Republic of Yemen
Ministry of higher Education and Scientific research
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Delta Robot for automated control (Lightweight Pick and Place Robot)

دلتا روبوت للتحكم الآلي

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A graduation project report submitted to the department of Engineering in partial fulfillment of the requirements of bachelor degree in Mechatronics.

2025

Authorization

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Acknowledgment

Before and above all, we would like to record our endless thanks to **Allah** for everything he gives us.

We wish to express our deepest gratitude and appreciation to **Dr. Radwan AL-Bouthigy** for excellent guidance, kind encouragement, scientific advice, helpful supervision and good wishes instilled the strength in us to make this work possible.

Last but not least, we owe a great deal of gratitude, thanks and appreciation to all members of our families, for their kind support, help and encouragement.

Supervisor Certification

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Summary

Nowadays, the use of robots is becoming widespread in some works such as transportation, sorting, stacking, cutting and assembling. Robotic systems, which have been used in industry, are basically divided into two main categories: Serial systems and parallel systems.

This project presents the design and development of a compact _Parallel_ Delta Robot prototype aimed at performing automated pick-and-place operations. The motivation arises from the need for cost-effective, precise, and lightweight robotic systems for small-scale industrial and educational environments.

The Delta Robot structure was primarily fabricated using 3D printed materials and mounted on a wooden and plastic outer frame, controlled via Arduino Uno with cnc shield v3 and DRV8825 drivers. A gripper, powered by a servo motor, handles object manipulation, while a conveyor system assists in simulating real-world automation.

The main objectives include developing the mechanical frame, integrating stepper motors and electronics, implementing control algorithms with inverse kinematics in Arduino, and simulating the robot's motion and workspace using MATLAB. Various components were carefully selected, including NEMA 17 stepper motors, sensors, limit switches, fans, and protective electronics housed in a waterproof enclosure. The system achieved accurate motion control and demonstrated the feasibility of low-cost automation.

Software tools used in this project included SolidWorks for CAD design, Arduino IDE for firmware development, MATLAB/Simulink for simulation, and Proteus for circuit testing. Experimental results confirmed the functionality of the prototype, though limitations remain in terms of industrial-grade precision. The project successfully combines theoretical modeling, hardware integration, and simulation into an educational robotic platform.

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List of Abbreviations

Acronym	Definition
DOF	Degree of freedom
CAD	Computer-Aided Design
TCP	Tool center point
FK	Forward Kinematic
IK	Inverse Kinematic
IDE	Integrated Development Environment
GUI	Graphical User Interface
PWM	Pulse Width Modulation
USB	Universal serial Bus
CNC	Computer numerical Control
PLA	Polylactic Acid
STL	Stereo lithography
FDM	Fused Deposition Modeling
NEMA	National Electrical Manufacturers Association
BR	Baud Rate
IC	Integrated Circuit

Mathematical Notation

Parameter	Description
θ_1	angle of the first upper arm attached to motor 1
θ_2	angle of the second upper arm attached to motor 2
θ_3	angle of the third upper arm attached to motor 3
α_1	frame rotation angle for arm attached to motor 1
α_2	frame rotation angle for arm attached to motor 2
α_3	frame rotation angle for arm attached to motor 3
l_A	length of upper arm
l_B	length of forearm
R_A	radius from base plate center to one of the three arms
R_B	radius from traveling plate center to one of the three forearms
J	Jacobian matrix for a Delta-3 robot
Xn	column vector, (x, y, z) T of TCP coordinates expressed in {R}
{R}	reference frame at the base plate
{Ri}	reference frame for arm i

Chapter 1

Introduction

Chapter 1: Introduction

1.1 Overview

With the industrial revolution, robots have become a part of our daily lives. Nowadays, the use of robots is becoming widespread in some works such as transportation, sorting, stacking, cutting and assembling. Robotic systems, which have been used in industry, are basically divided into two main categories: Serial systems and parallel systems.

Today the manufacturing industry is evolving rapidly, heavily around the automatization of manufacturing processes that require high performance and low cost. Due to the low moment of inertia of the end effector, the delta robot can achieve high-speed movement and while retaining high precision. Resulting in being a highly desired robot in the food, electrical, and pharmaceutical industry where fast pick-and-place is required [1]. Therefore, this project is designed to be used as a learning tool exploiting the bright future of the robotics industry. The robot will mainly be designed from 3D printed parts in polylactic acid (ABS, TPU Resin) designed in Solidworks software. The selected open-source single-board microcontroller is an Arduino Uno R3. A highly versatile open-source microcontroller that allows for the connection of external accessories and includes an easy-to-use Integrated Development Environment (IDE) [2]., the Arduino will send the information to a driver controlling the position of the stepper motor. A gripper will be mounted to the moving platform as the end effector, powered by a 5g servo motor. Implementing the inverse kinematics of the robot in the Arduino code will allow the user to input the desired coordinate of the end effector down to millimeter precision. This will allow the user to explore robotics concepts such as work envelope, maxima speed, sensory feedback, and computer system for control.

1.2 Problem Statement

In many small industrial and laboratory settings, there is a rising need for compact, cost-effective, and precise robotic solutions for repetitive tasks. Conventional industrial robots are often too large, complex, and expensive for such environments. This project addresses these limitations by creating a Small Delta Robot that simulate the laboratory big projects, this robot is affordable, simple to construct, and efficient for lightweight pick-and-place operations.

Therefore, there is a demand for a small-scale, cost-effective Delta Robot that can efficiently perform these tasks with acceptable accuracy and speed.

1.3 Aim and Motivation

Aim: The primary aim of this project is to design and implement a compact Delta Robot system capable of automated pick-and-place operations.

Motivation:

Motivation factors include:
- To apply interdisciplinary knowledge combining mechanical design, electronics, and control systems.
- To support the trend of Industry 4.0 by providing accessible robotic automation.
- To demonstrate the feasibility of using affordable components like Arduino and 3D printing for effective automation solutions.

1.4 Project Objectives

The main objectives of this project may be summarized in the following also describe in Table 1-1.

- ❖ Design and fabricate a robust structure using steel, wood and 3D printed components where utilize lightweight and strong materials to ensure durability and flexibility.
- ❖ Implement motion control using Arduino Uno, CNC Shield, and DRV8825 drivers.
- ❖ Integrate stepper motors with limit switches for accurate positioning.
- ❖ Design a basic pick-and-place gripper mechanism.
- ❖ Implement a conveyor system synchronized with the Delta Robot.

- ❖ Develop Arduino programs for movement control and Serial Monitor interfacing.
- ❖ Perform kinematic analysis using MATLAB, focusing on inverse kinematics.
- ❖ Validate the complete system through experimental testing.

Table 1-1 Objective Description.

Obj.No.	Objective Description
1	Design and fabricate Delta Robot structure with wood and 3D printed parts
2	Implement motion control using Arduino, CNC Shield, DRV8825 Drivers
3	Install limit switches for stepper motor safety
4	Develop and program the gripper mechanism
5	Integrate with conveyor belt system
6	Use MATLAB for inverse kinematic modeling
7	Test and validate robot performance

1.5 Project Scope and Limitations

- **Scope:**

  - Build a fully functional small-scale Delta Robot.

  - Employ 3D printing, steel and wood for mechanical parts.

  - Control the robot using Arduino Uno and monitor through Serial Monitor.

  - Implement basic safety mechanisms (Limit Switches, Emergency Stop).

  - Perform inverse kinematics analysis using MATLAB.

- **Limitations:**

  - Handling lightweight objects only (up to 100 grams).

  - Limited reach (arm lengths ~15 cm upper, ~30 cm lower).

  - No integration of advanced vision systems.

  - Basic open-loop control, limited closed-loop correction.

1.6 Project Methodology

The methodology involves a systematic workflow beginning with literature review and conceptual design, followed by mechanical modeling, electrical system development, software programming, simulation, and testing.

1. 1. Literature Review: Research on Delta Robots and parallel kinematic structures.

2. 2. Mechanical Design: 3D modeling using Solidworks and preparing parts for 3D printing.

3. 3. Electrical Design: Using Arduino Uno, CNC shield v3 DRV8825 drivers, NEMA 17 motors, limit switches, LEDs, fans, conveyor, dc motors, sensors and power supply systems.

4. 4. Fabrication: 3D printing structural components with ABS, TPU and resin, assembling the robot.

5. 5. Software Development: Programming Arduino with Inverse Kinematics; interfacing via Serial Monitor.

6. 6. Simulation and Testing: MATLAB simulation for kinematic analysis and practical testing of the prototype.

7. 7. Troubleshooting and Optimization: Iterative refinement based on observed performance.

1.6.1 Flowchart: Project Development Process

The following flow describes the sequence of activities during the project development:

Start
↓
Literature Review
↓
Mechanical and Electrical Design
↓
3D Printing and Assembly
↓
Software Programming (Arduino)
↓
Simulation (MATLAB)
↓
Testing and Troubleshooting
↓
Final Adjustments and Validation
↓
End

1.7 Report Organization

The rest of this report is organized as follows:

- Chapter1: Introductions
- Chapter2: Background and Literature Review
- Chapter3: Projects Methodology
- Chapter4: Mathematical Model & Simulation of The Proposed System
- Chapter5: Implementation of The Proposed System & Experimental Results
- Chapter6: Conclusions and Future Work

Chapter 2

Background and Literature Review

Chapter 2: Background and Literature Review

2.1 Background

2.1.1 Introduction

Robotics is a multidisciplinary field integrating mechanical engineering, electronics, computer science, and control systems. Robots have been increasingly employed in industries to perform repetitive, hazardous, or high-precision tasks, leading to improved efficiency and safety. Among the diverse robotic configurations, the Delta Robot stands out for its high speed, light weight, and excellent accuracy, making it ideal for pick-and-place operations. Delta Robots utilize a parallel kinematic structure as shown in Figure 2-1 and Figure 2-2, where multiple arms control a single end effector, resulting in faster and more stable movements compared to serial robots [1].

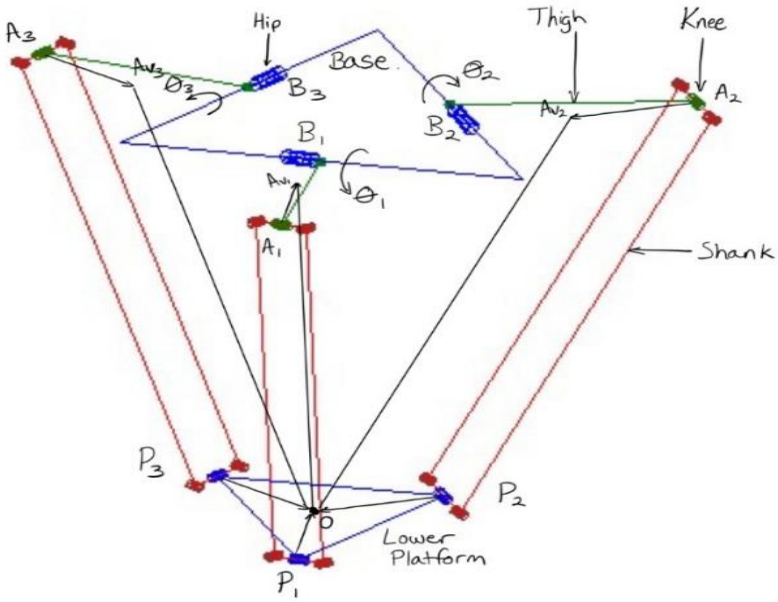

Figure 2-1 Typical Delta Robot Structure (skitch). [2]

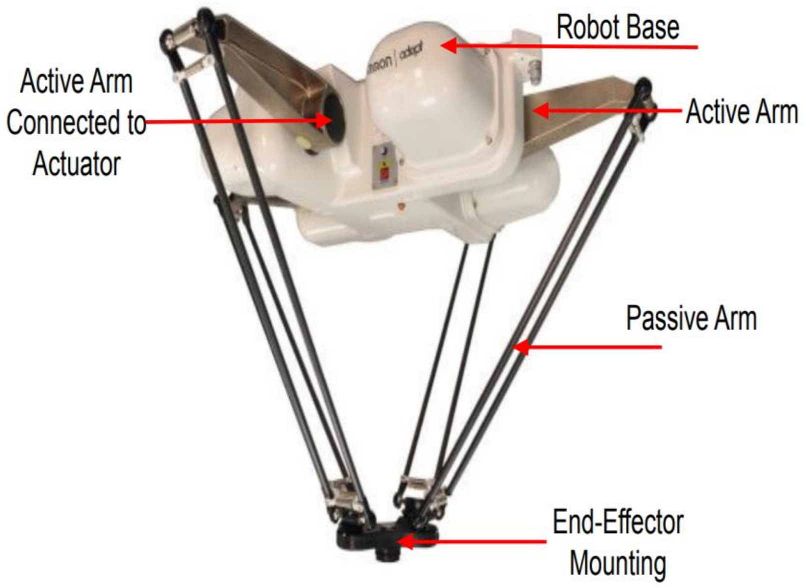

Figure 2-2 Typical Delta Robot Structure.[2]

2.1.2 Historical Background

The Delta Robot was invented by Reymond Clavel in 1985 [3], Reymond Clavel and his team at the Robotics Systems Laboratory at Ecole Polytechnique Federale de Lausanne (EPFL) began the research that would produce the delta robot following a visit to a chocolate factory. Clavel’s team was looking for repetitive labor applications for robots, and they found that the packaging of chocolate pralines was a candidate for this type of high-speed, low-payload automation.

