from either a serial monitor, keypad circuit, or Bluetooth web control. The control logic could be a pre-programmed sequence, or through input each time the robot operates. To home the robot, a limit switch or gyroscope will be used to detect the position of the robot arm.



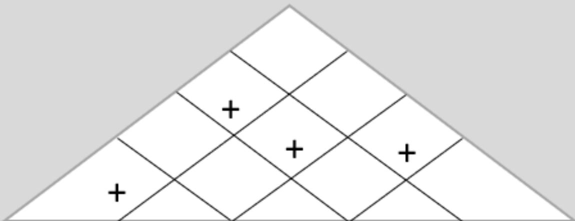
Concept A utilizes cheaper components to fit our budget. Limit switches, vacuum gripper, and stepper motors are provided. This concept can be reasonably done within the timeframe we are given, with the gear track being the simplest way to obtain linear motion and pre-written programming allowing us to not add inputs to the robot. Concept B would be the ideal design if we were given a higher budget and more time. A Bluetooth design would allow remote control and provide a simple user interface. The servo motors would detect their angular position, which saves space that we would need if we were to use limit switches. The gyroscope would detect if the surface were stable for an accurate homing. Finger gripper could hold materials regardless of its textures on the surface.

3.2 CONCEPT SELECTION

Design Alternatives



The square shaded in black on each sketch represents the placement of the microcontroller. Designs 1 and 4 have a revolute joint as the base but with different prismatic joint placements. Designs 2 and 5 have a prismatic joint and one revolute joint on the center of mass with the arm being slightly different. Design 3 and 6 are similar except 6 has a slanted arm. Design 8 would hang on a ceiling to save space; design 9 is like design 8 but hangs on a frame.



Correlation:

+		-
Positive	no correlation	Negative

Relationships:

9	3	1	
Strong	Moderate	Weak	None

	1: low, 5: high	Functional Requirements →	Energy-Efficient Gear	Proper Arm Dimensions	Arduino Controller	Stable Joints	Limit Switch For Homing		Competitive evaluation (1: low, 5: high)		
		Desired direction of improvement (↑,0,↓)									
	Customer importance rating	Customer Requirements ↓						Weighted Score	Our Robot Rating	Yamaha Robot Rating	Epson Robot Rating
1	4	Smooth Movement	9	3	3	9	3	108	4	5	5
2	5	High Precision	1	3	9	9	9	155	4	5	5
3	3	Easy to Control			9		3	36	4	3	3
4	5	Stability	1	3	1	9	1	75	4	5	5
5	2	Less Space Occupied		9	3			24	3	2	3
6	5	Low Cost	1	3	9		3	80	5	2	2
7	1	Low Weight		9	1	3	1	14	3	3	3
		Technical importance score	51	84	141	129	87	492			
		Importance %	10%	17%	29%	26%	18%	100%			
		Priorities rank	**5**	**4**	**1**	**2**	**3**				
		Current performance	2	4	3	2	1				
		Target	5	4	4	5	4				
		Difficulty	5	2	3	4	2	1: very easy, 5: very difficult			

The design is the most suitable because it addresses the most important customer requirements, such as the cost, the precision, and the stability. It outperforms most competitors mainly in terms of its cost efficiency and difficulty of use, through using components such as the Arduino controller. Although the performance of our robot is not the best among our competitors, it offers the best balance of overall cost and usability.

4 Mechanical Design

Our design consists of three joints: two **revolute joints** and one **prismatic (translational) joint**.

First Revolute Joint

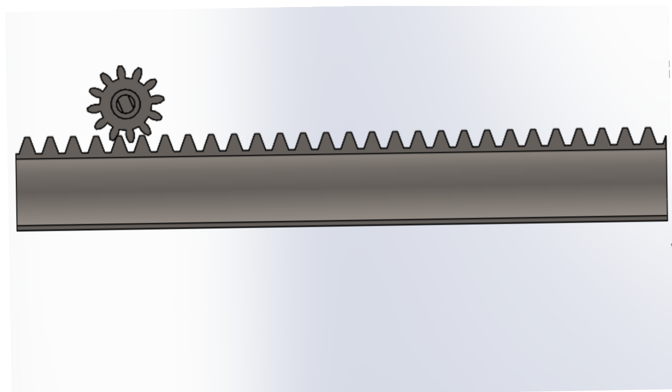
The first revolute joint is located between the SCARA robot's base and its arm. This joint enables **full 360-degree rotation** in both clockwise and counterclockwise directions. The rotation is facilitated by a fixed stepper motor attached to the rear arm ensuring efficient and smooth transmission of mechanical energy between the robot's components.

Second Revolute Joint

The second **revolute joint** is positioned at the midpoint of the arm, connecting the **rear arm segment** to the **front arm segment**. This joint provides enhanced **flexibility** and allows for a **270-degree rotation** in both **clockwise and counterclockwise** directions. Given that the front arm segment bears less of the robot's **load**, we opted for a **simpler rotation mechanism** to maintain efficiency.

Translational (Prismatic) Motion

The **translational motion** is achieved using a **rack-and-pinion system**, enabling **linear movement** of up to **7 inches** in either direction.



The accompanying image displays our **rack-and-pinion assembly**, with the pinion gear securely engaged. The **rack features a central perforation**, allowing for easy **attachment of the end effector** to the system.

The images above highlight the **core mechanical components** of our system. The remaining structural elements including the **base** and **arm,** were intentionally designed to **simplify circuit integration**, ensuring seamless attachment of electrical components to the robot.