Clavel’s team began by setting constraints on their design. First, the robot must perform at a rate of 3 picks per second. In order to place the chocolates correctly, the mobility of the robot required 4 degrees of freedom: translations along 3 axes, as well as rotation about the vertical axis. In order to achieve a high rate of work, Clavel added two more constraints to the design: the actuators of the robot would be fixed on the frame, and the moving part of the robot would be kept as light as possible.

Six months after the visit to the chocolate factory, a prototype of the delta robot was complete; by December as shown in Figure 2-3, a patent was filed. Two years later, the delta robot was industrialized by a small company called Demaurex Robotics and Microtechnology.

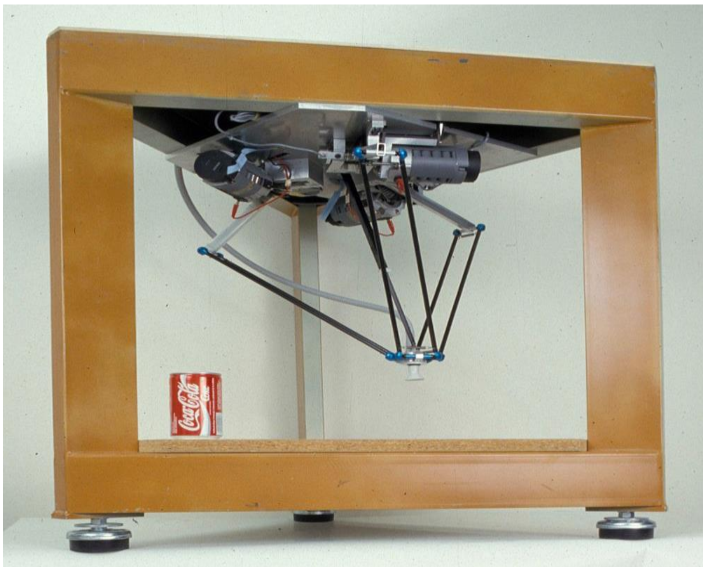

Figure 2-3 The first prototype of the delta robot (January 1986).[4]

2.2 Literature Review

The Delta Robot concept has been extensively studied and refined in both academic research and industrial applications. This section presents a review of selected studies and implementations relevant to the design and operation of Delta Robots, focusing on mechanical.[5]

2.2.1 Summary of Key Studies

- Clavel (1985) introduced the original Delta Robot design, optimizing for speed and minimal inertia [2].
- Zeng et al. (2008) presented an improved Delta Robot structure using carbon fiber materials to reduce weight and increase stiffness [4].
- Lee and Chang (2012) implemented vision-guided Delta Robots for automated high-speed sorting in the electronics industry [3].
- Pashkevich et al. (2010) developed a stiffness model for Delta Robots to predict deformation under load [4].

The below Table 2-1 will describe the differences.

Table 2-1 Literature Review Comparison.

Study	Focus Area	Key Contribution	Material Used	Application
Clavel (1985)	Design	Original Delta Robot concept	Aluminum	Pick and Place
Zeng et al. (2008)	Structural Enhancement	Lightweight carbon fiber arms	Carbon Fiber	Packaging Automation
Lee and Chang (2012)	Control System	Vision-guided sorting	Aluminum	Electronics Industry
Pashkevich et al. (2010)	Mechanical Analysis	Stiffness modeling	Various	Industrial Robotics

There are a lot of delta robot over the time furthermore the previous as shown in Figure 2-4

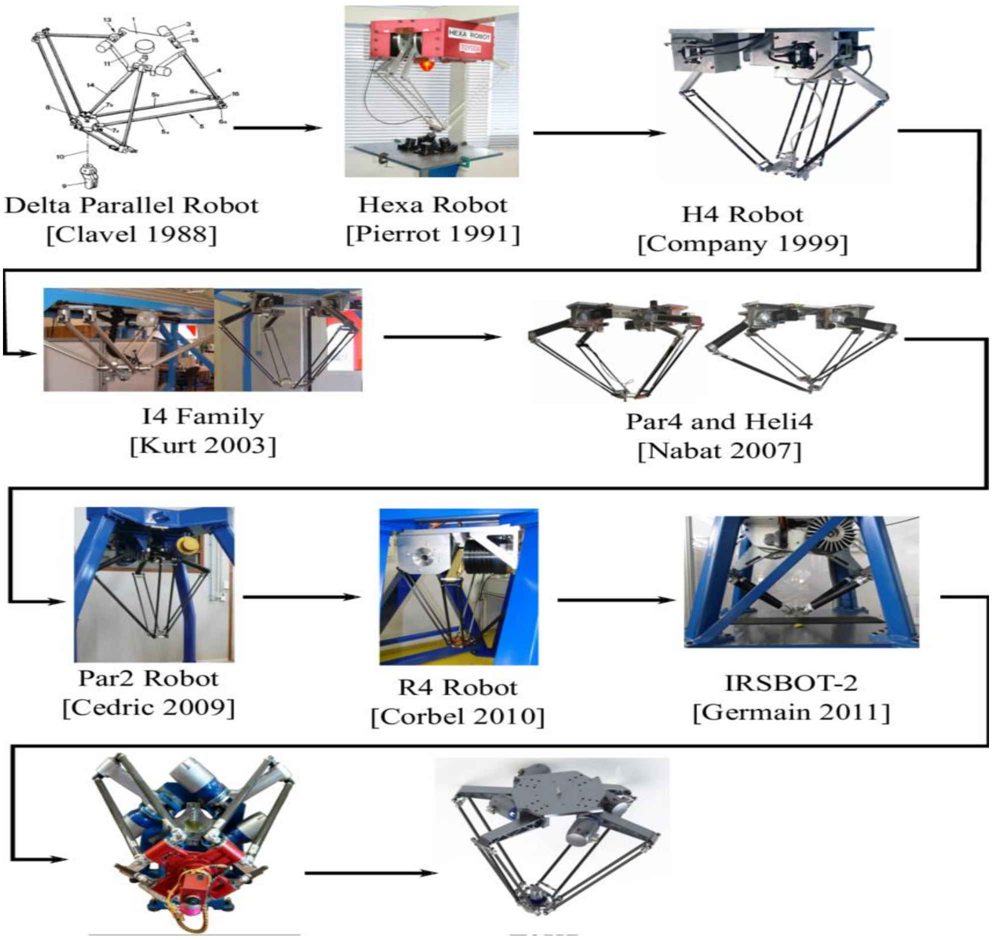

Figure 2-4 Evolution of Delta Robots Over Time.

2.2.2 Literature Review Conclusion

Based on the literature, the Delta Robot remains a leading choice for high-speed, precise automation tasks. Advancements have predominantly focused on enhancing material properties for better performance, integrating intelligent control systems, and extending the application domains. Despite these improvements, challenges like dynamic stability and workspace optimization continue to be active areas of research [4]. Our project builds on these foundational works by focusing on affordability and ease of fabrication using 3D printing and accessible electronics and simple controllers.

Chapter 3

Project Design and Components

Chapter 3: Project Design and Components

3.1 Introduction

This chapter outlines the complete design of a delta robot and the components used in the implementation of the Small Delta Robot. It presents the specifications, CAD designs, and all mechanical, electrical, and control parts involved in building the robot.

3.2 Project Specifications

The Small Delta Robot is designed for simple pick-and-place tasks using a lightweight structure. It consists of a 3D-printed robot body mounted on a wooden outer frame, controlled by an Arduino Uno with cnc shield and DRV8825 drivers. The following specifications shown in Table 3-1 define the key parameters of the system:

Table 3-1 Delta Robot Specifications.

No.	Specification	Value
1.	Robot Type	3DOF Delta Robot (Parallel)
2.	Project Function	Pick and place
3.	Operating Power	12v
4.	Controlling	Arduino Uno with DRV8825 drivers
5.	Motor Type	Stepper Motor Nema 17
6.	Communication	USB
7.	Safety	Emergency Push Button
8.	Upper base Diameter	100 mm
9.	End Effector Diameter	90 mm
10.	Upper Arm Length	120 mm
11.	Lower Arm Length	300 mm
12.	Motor Angle Separation	120°

3.3 Project Design

3.3.1 Design environment

The Most of mechanical parts and assemblies of the Delta Robot were designed using SolidWorks, a parametric CAD software.
The environment allowed for precision modeling and simulation of motion and mechanical interference.[7]

- **SolidWorks Environment:**

SolidWorks is a powerful computer-aided design (CAD) software widely used for 3D modeling, simulation, and product design. It allows engineers and designers to create detailed 3D models and assemblies of mechanical components, making it an essential tool in various industries, including robotics, automotive, aerospace, and consumer products. With SolidWorks, users can create intricate 3D models of parts and assemblies, enabling them to visualize complex designs.[6] The software also includes simulation tools that help analyze how designs will perform under different conditions, assessing structural integrity and motion. Additionally, SolidWorks facilitates the assembly of multiple parts, allowing designers to see how components interact and fit together. It can also generate 2D drawings from 3D models, providing the detailed documentation necessary for manufacturing.

3.3.2 Upper Body Design

The upper body as shown in figures below (Figure 3-1, Figure 3-2, Figure 3-3)include the stepper motors hub which the motor arranged at 120° to each other else the upper arms (arm movement transmission) and is 3D-printed using ABS and Resin .[9] It supports the pulleys and GT2 timing belts for arm movement transmission.

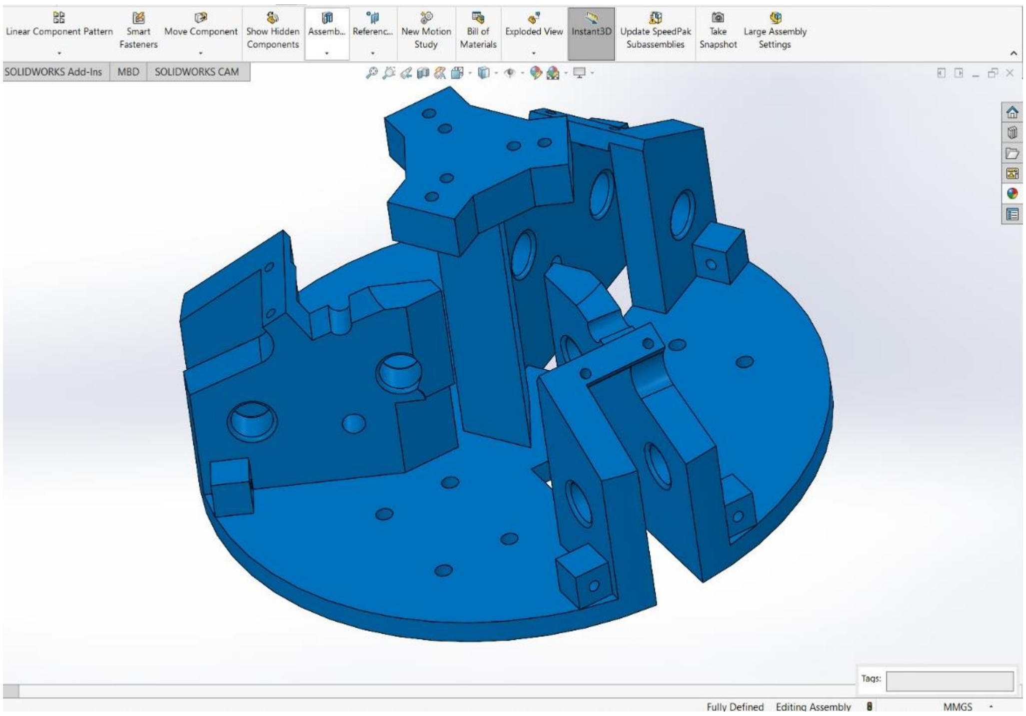

Figure 3-1 upper body (motor hub)

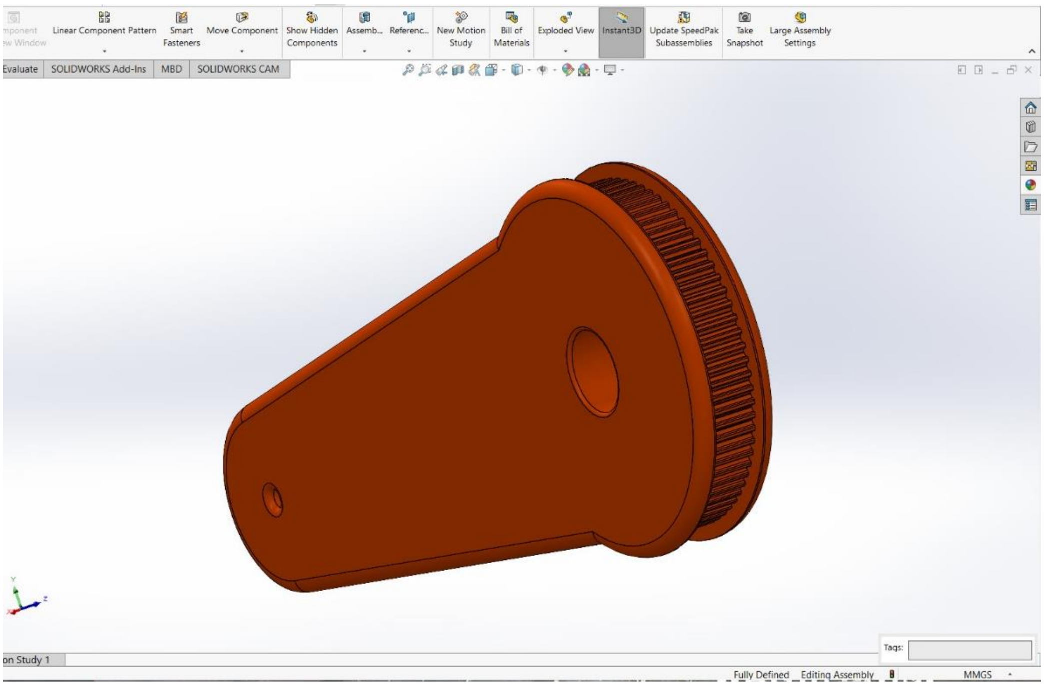

Figure 3-2 upper body (upper link)

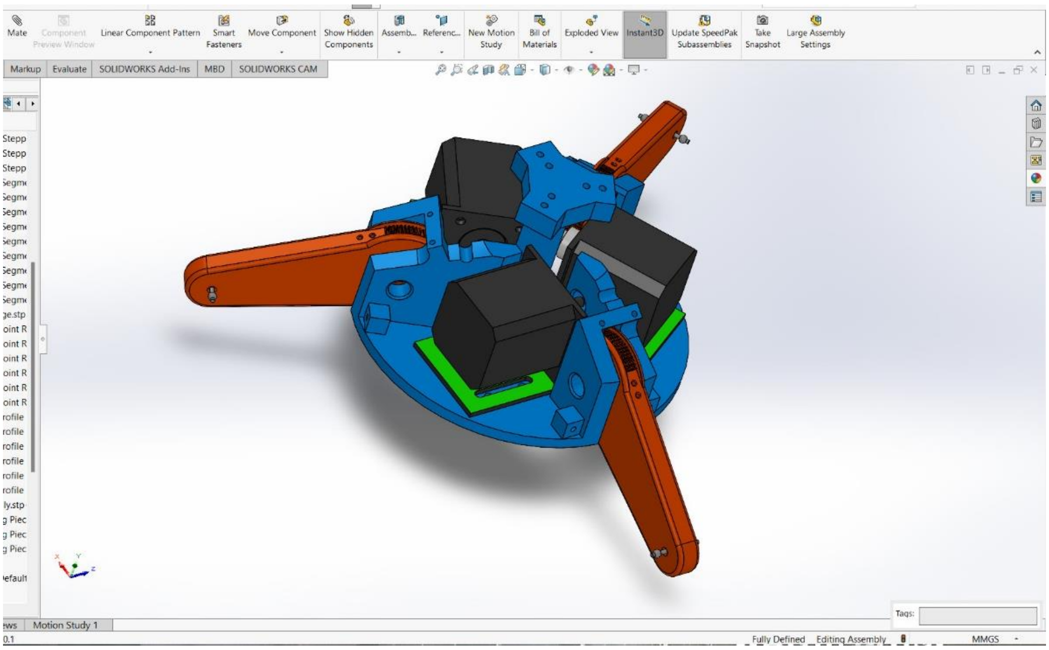

Figure 3-3 upper body (Motor hub – and upper Arms)

3.3.3 Lower Body Design

The lower body as shown in figures below (Figure 3-4, Figure 3-5, Figure 3-6, Figure 3-7) include the joints ball, links and end effector.

Figure 3-4 lower body (joint ball)

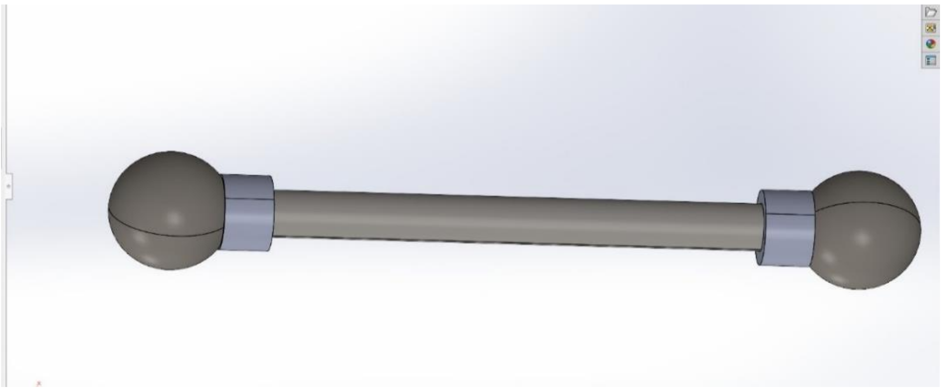

Figure 3-5 lower body (joint ball with link).

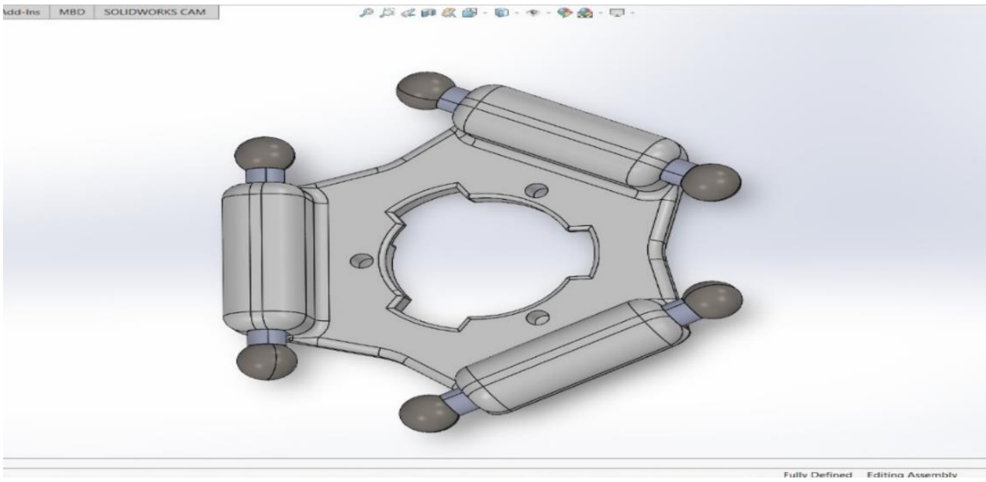

Figure 3-6 lower body (End effector).

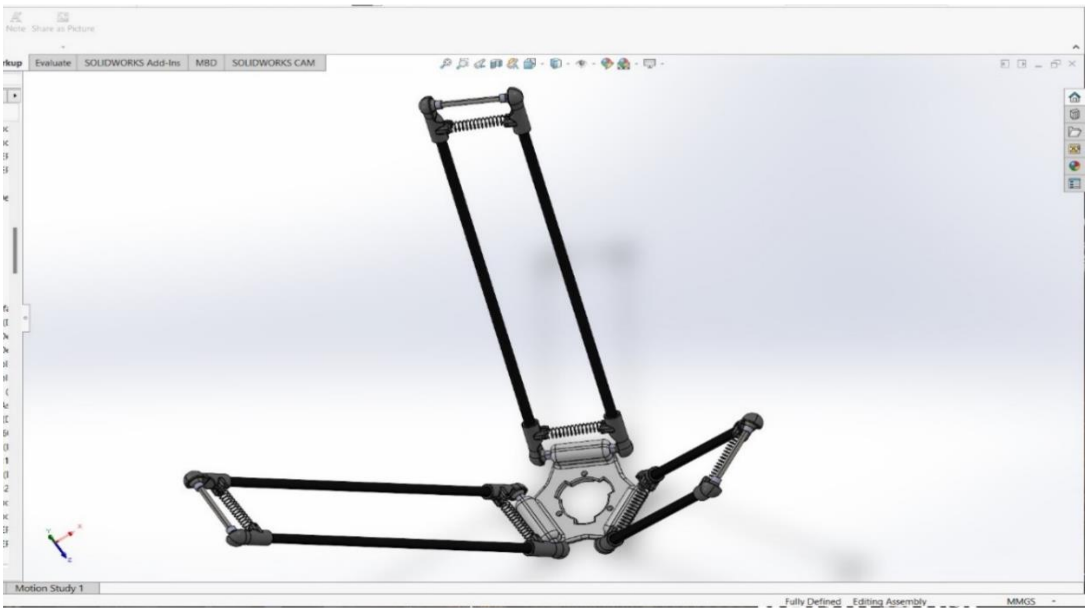

Figure 3-7 lower body.

3.3.4 Gripper Design

The gripper, 3D-printed in ABS, TPU for enhanced precision, connects to the end effector and contain the servo motor SG90g. It is designed to pick small parts from the conveyor. It is lightweight and mounted on the triangular moving platform via linkages. The gripper and it`s parts shown in figures (Figure 3-8, Figure 3-9) below:

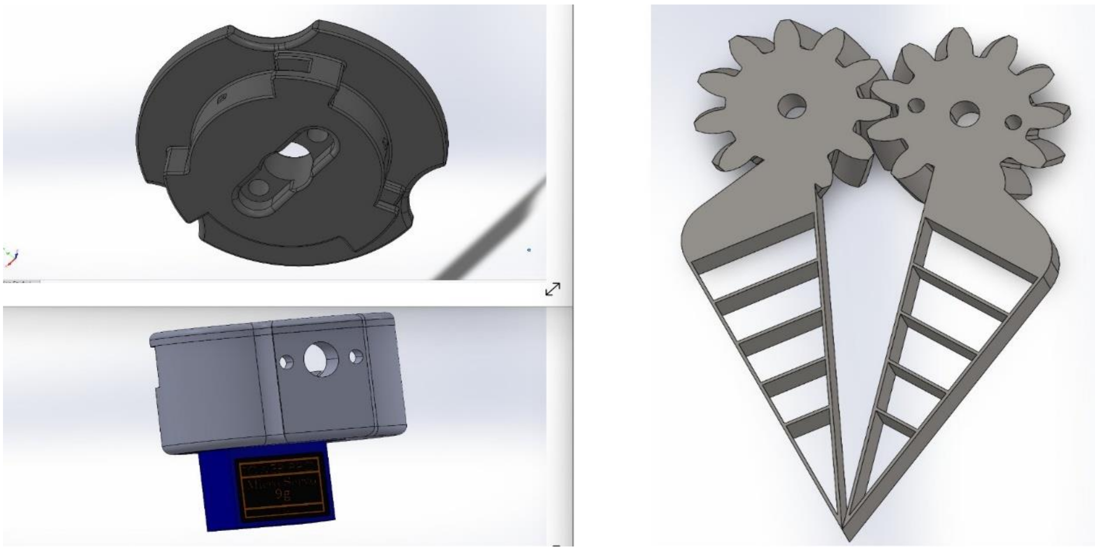

Figure 3-8 Gripper parts (Box - Holder - Gears).