4.1 ENGINEERING DRAWINGS

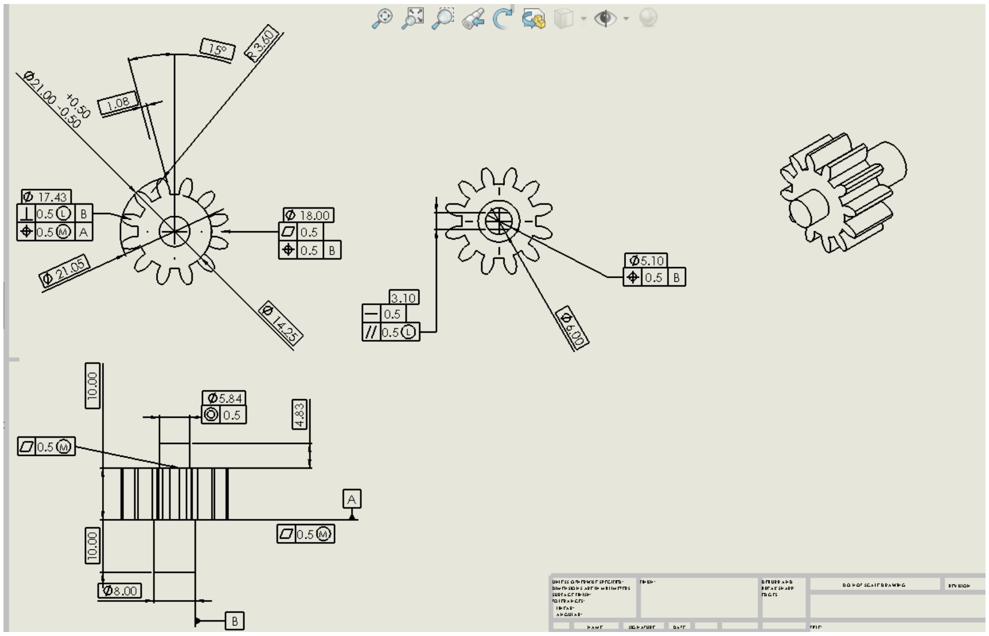


Figure 4.1.2: Engineering Drawing of the SCARA rack and pinion gear

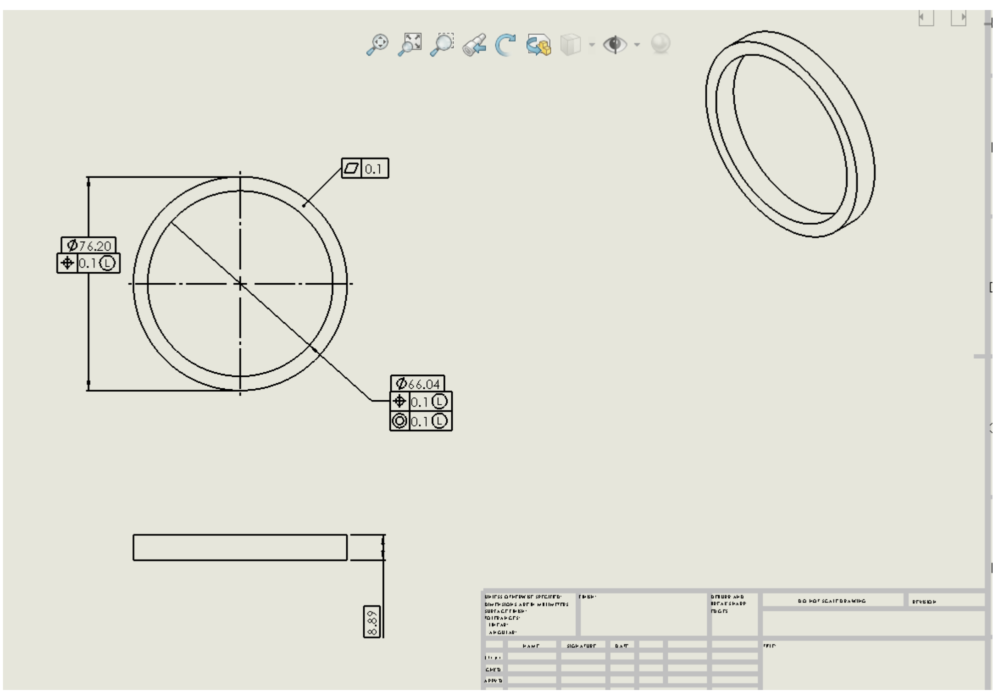


Figure 4.1.3: Engineering drawing of the SCARA support used to attach rear arm and base