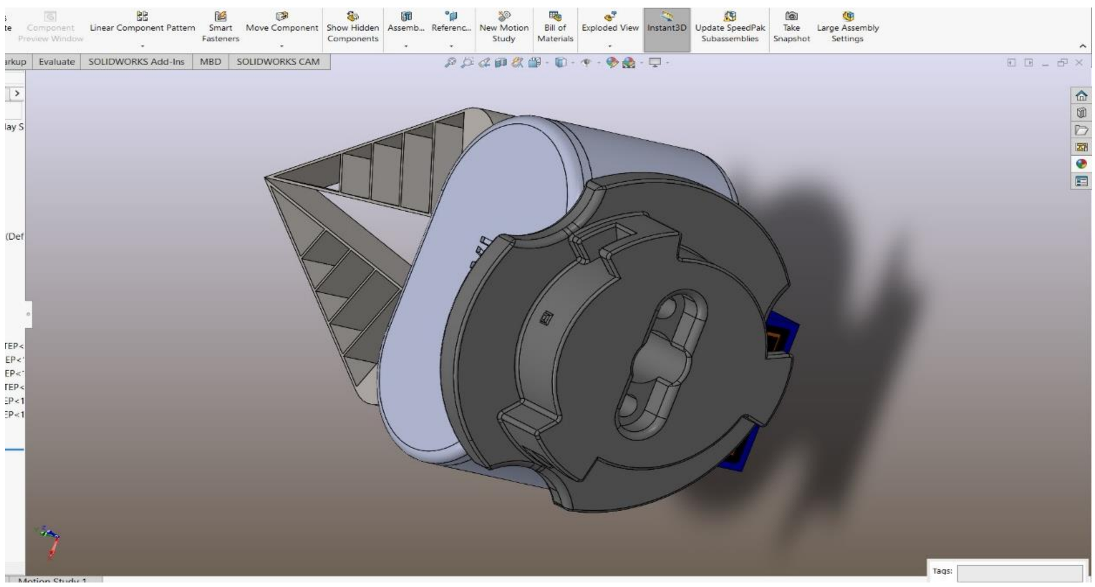

Figure 3-9 Gripper.

3.3.5 Delta Robot Design Assembly

The assembled robot in SolidWorks as shown in Figure 3-10 below includes all parts aligned with joints and motion constraints.

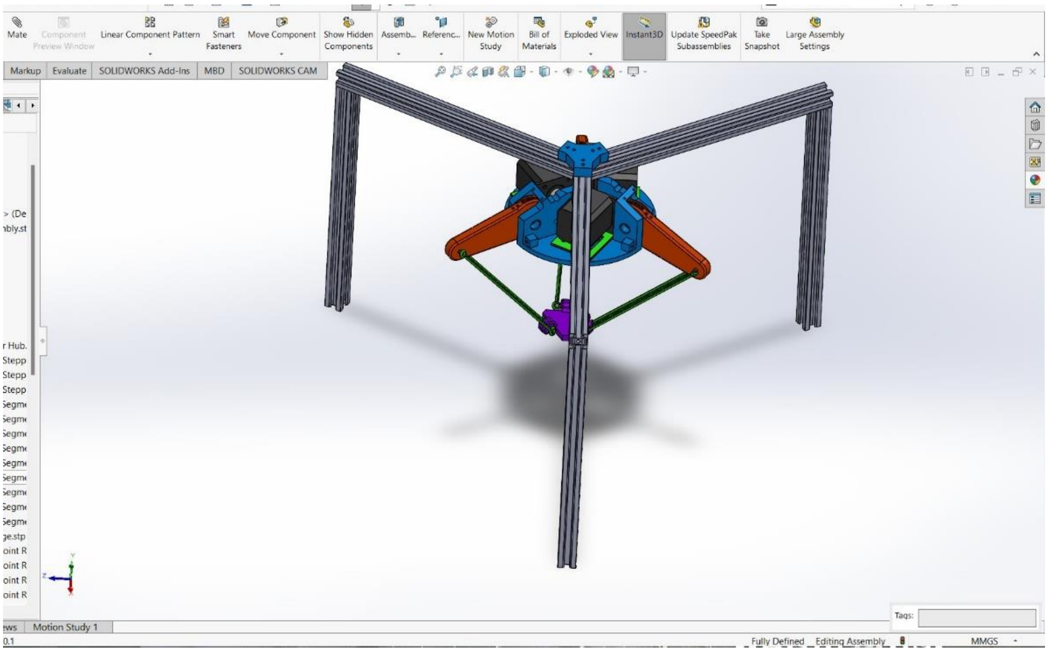

Figure 3-10 Delta Robot assembly.

3.4 Hardware Components (Project parts)

In this section, we will show the hardware components that divide into four sections:

3.4.1 3D Printed Parts

The following Table 3-2 shows the main 3D printed parts used in the robot:

Table 3-2 3D Printed Parts.

Part	Component	Quantity	Material
Upper Body	Delts Robot Motor Hub	1	ABS
	Delta Robot Arm Segment	3	ABS
Lower Body	Rod End Bearing	12	ABS
	joint link	6	Resin
	Spring Stick	12	Resin
	Base - End effecter	1	ABS
	Joint Ball	12	Resin
	link Cover	12	Resin
Gripper	Flexible Gripper - control Gear	1	Resin
	Flexible Gripper _ Soft Hold	2	TPU
	Flexible Gripper _Driven Gear	1	ABS
	Flexible Gripper _Box	1	ABS
	Flexible Gripper _Lib	1	ABS
	Flexible Gripper _Top	1	ABS

These components are fabricated using ABS filament with FDM 3D printing. The strength and weight considerations were balanced to ensure reliable movement. Also use Resin for mechanical small Joints and links, it has an excellent mechanical Propriety. TPU has elastic Propriety.[9]

The following Figure 3-11 shows the main 3D printed parts used in the robot and Figure 3-12. shows the all parts STL in Cura Program:

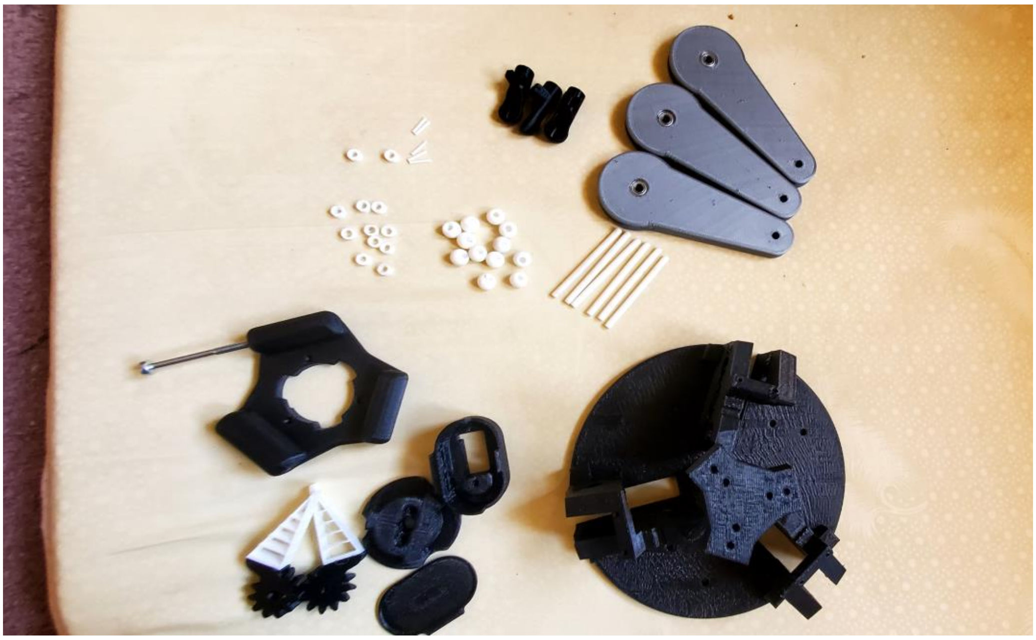

Figure 3-11 3D Printed Parts.

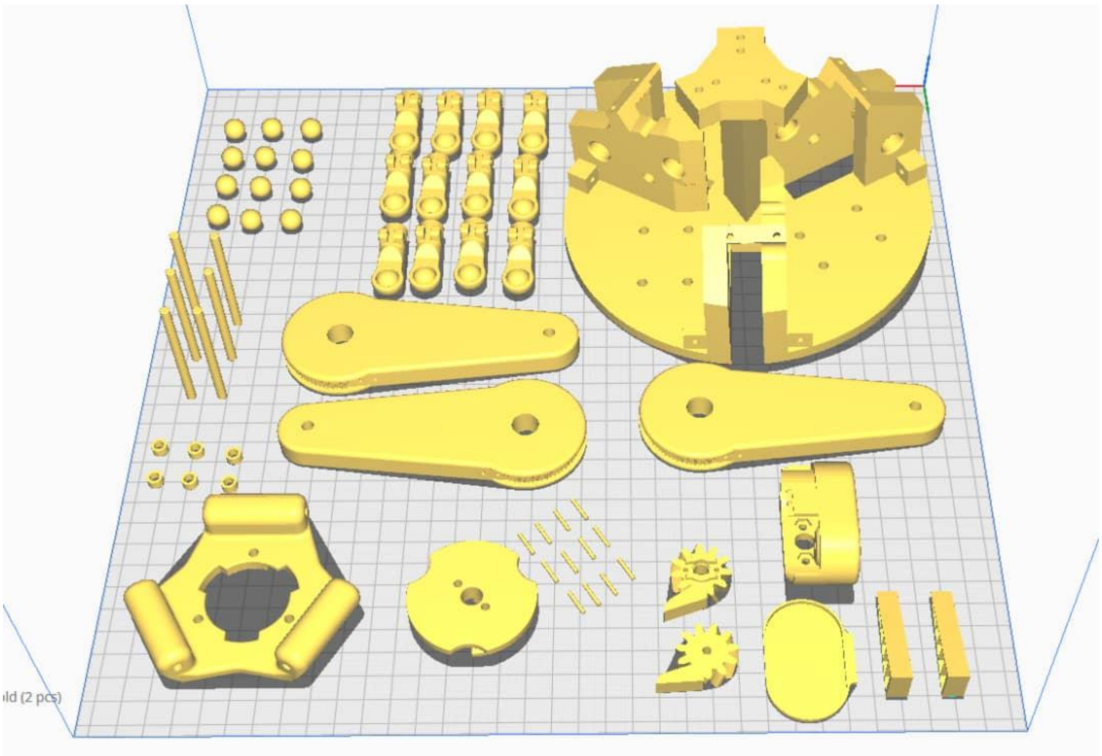

Figure 3-12 All 3D printed parts as STL.

3.4.2 Controlling Components

The control system is centered around Arduino UNO with driver circuits and safety mechanisms. The following Table 3-3. shows the main Controlling Components used in the robot:

Table 3-3 Controlling Components.

Component	Quantity	Function
Arduino UNO	1	Main microcontroller
CNC Shield	1	Connect all parts
DRV8825 Driver	3	Stepper motor control

3.4.2.1 Arduino UNO

The main microcontroller in our robot. The UNO board shown in Figure 3-13 is the flagship product of Arduino. Use the UNO R3 as a tool for education purposes or industry-related tasks, the UNO R3 is a flexible treatment controller board.[10]

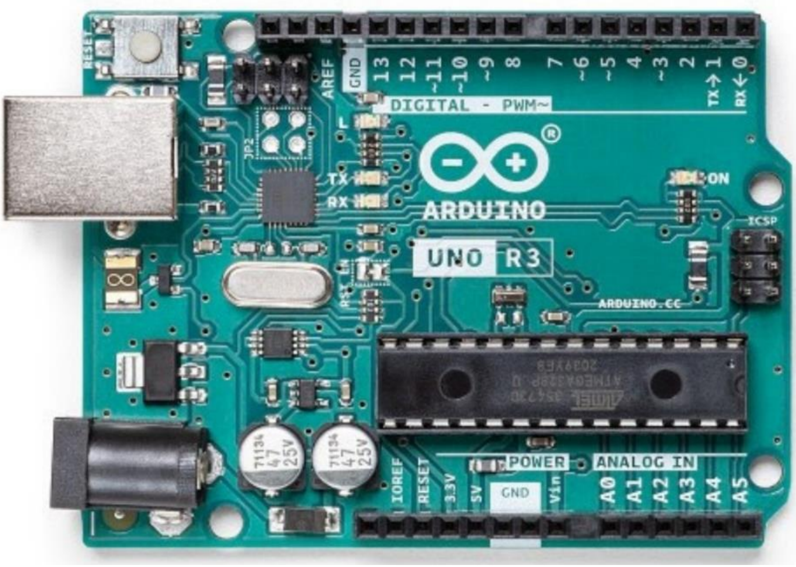

Figure 3-13 Microcontroller Arduino Uno.[10]

3.4.2.2 CNC Shield V3

The CNC Shield V3 as shown in Figure 3-14 is an expansion board for the Arduino Uno that allows you to easily control a CNC (Computer Numerical Control) machine. It is designed to be compatible with GRBL firmware, making it ideal for DIY CNC projects. This shield can control up to four stepper motors and includes sockets for A4988 or DRV8825 stepper motor drivers.[14]

➢ **Applications:**

1. DIY CNC machines
2. 3D printers
3. Laser cutters Engraving machines
4. Robotics projects

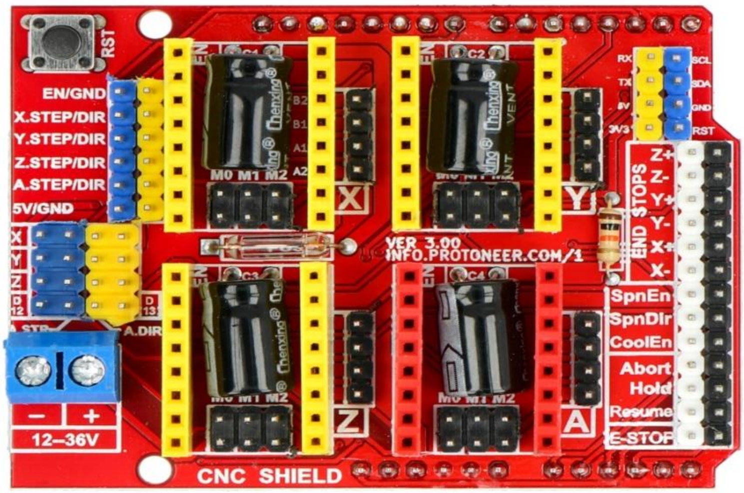

Figure 3-14 CNC Shield V3.