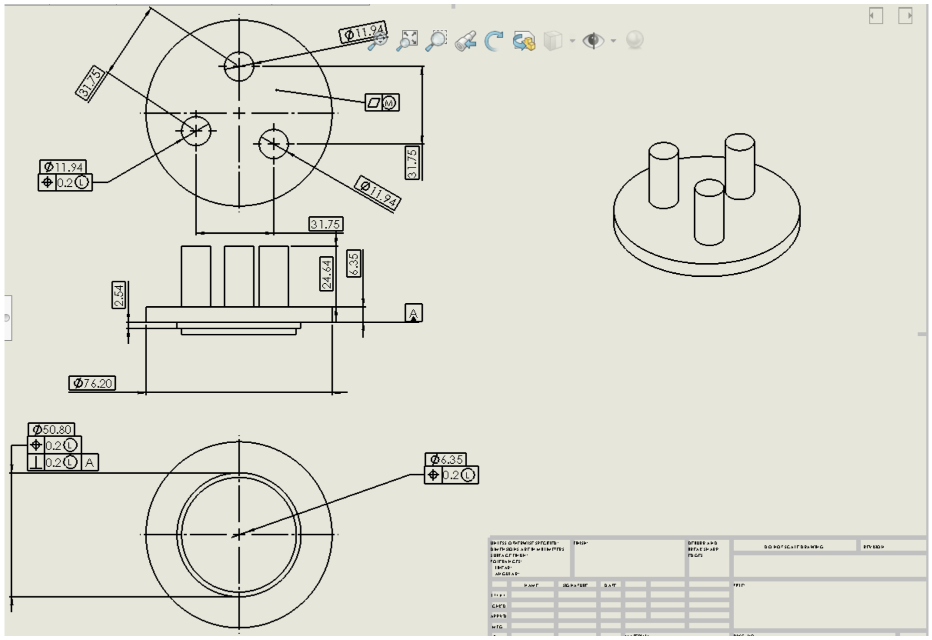


Figure 4.1.4: Engineering drawing of SCARA Base arm connector

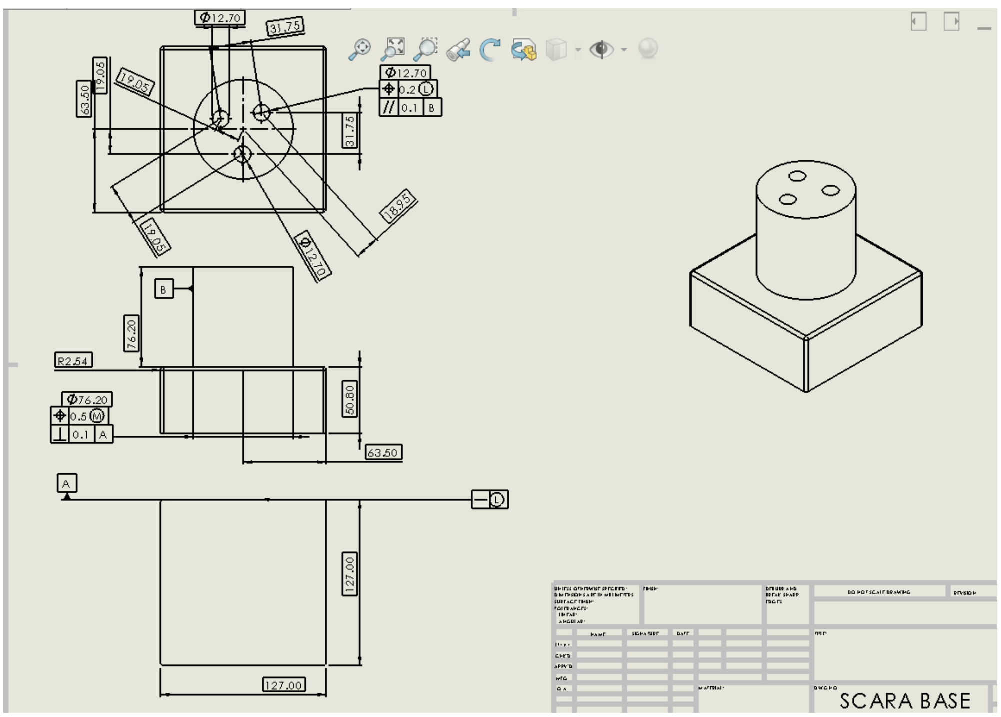


Figure 4.1.5: Engineering Drawing of SCARA base

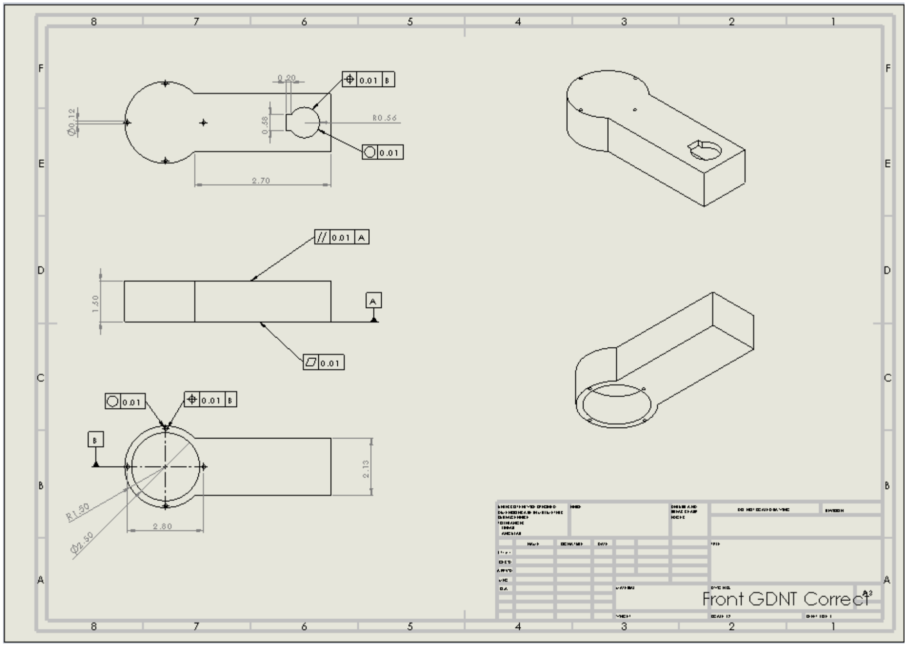


Figure 4.1.6: Engineering Drawing of First Arm

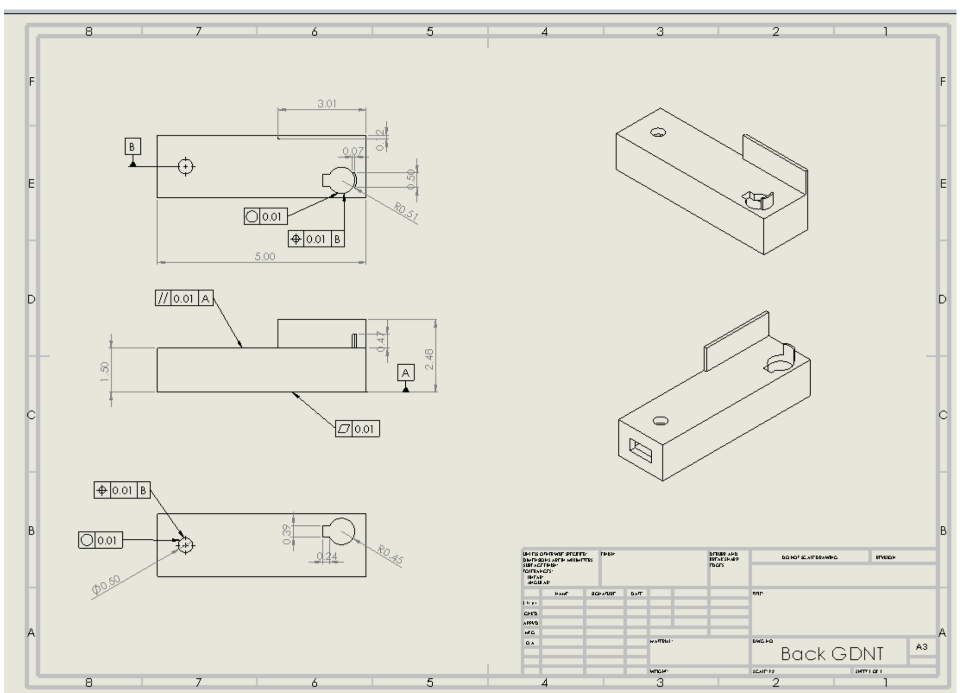


Figure 4.1.7: Engineering Drawing of Second Arm

4.2 CAD IMAGES

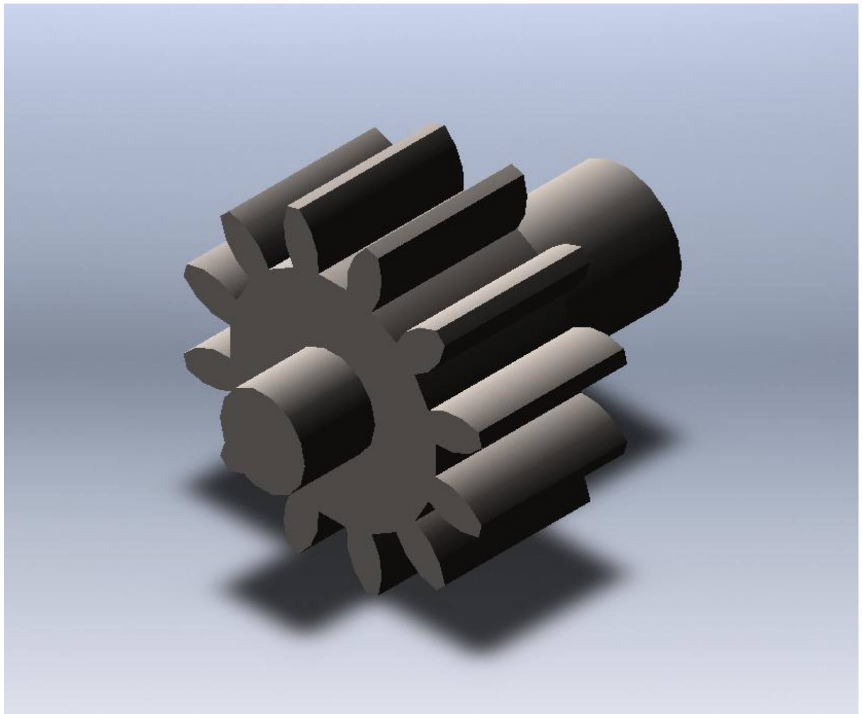


Figure 4.2.1: Rack and pinion gear

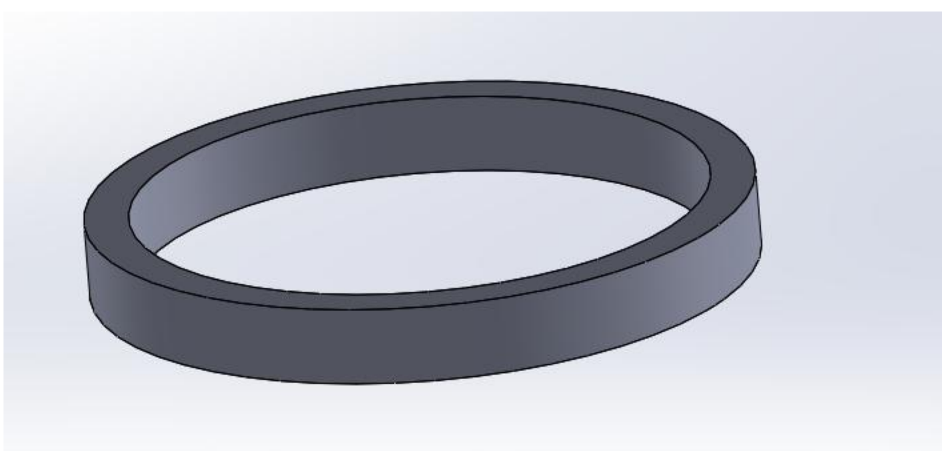


Figure 4.2.2: Support used to attach rear arm and base

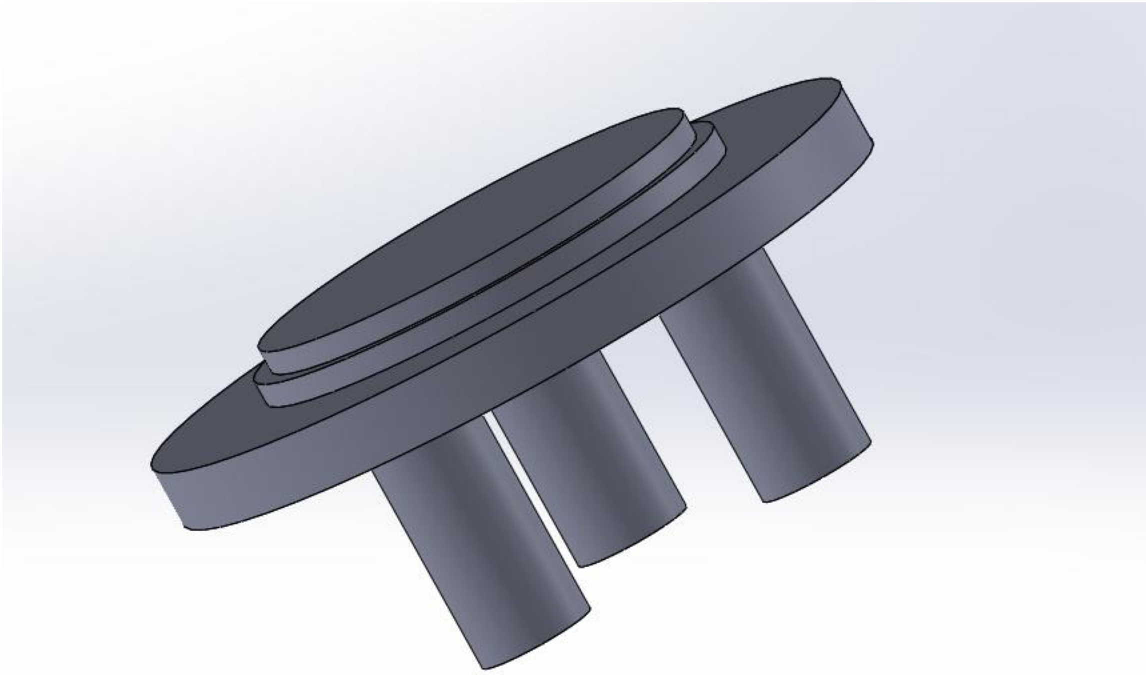


Figure 4.2.3: Base and Arm connector

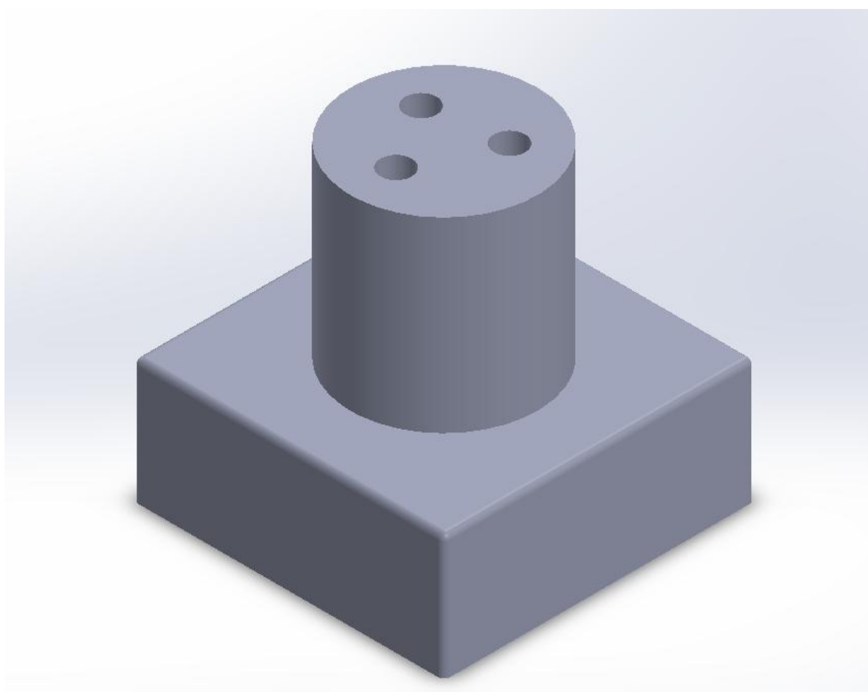


Figure 4.2.4: SCARA Base

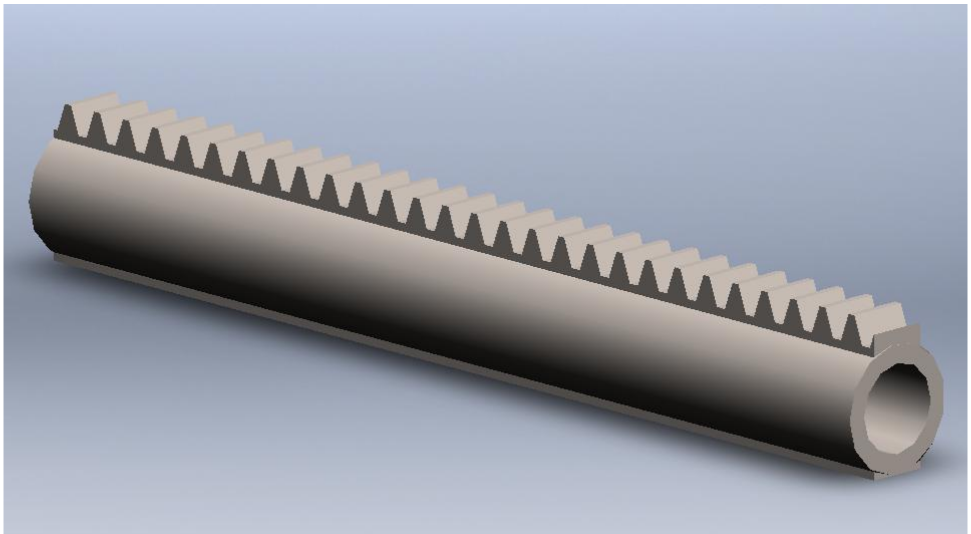


Figure 4.2.6: Geared rack for the rack and pinion system

4.3 TECHNICAL SPECIFICATIONS

Our robot features an adjustable height mechanism, standing **8 inches (20 cm) tall** when retracted and extending to **13 inches (33 cm)** when fully raised. The arm provides **10 inches (25.4 cm) of reach** when fully extended, while maintaining a compact **5-inch (13 cm) wide base** for space efficiency.

With a **lightweight design of about 800 grams**, the robot remains highly portable while incorporating all electronic systems. This optimized weight allows for easy transportation and deployment in various environments.