➢ **Technical Specifications:**

1. Input Voltage: 12-36V DC.
2. Supported Stepper Drivers: A4988, DRV8825.
3. Number of Axes: 4 (X, Y, Z, A) .
4. Micro stepping Settings: Full step, half step, 1/4 step, 1/8 step, 1/16 step.
5. Compatible Microcontroller: Arduino Uno.
6. Dimensions: 68 x 53 mm.

3.4.2.3 DRV8825 Driver

It is a breakout board for the Texas Instruments DRV8825 stepper motor controller, see Figure 3-15. You can use this board to act as interface between your microcontroller and stepper motor. The DRV8825 is able to deliver up to 2.5A and can be controlled with a simple step/direction interface.[13] The controller has a resolution of min. 1/32 step and protective features for over-current, short circuit and over-temperature. The DRV8825 driver specifications are declare in Table 3-4 DRV8825 driver specifications.

Table 3-4 DRV8825 driver specifications.

Controller	DRV8825
Operating Voltage (logic)	3-5.25V
Operating Voltage (vmot)	12-24V
Max current	2.5A
Dimensions	20.4x15.6mm

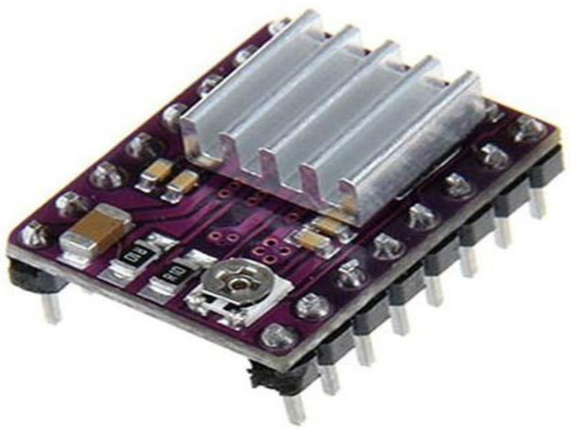

Figure 3-15 DRV8825 Driver.[13]

The following Table 3-5 explains and declares the DRV8825 Pins Function:

Table 3-5 DRV8825 Pins Function.

Name	Description
Enable	Enable/disable the stepper driver HIGH – Disable LOW – Enable *
M0 – M2	Step resolution setting, see chapter 'step resolution configuration'
RESET	Enable/disable the H-bridge output * LOW – Disable * HIGH – Enable
SLEEP	Enable/disable low-power sleep mode LOW – Sleep * HIGH – Active
STEP	LOW → HIGH, move one step
DIR	LOW / HIGH switches direction
VMOT	Motor power (12-24V)
GND	System ground
FAULT	LOW when the stepper driver is in fault condition. You can provide 5V on this pin for compatibility with stepstick A4988

3.4.3 Electric Components

Electrical parts as shown in Table 3-6. provide power, safety control, and visual feedback. Electronic components are the basic elements that form the basic parts of electronic circuits. Here is a general guideline on our electronic components in Delta robot.

Table 3-6 Electrical Components.

Component	Quantity	Function
NEMA 17 Stepper Motor	3	Motion generation
Power Supply	1	12V, 16A
Step-down Converter	1	Voltage regulation
Servo Motor SG90	1	Gripper move
DC Gear Motor	1	Moving the conveyor
Emergency Stop	1	Safety shutdown
Toggle Switch	1	Start – Stop switch
Limit Switch	3	Axis end detection
Start, Stop Pushbutton	1	Start – Stop
Indicator Lamp	2	Red (Stop), Green (Start)
Temp Sensor	1	Monitor temperature
IR sensor	1	Detect product in conveyor
Power Relay MY2N	1	Latching start and stop lamp
5V Mount Relay – SPDT	1	Starting fan
Water Proof Box	1	For electric components
DC Fan	1	Cooling
Wires & Connectors	Several	Connect the circuit

3.4.3.1 NEMA 17 Stepper Motor

A stepper motor to satisfy all your robotics needs! See, Figure 3-16. This 4-wire bipolar stepper has 1.8° per step for smooth motion and a nice holding torque. The motor was specified to have a max current of 350mA so that it could be driven easily with an Adafruit motor shield for Arduino (or other motor driver) and a wall adapter or lead-acid battery.[11]

Figure 3-16 Nema 17 Stepper Motor.[11]

- **Technical Details:**

1. 200 steps per revolution, 1.8 degrees.
2. Coil #1: Red & Yellow wire pair. Coil #2 Green & Brown/Gray wire pair.
3. Bipolar stepper, requires 2 full H-bridges!
4. 4-wire, 8-inch leads.
5. 42mm/1.65" square body.
6. 31mm/1.22" square mounting holes, 3mm metric screws (M3).
7. 5mm diameter drive shaft, 24mm long, with a machined flat.
8. 12V rated voltage (you can drive it at a lower voltage, but the torque will drop) at 350mA max current.
9. 28 oz*in, 20 N*cm, 2 Kg*cm holding torque per phase.
10. 35 ohms per winding.

3.4.3.2 Servo Motor SG90s

The MG90S 180° metal gear servo motor as shown in Figure 3-17 is a compact and powerful motor ideal for robotics, Arduino, and electronics projects. It's a popular choice among hobbyists and students due to its reliability, precision, and lightweight design. This servo motor comes with full metal gears and a ball bearing setup, ensuring durability and smooth operation for various applications like robotic arms, sensor positioning, or RC models.

Figure 3-17 Servo Motor SG90s.

❖ **Specifications:**

- Model: MG90S.
- Operating Voltage: 4.8V to 6V (typically 5V).
- Rotation Angle: 0° to 180°.
- Stall Torque: 1.8 kg/cm (4.8V), 2.2 kg/cm (6V).
- Operating Speed: 0.1s/60° (at 4.8V).
- Gear Type: Metal Gears with Full Ball Bearing Weight: 12.2 grams.
- Dimensions: 22.8 x 12.2 x 28.5 mm.
- Wiring: Red (VCC), Brown (GND), Orange (Signal).
- Package Includes: Servo motor with gear horns and screws.

3.4.3.3 Power Supply

- Code: WP-12A16
- Name: Rainproof power supply. See, Figure 3-18.

➢ **Features**

- Aluminum cabinet with small space but good heat dissipation.
- Rainproof design to avoid electric shock, protect terminal box, and prevent touch.
- Overload, overheat, short circuit and other protection functions.

Figure 3-18 12V 200W LED Outdoor Rainproof Switching Power Supply.

3.4.3.4 Step-down Converter

LM2596 DC – DC converter stepdown shown in Figure 3-19.

- **Product details**
  - Input voltage range: DC 3.2V to 35V (input voltage must be higher than the voltage output to 1.5V or more cannot be boosted.)
  - Output: 1.25V to 30V DC voltage is continuously adjustable, high efficiency and maximum output current of 3A.
  - All solid capacitors using SANYO
  - 36u thick circuit boards
  - High-Q inductors with high power output LED indicator

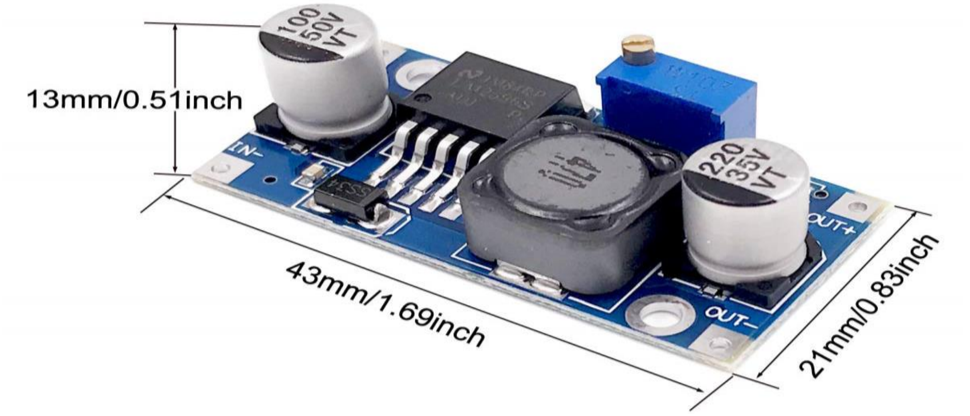

Figure 3-19 DC-DC Converter Step Down.

3.4.3.5 Emergency Stop (On – Off Push Button)

On – Off push button. See, Figure 3-20.

Figure 3-20 Emergency Stop (On – Off Push Button).

3.4.3.6 Toggle Switch SPDT

➢ **Description**

This Mini Panel Mount SPDT Toggle Switch as shown in Figure 3-21. is great for any project where you have two options to select between. Maybe you'll be selecting between two voltages? Two audio outputs? Two sensor inputs? It's up to you! It's short, sweet, blue, and to the point! The part is marked at 6A 125VAC but we haven't tested it at such high current/voltages and don't recommend it for more than 1A at 24V.

➢ **Features**

- SPDT 3 Terminal ON-ON 2 - Position Latching Toggle Switch.
- Each switch is assembled with two hex nuts, a flat and a locking washer.
- Easy installation, fits into any 6mm hole.

➢ **Technical Details**

- Product Dimensions: 32.9mm x 13.1mm x 12.0mm / 1.3" x 0.5" x 0.5"
- Product Weight: 5.0g / 0.2oz

Figure 3-21 Toggle Switch SPDT (On - Off - On)

3.4.3.7 Limit Switch (End Stop)

This lever end stop switch module is designed for use as an end stop for 3D printers but it can be used for other contact detection applications as well. See, Figure 3-22.

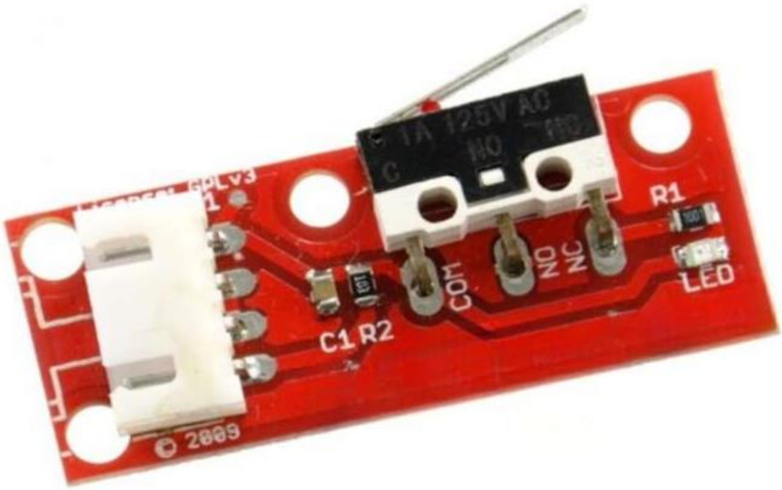

Figure 3-22 Limit Switch (End Stop Sensor).

- **Module Connections**

Note that the board is not labeled, but you can go by the cable wire colors to make connections 1×4 Connectors

- Red Wire = VCC (3.3 or 5V to match the uC.)
- Black Wire = Ground which should be common with the uC.
- N/C = Not connected, but is grounded on module side
- Green Wire = Signal output of the module. This pin is normally pulled HIGH via a 10K pull-up resistor. When the switch is depressed, the output goes LOW (shorted to ground).

3.4.4 Start /Stop Pushbutton Box

It’s shown in Figure 3-23.

Figure 3-23 Start /Stop Pushbutton Box.

3.4.4.1 Indicator Lamp (Start - Stop)

See, Figure 3-24.

Figure 3-24 Indicator Lamp (Start - Stop Condition).

3.4.4.2 Temperature Sensor

A temperature sensor as shown Figure 3-25 is an integrated circuit sensor that measures the centigrade temperature and provides an output voltage that is linearly proportional to the temperature.

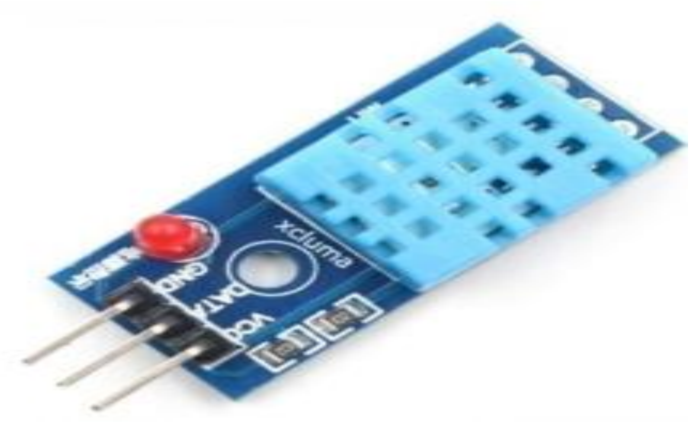

Figure 3-25 Temperature Sensor.

3.4.4.3 IR sensor

Infrared IR Obstacle Avoidance Sensor Board 3 Pin is perfect for Arduino or Micro: bits. See, Figure 3-26. The Infrared Obstacle Avoidance Sensor has a pair of infrareds transmitting and receiving sensors. The infrared LED emits Infrared signals at a certain frequency. Then when an obstacle appears on the line of infrared light, it is reflected by the obstacle. When the sensor detects an obstacle, the LED indicator lights up, giving a low-level output signal in the OUT pin. The sensor detects a distance of 2 – 30cm. Additionally, the sensor has a potentiometer that can be adjusted to change the detection distance.

Figure 3-26 Infrared IR Obstacle Avoidance Sensor Board 3 Pin.

3.4.5 Power Relay MY2N

220/240V AC Coil DPDT Power Relay MY2N 8 Pin DPDT general purpose relay. The relay plays the role as a protector or a circuit switch. It can protect your electric equipment very well. See, Figure 3-27.

➢ **Specifications:**

- Product Name: Power Relay.
- Relay Model No.: MY2N-J.
- Coil Voltage: AC 220-240V.

Figure 3-27 220/240V AC Coil DPDT Power Relay MY2N.

3.4.6 5V PCB Mount Relay – SPDT

A relay is an electrically operated switch. Shown in Figure 3-28. It consists of a set of input terminals for single or multiple control signals, and a set of operating contact terminals. Relays are used where it is necessary to control a circuit by an independent low-power signal, or where several circuits must be controlled by one signal.

➢ **Specifications:**

- Relay Type: SPDT
- Coil Voltage Rating: 5V

Figure 3-28 5V 3A PCB Mount Relay – SPDT.

3.4.6.1 Water Proof Box

See, Figure 3-29.

Figure 3-29 Water Proof Box (Box for Electrical Parts).

- **General description**
  - Brand: Hi-Tech
  - Product: Waterproof Box ip65
  - Size: 230x190x60mm
  - Purpose use: External Boxing
  - Color: White
  - Material: Plastic

3.4.7 Mechanical Components

These mechanical parts provide motion and structural functionality. The following Table 3-7 shows the main Mechanical Components used in the robot:

Table 3-7 Mechanical Components.

Component	Quantity	Function
Round Metal Rod	2	Connect motor hub with arms
GT2 Timing Belt	3	Transmitting motion
Bearings	6	Joint smooth motion
Pulleys	3	Motion translation
Conveyor Belt	1	Object transportation
Wooden Frame	Frame	External structure
Screws	many	Connect Hardwares

3.4.7.1 Round Metal Rod

- **General description**
  - Product Name: Round Metal Rod. Shown in Figure 3-30.
  - Material: Metal.
  - Size: 5mm x 100mm (0.2" x 4") (D*L); For: DIY RC Model.
  - Net Weight: 77g; Main Color: Silver Tone.
  - Package Content: 5 Pcs x Round Metal Rod.

*Figure 3-30 Round Metal Rods M5*100mm.*

3.4.7.2 Pulleys and GT2 Timing Belt

It’s shown in Figure 3-31.

Figure 3-31 Pulleys and GT2 Timing Belt.[14]

3.4.7.3 Bearings (685zz)

See, Figure 3-32.

Figure 3-32 Bearings.

3.4.7.4 Screws

See, Figure 3-33.

Figure 3-33 Types of Screws and nuts using in Project.

Chapter 4

Requirements Analysis And Modeling

Chapter 4: Requirements Analysis and Modeling

4.1 Introduction

This chapter presents a comprehensive analysis of all requirements for the Small Delta Robot—functional, non-functional, hardware and software, and then develops its kinematic models (forward and inverse), performs workspace analysis, and describes the simulation tools used to validate the design.[15]

To derive a workspace of the Delta robot, the Cartesian reachable position of the Delta-robot end effector can be efficiently identified using an inverse kinematics. By varying upper-arm and fore-arm lengths, a maximize workspace for a desired reachable work area could be obtained. Furthermore, a trajectory tracking of the Delta robot for pick-and-place operation can be analyzed in terms of load-carrying ability using simplified dynamic equations such that proper actuators and gears could be correctly chosen in the design phase before constructing the Delta robot.[16]

4.2 Requirements Analysis

4.2.1 Functional Requirements

Functional requirements define what the Delta Robot system is expected to perform. These include movement control, object manipulation using the gripper, interaction with the conveyor belt, and responding to emergency stop commands as they described in Table 4-1.

Table 4-1 Description of the functional requirements.

Req.ID	Description	Priority
FR1	Move end-effector to a desired X, Y, Z position	High
FR2	Grip and release objects from the conveyor	High
FR3	Stop robot immediately in case of emergency	Critical
FR4	Read position sensors and limit switches	Medium
FR5	Provide feedback through indicator LEDs	Low
FR6	Provide real-time status via Serial Monitor	_____

The functional requirements shown above in Table 4-1. outline the core tasks that the system must perform. High priority tasks focus on the motion control of the Delta Robot, while secondary tasks like LED indicators serve to improve system usability.

4.2.2 Non-Functional Requirements

Non-functional requirements specify criteria that can be used to judge the operation of a system, rather than specific behaviors.

Table 4-2 Description of the Nonfunctional requirements.

Req.ID	Description	Importance
NFR1	System must operate continuously for at least 4 hours	High
NFR2	Heat dissipation through cooling fan must maintain safe temperature	High
NFR3	Power consumption must remain under 200W	Medium
NFR4	Circuitry must be protected using waterproof enclosures	Medium
NFR5	Energy efficiency with 12 V supply	Medium

These non-functional requirements as describe in Table 4-2. above aim to ensure the stability and efficiency of the system in the long term, particularly during extended operational periods.

4.3 Software Requirements & Analysis

The project uses the following software tools: Arduino IDE for firmware development, MATLAB/Simulink for kinematic modelling and workspace simulation, SolidWorks for mechanical design, and Proteus for circuit capture and co-simulation as shown in Table 4-3.

Table 4-3 Software Tool Requirements.

Software	Purpose	Version	Soft. Icon
Arduino IDE	Firmware coding & Serial Monitor	1.8.7	
MATLAB & Simulink	Kinematic modelling & 2D/3D simulation	R2022a	
SolidWorks	3D CAD & Motion Study	2023	
Proteus 8	Circuit capture & SPICE/MCU co-simulation	8.13	

4.4 Kinematic Modelling

Unlike the more common serial-geometry mechanisms, all three of the primary actuators of this parallel mechanism work together to produce the three Cartesian translation degrees of freedom.

Kinematic modelling of the Delta Robot is essential to determine the mathematical relationship between the position of the end-effector and the joint angles of the actuators. This section covers both the forward and inverse kinematics models of the Delta Robot along with workspace analysis.

In general, parallel robot is a closed-loop manipulator, see Figure 4-3, Figure 4-3 which is rather inconvenient for kinematic calculation. The movable platform remains connected to the base platform, and the direction around the vertical axis on the base plate is zero at all times. As shown on Figure 4-1, it is stationary, movable platforms are circular with radius of R, and r. Junction points of stationary platform to stationary poles are S_1, S_2 and S_3. *x*, *y*, and *z* coordinates of these points are provided in 4-1. Motors used in the movable and stationary platform have been placed with the angle of 120. Geometrical parameters of the Delta-type parallel robot are shown on Figure 4-2.

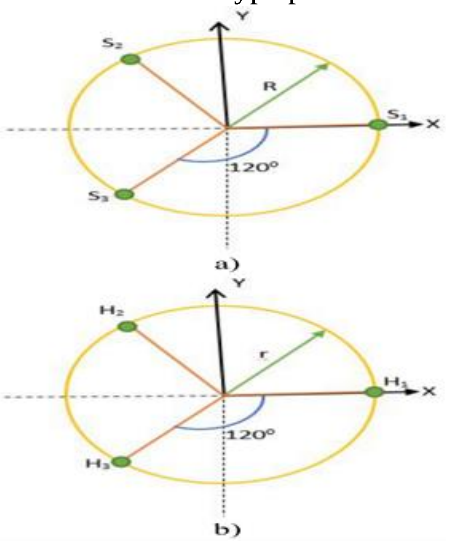

Figure 4-1 Stationary and movable platform of the Delta-type.

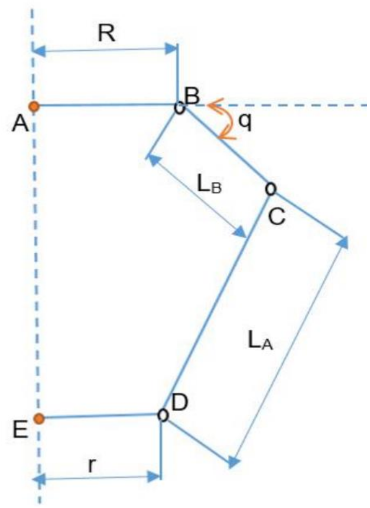

Figure 4-2 Geometrical parameters of the Delta-type

$$\begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix} = \begin{bmatrix} 5 & -\frac{R}{2} & -\frac{R}{2} \\ 0 & \frac{R\sqrt{3}}{2} & -\frac{R\sqrt{3}}{2} \\ 0 & 0 & 0 \end{bmatrix} \quad \text{4-1}$$

Junction points of the movable platform to parallelograms are H_1, H_2 and H_3 points. *x*, *y*, and *z* coordinates of these points are provided in 4-2.

$$\begin{bmatrix} H_1 \\ H_2 \\ H_3 \end{bmatrix} = \begin{bmatrix} 5 & -\frac{r}{2} & -\frac{r}{2} \\ 0 & \frac{r\sqrt{3}}{2} & -\frac{r\sqrt{3}}{2} \\ 0 & 0 & 0 \end{bmatrix} \quad \text{4-2}$$

Our delta robot Parameters is shown in Table 4-4.

Table 4-4 The Physical Parameters of a Delta type Parallel.

Parameter	Symbols	Value (cm)
Upper Arm Length	L_B	12
Lower Arm Length	L_A	30
Base Radius	R	5
End-effector Radius	r	4.5
Angle between arms	θ_m	120°

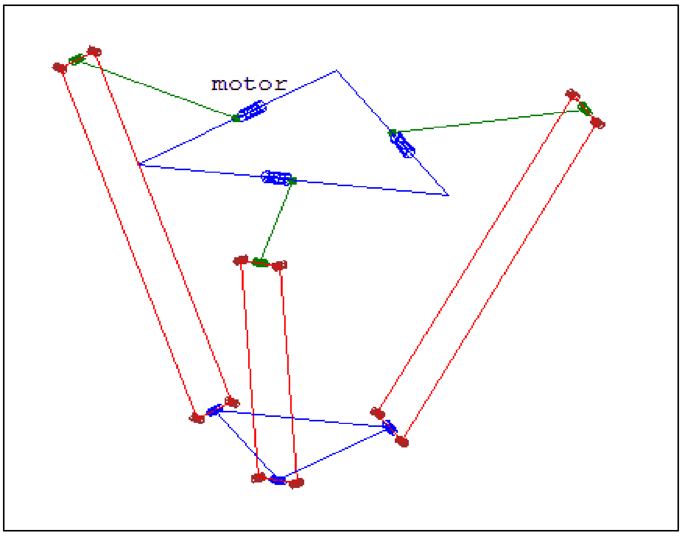

Figure 4-3 Motion of the Delta robot.