The motion system delivers **10 revolutions per minute (RPM)** with ultra-precise **2,048 steps per revolution**, ensuring both speed and exceptional accuracy for pick-and-place operations.

5 ELECTRONICS AND CONTROL DESIGN

5.1 COMPONENTS

Power Supply: Provides power to all the electrical components.

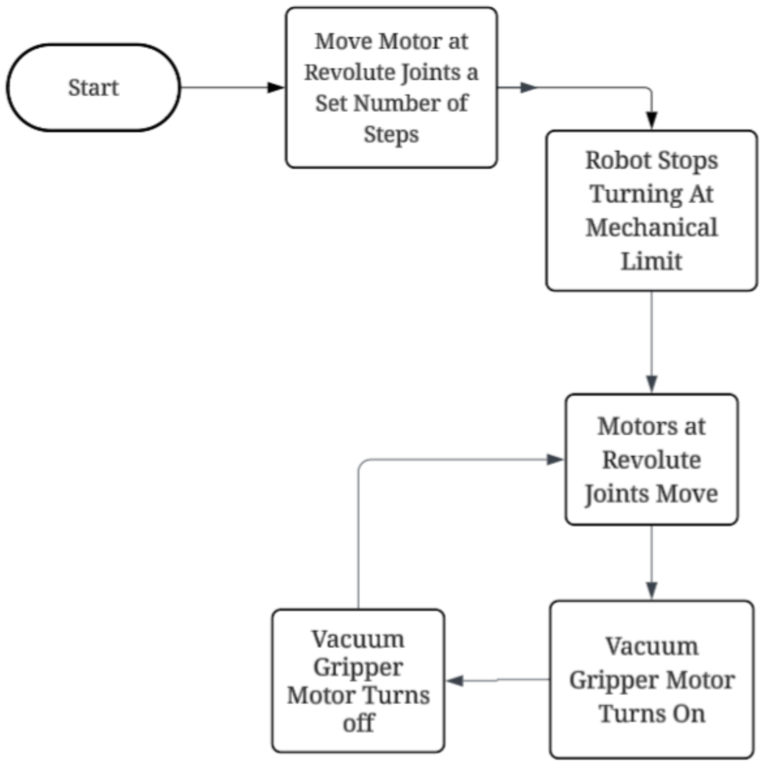
Breadboard: Helps connect components to power supply and the microcontroller.

Jumper Wires: Connects the electrical components to the microcontroller to transfer power and signal.

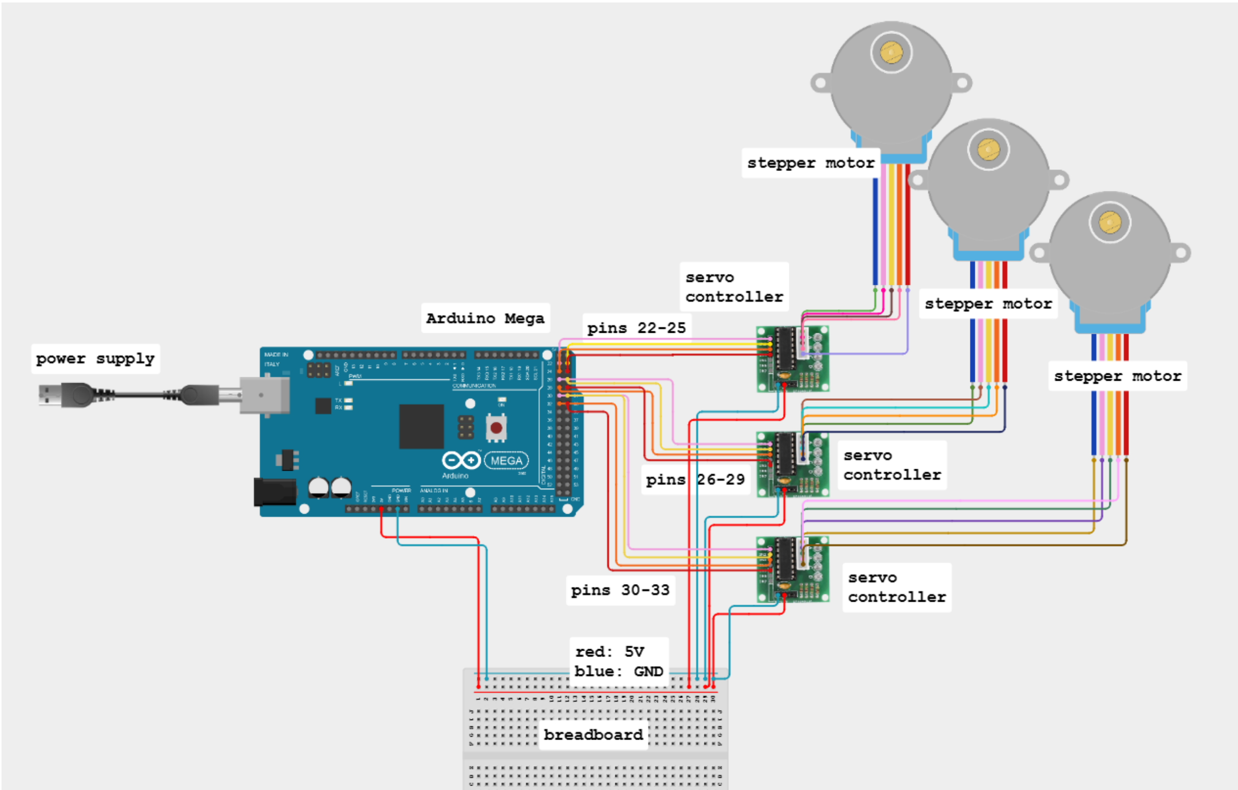
Arduino Mega: Executes the program code, sends signal to stepper motors for arm movement.