4.4.1 Forward Kinematics (FK)

The forward kinematics also called the direct kinematics of a parallel manipulator determines the (*x, y, z*) position of the travel plate in base-frame, given the configuration of each angle θ_i of the actuated revolute joints, see Figure 4-4.

Given the actuator angles θ_1, θ_2, θ_3, the position of each upper joint is calculated, and a set of nonlinear equations based on the spherical joints of the parallelogram is solved to find the intersection point of the three spheres that represent the lower arms.

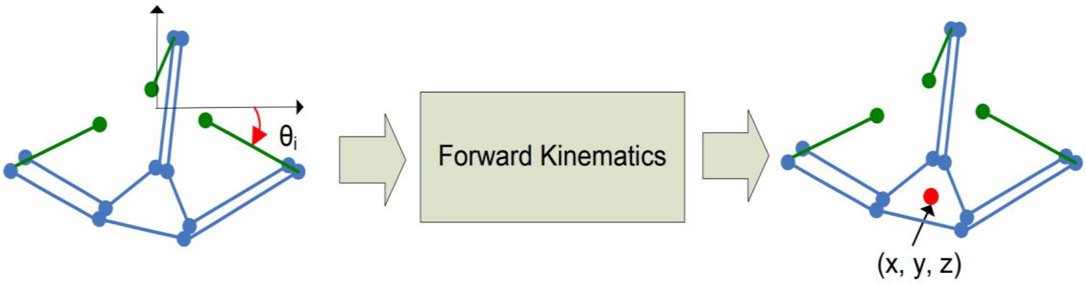

Figure 4-4 forward kinematics transforms the three-arm angle positions1,2,3 into the x, y and z components of the TCP position.[19]

The position of each spherical joint can be expressed as a function of its rotation angle and the geometry of the arms. Solving for the common point yields the Cartesian coordinates of the end-effector.

Forward kinematic equations, calculating the *xyz* cartesian space of the robot's junction lead position in junction variable values through the use of such angles, were calculated as follows.[17]

$$x_i = (R + L_A \cos\theta_i)\cos\alpha i \qquad 4\text{-}3$$

$$y_i = (R + L_A \cos\theta_i)\sin\alpha i \qquad 4\text{-}4$$

$$z_i = L_A \sin\theta i \qquad 4\text{-}5$$

$$(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 = L_B{}^2 \quad \text{4-6}$$

Geometrical parameters of the delta robot are L_A, L_B, R, r and θi as defined on Figure 4-2, and the variables are the junction angles defining the i = 1,2,3… configuration. According to the aforementioned equations, there are three unknowns (x, y, z). Therefore, three equations have been attained by replacing such unknowns with ' i ' values.

$$(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 = L_B{}^2 \quad \text{4-7}$$

$$(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2 = L_B{}^2 \quad \text{4-8}$$

$$(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2 = L_B{}^2 \quad \text{4-9}$$

When the equations above are solved in turn and certain limitations were applied for ease of operation, the following equations were attained.[16]

$$x_0 = \frac{a_1 z_0 + b_1}{d}$$
$$y_0 = \frac{a_2 z_0 + b_2}{d} \quad \text{4-10}$$
$$z_0 = \frac{-b \pm \sqrt{\Delta}}{2a}$$

In general, there are two possible solutions; which are the two possible configurations for the given junction angles from the movable platform to the base. Equation 13 was obtained upon use of an epitomic resultant vector value.

$$\overrightarrow{S_1O} + \overrightarrow{OP} + \overrightarrow{PH_1} = \overrightarrow{S_1H_1} = L \quad \text{4-11}$$

4.4.2 Inverse Kinematics (IK)

Inverse kinematics involves determining the required angles *θ1, θ2, θ3* for a given end-effector position (*x, y, z*) as shown below Figure 4-5. This is more computationally efficient than forward kinematics and is usually used in real-time control.[16]

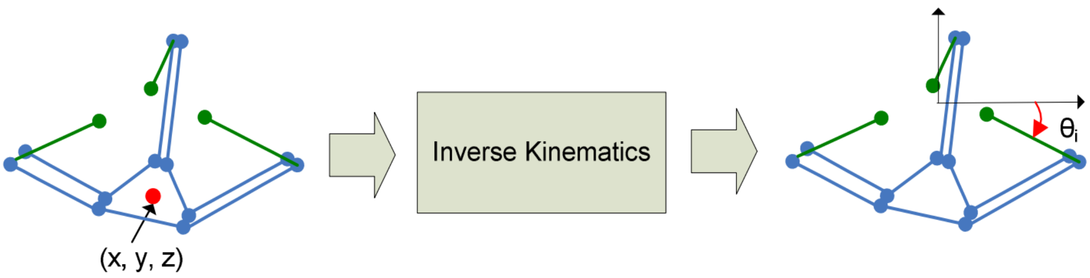

Figure 4-5 inverse kinematics transforms the robots TCP position (x,y and z component) into the three upper arm.[19]

Inverse kinematic problem is caused by

determining the θ_i (i =1,2,3) angle values in cases of characteristic point or the end effector (TCP-Tool Center Point) positions based on general coordinates: x_p, y_p, z_p

$$a_i + b_i cos\theta_i + c_i sin\theta_i = 0 \quad \text{4-12}$$

$$a_i = ((R-r)cosai - x)^2 + ((R-r)sin\theta i - y)^2 + z^2 - L_2^2 - L_1^2 \quad \text{4-13}$$

$$bi = 2((R-r)cosai - x)L_1 cosa_i + 2((R-r)sina_i - x)L_1 sina_i \quad \text{4-14}$$

$$c_i = 2zL_i \quad \text{4-15}$$

$$\theta_i = 2arcta\frac{-c_i \mp \sqrt{c_i^2(a_i^2 - b_i^2)}}{(a_i - bi)} \quad \text{4-16}$$

The equations provided above are the general equations intended for inverse kinematic analysis of the system.[17]

For the 3-DOF parallel manipulator with the system structure, each arm can satisfy the same TCP with to different approaches which were called elbow up and elbow down for the serial robot. Together the three arms of the 3-DOF parallel manipulator result in eight different combinations of the θ vector for a single goal, see Figure 4-6.

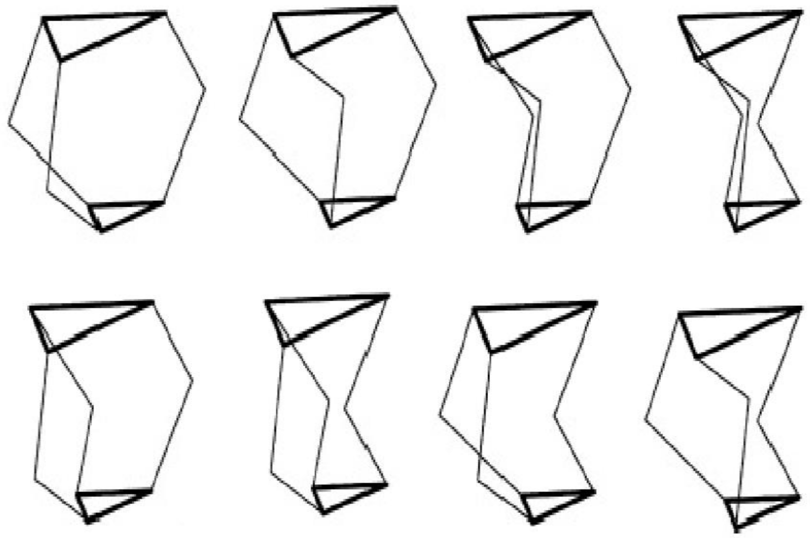

Figure 4-6 The eight solutions of the inverse kinematic for a Delta-3 robot.[20]

4.4.3 Jacobian Matrix and Conditioning Index (CI)

The Jacobian matrix is defined as the matrix that maps the relationship between the velocity of the moving platform and the vector of actuated joint rates. Then we should firstly consider the velocity equation of the robot to get the Jacobian matrix.[16]

Equations 4-6 can be differentiated with respect to time to obtain the velocity equations, which leads to:

$$(z - zi)\dot{z}\,i = (x - xi)\dot{x} + (y - yi)\dot{y} + (z - zi)\dot{z} \quad \text{4-17}$$

Rearranging Equations 4-12 leads to an equation of the form

$$\dot{\rho} = J\dot{p} \quad \text{4-18}$$

where $\dot{p}$ is the vector of output velocities defined as:

$$\dot{p} = (\dot{x}\ \dot{y}\ \dot{z})^T \quad \text{4-19}$$

and $\dot{\rho}$ is the vector of input velocities defined as:

$$\dot{\rho} = (\dot{z}_1\ \dot{z}_2\ \dot{z}_3\ )^T \quad \text{4-20}$$

Then, the Jacobian matrix of the robot can be written as:

$$\mathbf{J} = \begin{bmatrix} \frac{x - x_1}{z - z_1} & \frac{y - y_1}{z - z_1} & 1 \\ \frac{x - x_2}{z - z_2} & \frac{y - y_2}{z - z_2} & 1 \\ \frac{x - x_3}{z - z_3} & \frac{y - y_3}{z - z_3} & 1 \end{bmatrix}. \qquad 4\text{-}21$$

The conditioning index (CI) is defined as the reciprocal of the condition number of the Jacobian matrix. That is

$$\mu = \frac{1}{\kappa} \qquad 4\text{-}22$$

where κ is the condition number of the Jacobian matrix, and $\kappa = \| J^{-1} \| \| J \|$ in which $\| \cdot \|$ denotes the any norm of a matrix.[18] In fact, the condition number of a matrix is used in numerical analysis to estimate the error generated in the solution of a linear system of equations by the error on the data. When applied to the Jacobian matrix, the condition number will give a measure of the accuracy of the Cartesian velocity of the moving platform and the static load acting on the moving platform. μ is a value between 0 and 1. Actually, the CI μ is such an all-around index that can evaluate the dexterity, isotropy, as well as the static stiffness of a robot. It can also be used to evaluate the distance to the singularity.

μ = 1 means the robot is in its isotropy configuration.

When μ = 0, the robot is in its singularity, where the robot will be out of control. Therefore, the larger the CI, the farther the distance to the singularity.[17]

4.5 Workspace Analysis

The workspace is defined as the volume in which the end-effector can reach. It is limited by the physical dimensions of the robot and mechanical constraints.

Parameter	Value (cm)
Upper Arm Length (L)	12
Lower Arm Length (l)	30
Base Radius	5
End-effector Radius	4.5
Angle between arms	120°

One of the disadvantages of parallel robots is their relatively small workspace as shown in Figure 4-7. Moreover, there are some irregular protuberances, where a robot is always in or near the singular pose.[20]

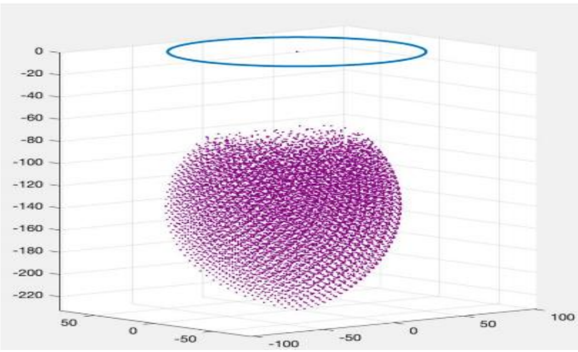

Figure 4-7 Work envelope.

Using these parameters, the workspace can be simulated in MATLAB by sweeping valid ranges of angles for each motor and checking feasible end-effector positions. The workspace is roughly a bowl-shaped volume with limited vertical range.[21]

See following figures Figure 4-8, Figure 4-9, Figure 4-10.

MATLAB enables engineers to visualize the dome-like workspace and identify reachable regions and constraints.