Stepper Motor: Creates rotational movement at the joints of the robot.

5.2 CONTROL LOGIC



5.3 Wiring Diagram



6 Prototyping and Fabrication

The design of our SCARA robot followed five key stages: **Opportunity Identification, Problem Formulation, Conceptual Design, Embodiment Design, and Detail Design**.

Given the widespread applications of SCARA robots, we first identified a sector in critical need of improvement and determined how our solution could address it, this was accomplished during the **Opportunity Identification** and **Problem Formulation** phases.

Next, in the **Conceptual Design** stage, we generated nine different design concepts and used a **decision matrix** to evaluate them based on feasibility, stability, and cost-effectiveness. The most optimal design was selected for further development.

Finally, we progressed to the **Embodiment Design** and **Detail Design** phases, where we utilized CAD software, primarily **SolidWorks** to finalize the design and conduct simulations.

The next stage of prototyping involved the **manufacturing process**, where we utilized **3D printing with PLA (Polylactic Acid)** as the primary material. We chose 3D printing due to its **speed, precision, and efficiency** in producing complex components. Additionally, PLA was selected for its **environmentally friendly properties**, as it is biodegradable and has a lower environmental impact compared to many conventional materials

During production, we encountered an issue with **excessive friction** in the first print iteration. The parts were **too tightly fitted**, resulting in restricted arm movement and requiring the motor to exert excessive energy to achieve rotation. To resolve this, we **adjusted the tolerances and reprinted the design**, ensuring smoother motion and optimal energy efficiency.

7 CONCEPT PROOF

To ensure the functionality of our SCARA robot, we conducted a series of tests that focused on movement, stability, and repeatability. The tests include joint functionality, motion range, and verifying the designed components integrated properly and assembled as intended. Each joint was tested for a smooth and controlled rotation, confirming that every part could perform its designated task prior to printing the design for assembly. The prototype meets each of the requirements by using an innovative design capable of picking up and placing 1-inch wooden cubes, effectively simulating a repetitive industrial task suitable for industrial scale production. All components were created using SolidWorks CAD software. The robot's control system was built around an Arduino Mega, which was programmed to operate the stepper motors. The prototype demonstrated strong potential for consistent and efficient operation in commercial industries.

8 TIMELINE

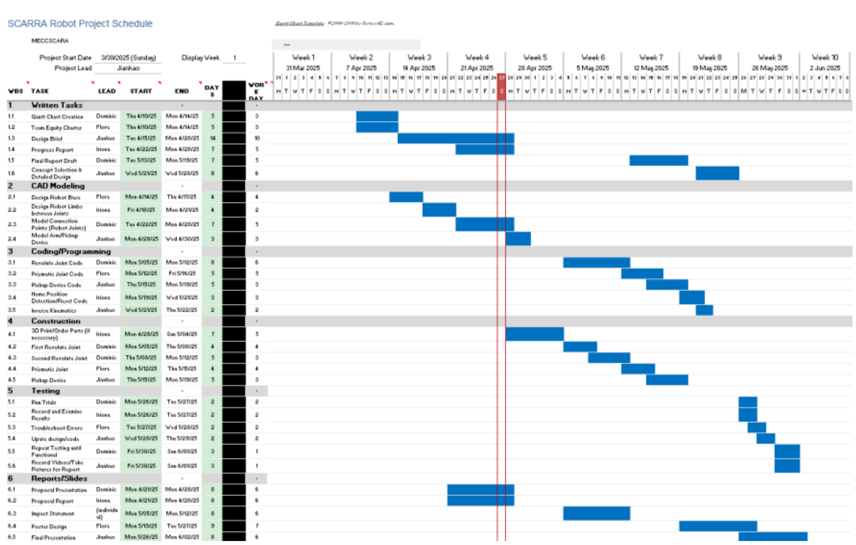


Figure 8.1: Initial Project Gantt Chart

Figure 8.2: Final Project Gantt Chart

As our SCARA robot project progresses, we have identified the need to adjust the Gantt chart due to constraints encountered and time management challenges. While the initial and revised Gantt charts retain the same number of tasks and unchanged work division, the primary adjustment concerns **Task 4 (Construction)**. Initially, we accounted for potential delays in 3D printing and SolidWorks design; however, we overlooked the possibility of part assembly failures post-printing. This oversight caused unexpected delays in Task 4, necessitating schedule revisions. Fortunately, the remaining tasks were completed on time thanks to the collaborative efforts of all team members.

9 Impact Statement

For the SCARA robot our team is creating, it is important to analyze not just how the product will have an impact on our target market, but also how it will affect society as a whole. Engineering should always be done with sustainability and social justice in mind, not just the needs of the customer, and this is no different for our project.

In our case, we are specifically targeting industrial manufacturers and factory owners as the main audience for our product. Through our SCARA robot, we hope to facilitate production lines and assembly processes by providing a means to move materials without the need for actual workers. This causes two main things. First, our customers would benefit highly from this, as our robots don't need breaks and don't fatigue, booting overall production and productivity. Also, our robots don't require payment, so the only recurring cost for them would be occasional maintenance. Secondly, however, factory and assembly line workers would be damaged as a result of our product, as we are effectively taking their jobs from them. This would have detrimental effects on not only these people, but also communities centered around factories or industrial complexes, as local unemployment would surge in these areas. In this sense, our robot is a double-edged sword, as it creates an arguably larger problem in the process of solving another.

Additionally, environmental impacts are extremely important when designing products. No matter how reliable our robot may be, there will come a time when it will become obsolete and no longer useful. In this event, it is important that our product is sustainable and is able to be recycled or reused for another field or industry. Our robot will mainly be comprised of steel. Not only is this a great option for strength and stability, but also for sustainability. Steel is completely recyclable, and any melting, casting or rolling done on the steel has no effect on quality [3]. Additionally, as stated in [3], 50% of all steel production worldwide is from recycled sources. As for the electronics in the robot, these components are less recyclable and tend to not be reused after usage. As electronic technology develops, older generation technology rapidly decays in value and reusability [4]. Both recovery and resale value drop as their respective technology ages [4]. As a result of this, the electronic components of our robot will most likely be disposed of and end up in landfills, damaging the environment and overall sustainability of our project.

10 CONCLUSIONS

10.1 ACHIEVEMENTS

In the development of our SCARA robot, we successfully designed the mechanical components using SolidWorks and manufactured them by 3D printing. In our design process we made several adjustments to the design to improve both the fit and functionality of the prototype. We ultimately produced a fine-tuned version ready for assembly. Although we have not yet completed the full assembly of the robot we have each of the parts printed. Each 3D printed part has been tested for smooth and controlled rotation in SolidWorks to ensure each part meets its requirements for a fully functional robot. Regarding the electronic systems, the control code for the Arduino Mega has been successfully programmed and tested to operate the stepper motors. Overall, the prototype is partially functional, prior to full integration, but our robot shows a strong potential for reliable and successful performance.

10.2 LESSONS LEARNED

This project provided an opportunity to have detailed learning experience. This project allotted time to improve technical skills, communication, project management, and practice collaboration in a work environment. Technically speaking we gained hands-on experience in Arduino Uno programming, SolidWorks 3D modeling, and digital timeline development and modification. Non-technically speaking, as a team we learned how to receive insight from one another, combine each of our best ideas, and produce the best result for the team. We had practice fulfilling our individual responsibilities to the group while staying on course with timelines we created for each other. In doing so, we also made sure to communicate when timelines need to be updated for either a sooner or later deadline. In addition, we improved our in-person presentation skills by presenting our proposal in a formal manner. The proposal required our group to strengthen our public speaking, writing, research, and formatting skills. Overall, this project has strengthened the engineering and collaborative skills that we will someday need in the workplace.

10.3 CHALLENGES AND SOLUTIONS

Throughout the development of our SCARA robot, we encountered several challenges that required technical problem-solving and strong collaboration. One major obstacle was determining a base structure that would provide both stability and compatibility with the overall design. We also faced difficulties ensuring that the robot's arm would not be too heavy, which could compromise movement and accuracy. Additionally, we underwent frequent design modifications to improve the functionality of our robot. Despite these challenges, we overcame them by maintaining regular in-person meetings, effectively managing our time around busy schedules, and continuously communicating as a team. By combining our individual ideas and skill sets, we were able to create a refined and functional robot design. Alongside technical work, we also improved our ability to properly format sources and strengthened our teamwork and decision-making skills, allowing us to build and code a successful prototype.

10.4 FUTURE WORK

If we have the opportunity to continue with the development of our robot, we would be sure to analyze each aspect of our robot to produce this robot at a commercial level. Those details include improving speed and precision, and with exploring more durable materials to enhance stability and longevity for an industrial environment. Improving speed and precision directly enhances the robot's efficiency and accuracy in performing repetitive tasks. Doing so will be particularly essential for maintaining high productivity and consistent quality while competing with other companies. Exploring more durable materials will increase the robot's stability and lifespan. This will allow the robot to handle the demanding conditions of industrial environments. For the control system, the Arduino Mega would be replaced with a new system capable of handling more detailed and complex tasks. Focusing on these improvements will allow us to create a robot capable of handling integration into industrial settings.

11 REFERENCES

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[3] B. Davison and G. W. Owens, "Steel Designers' Manual: The Steel Construction Institute: Sixth Edition," Feb. 11, 2008. https://www.researchgate.net/publication/296409375_Steel_Designers

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12 APPENDICES

12.1 APPENDIX A. PICTURES OF FABRICATION AND TESTING PROCESS.

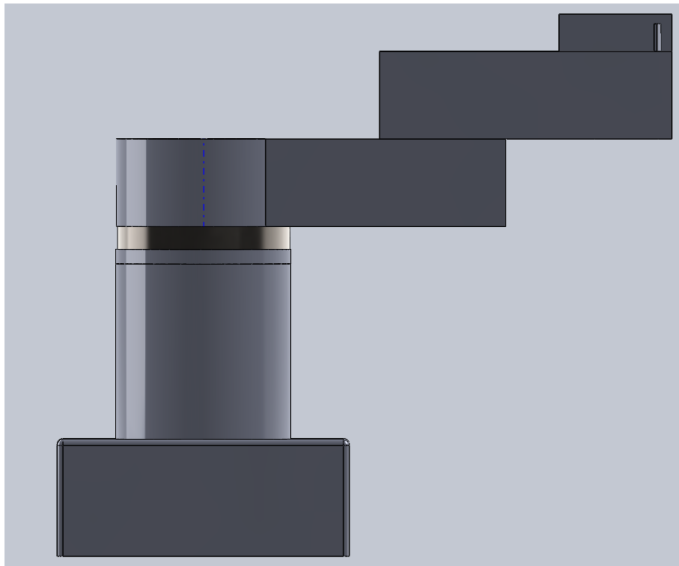

Figure 12.1.1: Side view of MECCSCARA

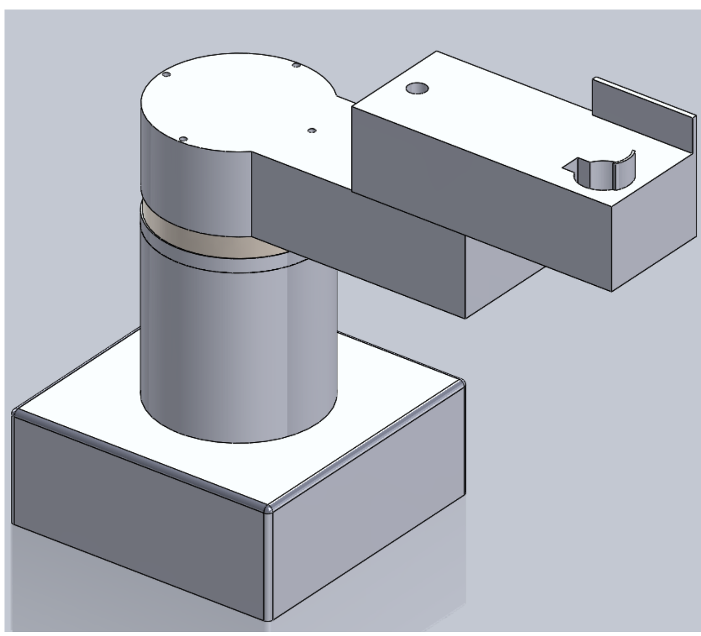

Figure 12.1.2: Isometric view of MECCSCARA

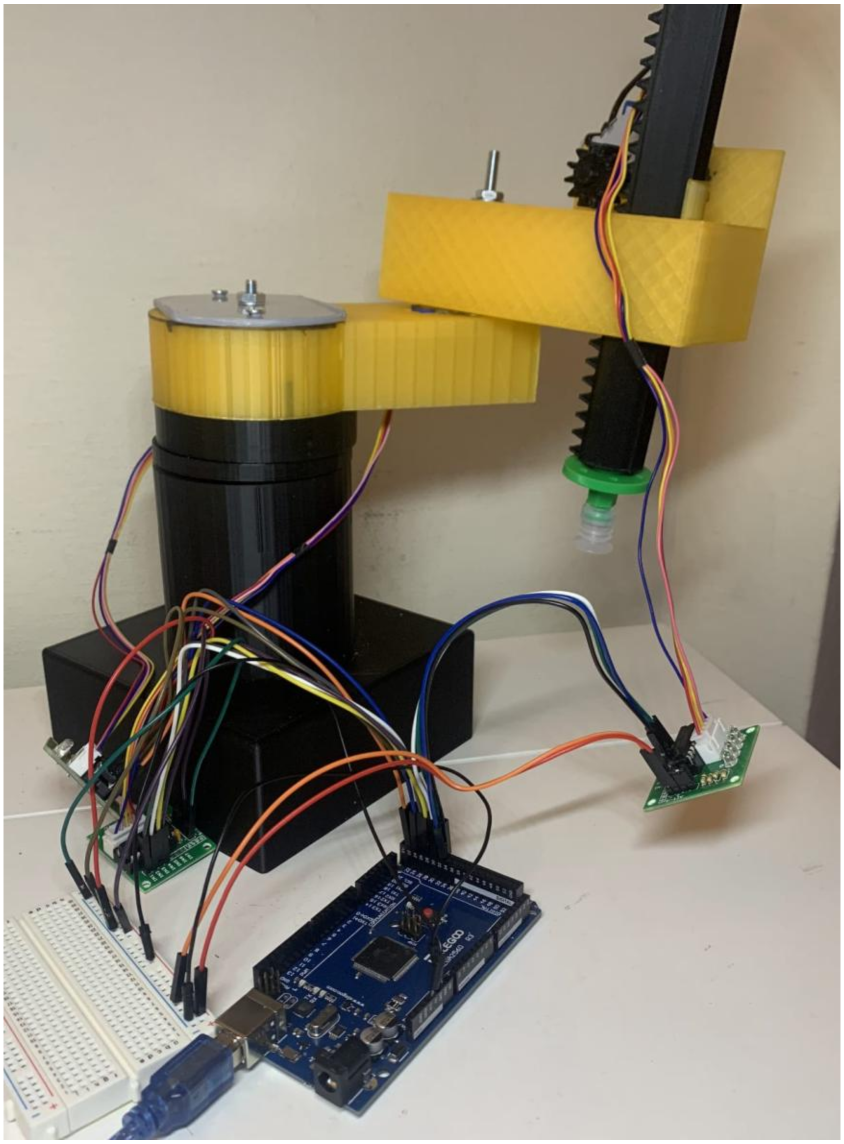

Figure 12.1.3: MECCSCARA Prototype

12.2 Appendix B. Microcontroller code.

```
#include <Stepper.h>
#include <math.h>

const int stepsPerRevolution = 2048;

int suck = 6;
int release = 7;

Stepper motor1(stepsPerRevolution, 22, 24, 23, 25);
```

```
Stepper motor2(stepsPerRevolution, 26, 28, 27, 29);
Stepper motor3(stepsPerRevolution, 30, 32, 31, 33);

float theta1 = 0;
float theta2 = -20;
float theta3 = 0;
float tarTheta1 = 0;
float tarTheta2 = 0;
float tarTheta3 = 0;

void setup() {
  motor1.setSpeed(10);
  motor2.setSpeed(10);
  motor3.setSpeed(10);

  pinMode(ls1, INPUT);

  pinMode(suck, OUTPUT);
  pinMode(release, OUTPUT);

  digitalWrite(suck, LOW);
  digitalWrite(release, HIGH);

  homePosition();

  moveMotors(-179, -560, 0);
  moveMotors(0, 0, 1124);
  digitalWrite(suck, HIGH);
  digitalWrite(release, LOW);
  delay(500);
  moveMotors(0, 0, -1024);

  moveMotors(240, 1000, 0);
  moveMotors(0, 0, 1024);
  digitalWrite(suck, LOW);
  digitalWrite(release, HIGH);
  delay(500);
  moveMotors(0, 0, -1024);

  moveMotors(-560, -390, 0);
  moveMotors(0, 0, 1124);
  digitalWrite(suck, HIGH);
  digitalWrite(release, LOW);
  delay(500);
```

```
  moveMotors(0, 0, -1024);

  moveMotors(500, 210, 0);
  moveMotors(0, 0, 1024);
  digitalWrite(suck, LOW);
  digitalWrite(release, HIGH);
  delay(500);
  moveMotors(0, 0, -1024);
}

void loop() {

}

void moveMotors(long s1, long s2, long s3) {
  long steps1 = abs(s1);
  long steps2 = abs(s2);
  long steps3 = abs(s3);

  int dir1;
  int dir2;
  int dir3;

  if (s1 >= 0) {
    dir1 = 1;
  } else {
    dir1 = -1;
  }
  if (s2 >= 0) {
    dir2 = 1;
  } else {
    dir2 = -1;
  }
  if (s3 >= 0) {
    dir3 = 1;
  } else {
    dir3 = -1;
  }

  long maxSteps = max(steps1, max(steps2, steps3));

  long stepCounter1=0;
  long stepCounter2=0;
  long stepCounter3=0;
```

```
  for (int i = 0; i < maxSteps; i++) {
    if ((i * steps1) / maxSteps > stepCounter1) {
      motor1.step(dir1);
    stepCounter1++;
    }
    if ((i * steps2) / maxSteps > stepCounter2) {
      motor2.step(dir2);
      stepCounter2++;
    }
    if ((i * steps3) / maxSteps > stepCounter3) {
      motor3.step(dir3);
      stepCounter3++;
    }
    delay(2);
  }
}

void homePosition() {
  moveMotors(-750, 0, 0);
  moveMotors(400, 0, 0);
  moveMotors(0, -1524, 0);
  moveMotors(0, 820, 0);
}
```