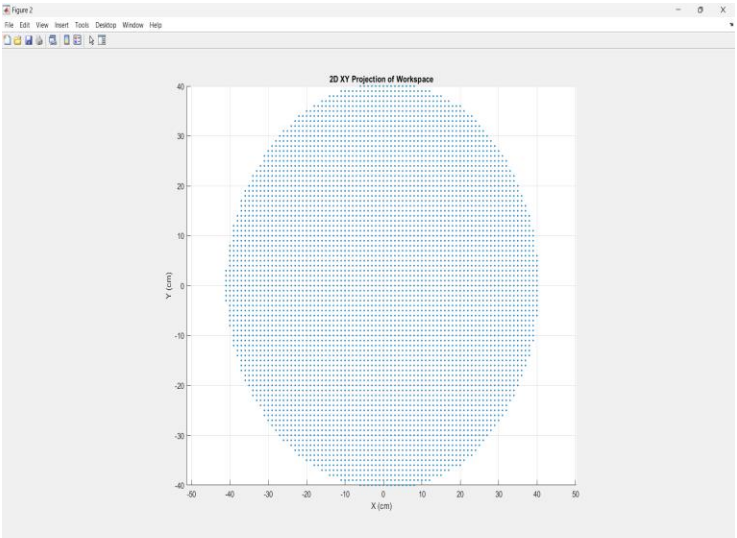

Figure 4-8 2D XY Projection of Delta Robot Workspace.

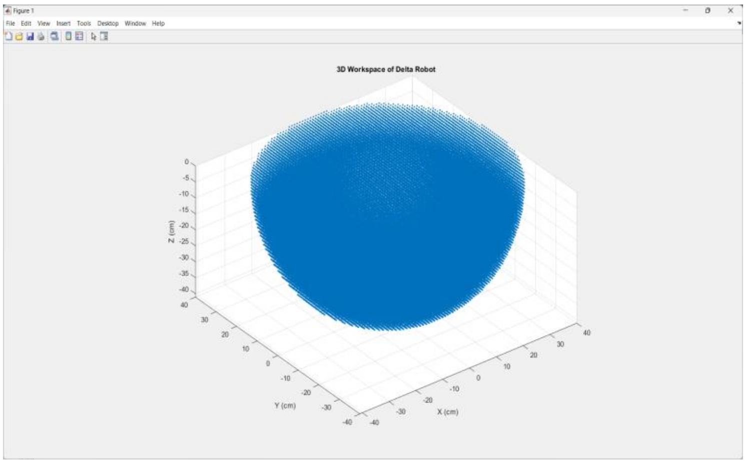

Figure 4-9 3D Visualization of Delta Robot Workspace.

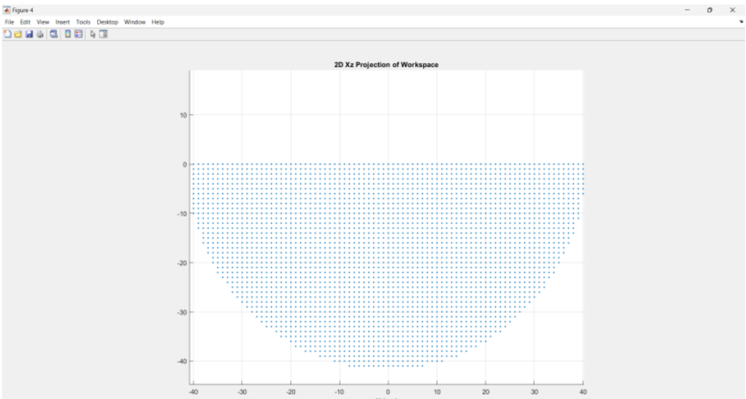

Figure 4-10 2D XZ Projection of Delta Robot Workspace.

Chapter 5

Implementation and Test & Experimental Results

Chapter 5: Implementation & Experimental Results

5.1 Introduction

This chapter presents the practical realization and experimental validation of the Delta Robot prototype. After completing the mechanical design and system integration.

The implementation phase involved constructing the Delta robot hardware, integrating the electronics, writing control software, and conducting experiments. This chapter documents each step: building the mechanical frame, assembling the arms and joints, wiring the electronics, programming the microcontroller, and validating the system via simulation and testing. The goal is to show how the design from earlier chapters was realized in practice and to report the performance metrics.

5.2 Project Assembly

5.2.1 Structural Frame Construction

The structural frame of the Delta Robot was built using a combination of wood, plastic, and foam. The lower base was constructed as a triangular wooden plate with each side measuring 55 cm and internal angles of 60°, supported by vertical plastic pillars. The triangular base was reinforced using screws, zip ties, and adhesive. Foam sheets were applied on the wooden base to enhance support and minimize vibration. The upper base, also triangular, was fabricated from cardboard wood and foam and fixed to the plastic columns to complete the supporting structure. See, Figure 5-1 and Figure 5-2

Figure 5-1 Outer frame structure.

Figure 5-2 Outer frame assembly.

5.2.2 Mechanical and 3D Printed Component Assembly

The mechanical assembly began with joining the upper body together, then the lower body using 3D-printed components as shown in Figure 5-3. The 3D-printed arms and joints were aligned and secured. The gripper was mounted to the end-effector platform. Wooden linkages were cut to appropriate lengths and connected with ball bearings to allow smooth rotation. All mechanical parts were tested manually to ensure correct articulation and motion. Each connection was checked for smooth movement and zero backlash. The three arms were mounted 120° apart.

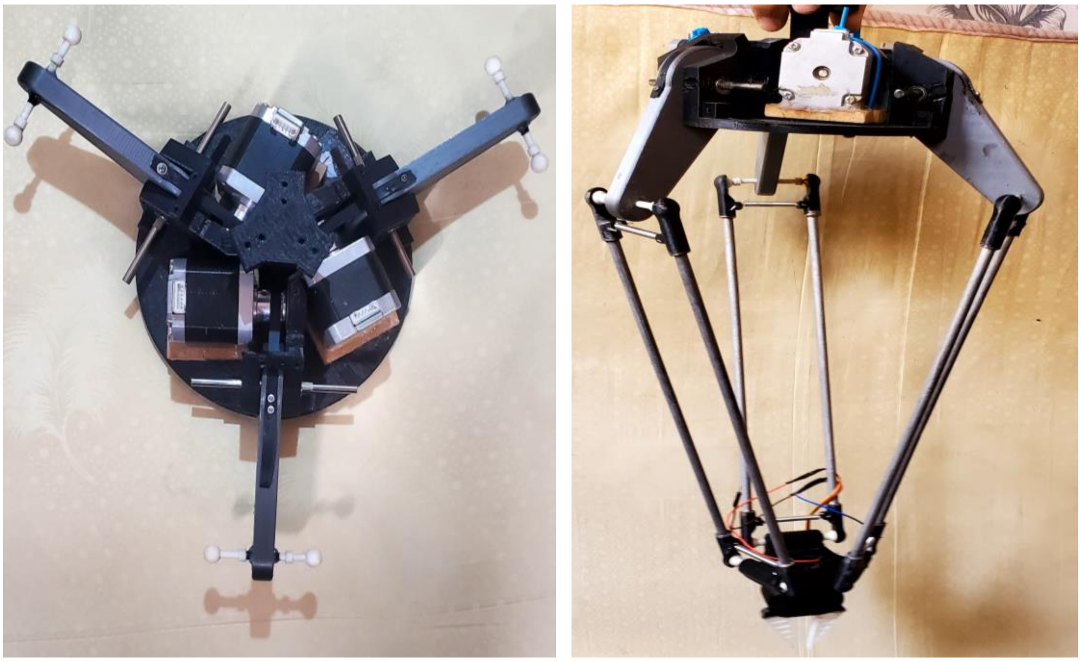

Figure 5-3 The delta robot 3D printed assembly.

5.3 Electrical and Electronic Circuit Integration

5.3.1 Practical Wiring and Power Distribution

Three DRV8825 stepper drivers were installed on a CNC Shield mounted over an Arduino Uno. Each driver was wired to a NEMA 17 stepper motor. As shown in Figure 5-4 A 12V 16A DC power supply provided main power which connected to the start and stop industrial pushbutton and 220v red and green lamp which changes the situation by the 220v power relay. Limit switches were connected to the Arduino's digital pins on the cnc shield. Step and direction signals were routed from Arduino to drivers by cnc shield. We add a simple cool circuit controlled by Arduino where the temperature sensor will detect the temperature upon the controlling parts and start the 12v fan. See, Figure 5-5.

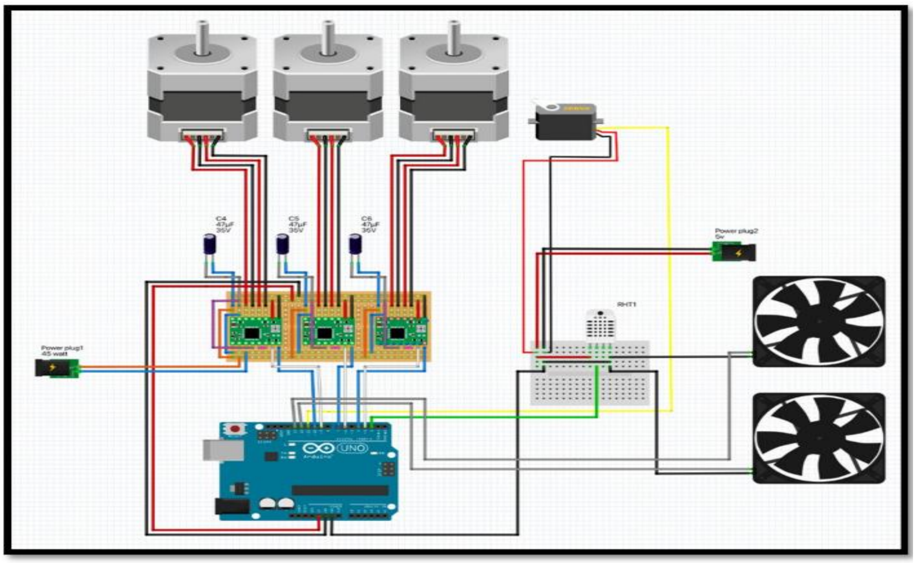

Figure 5-4 Electric Wiring.

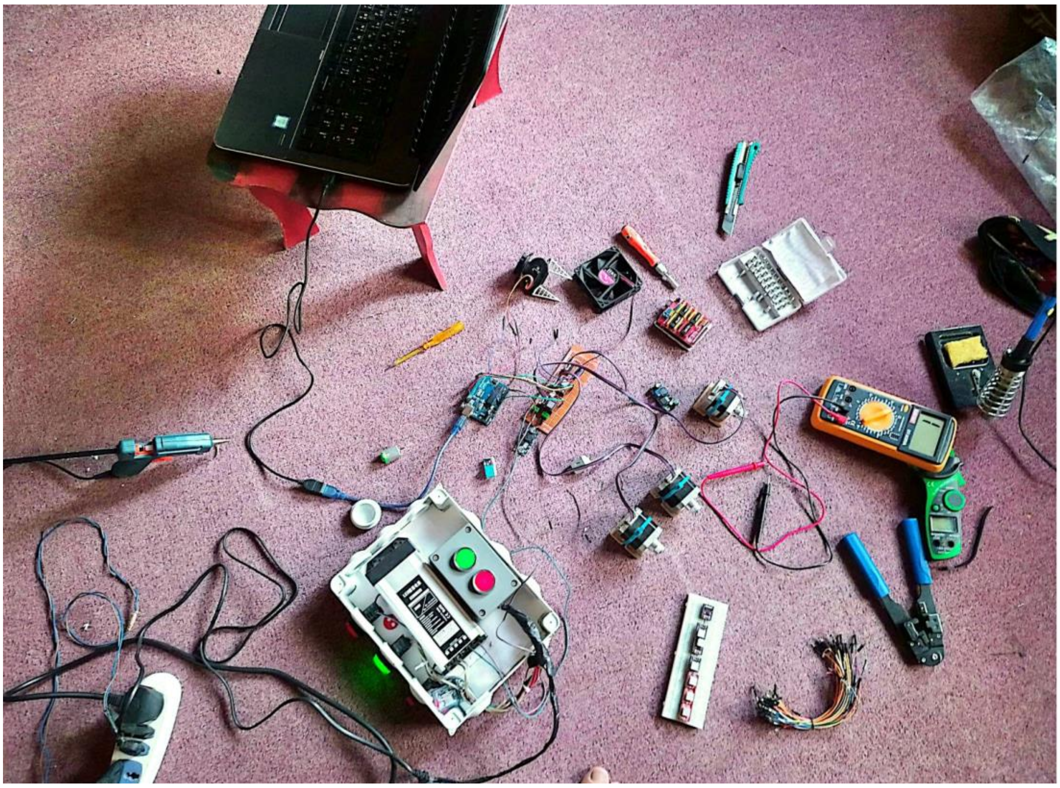

Figure 5-5 Structure Connected electric components.

5.3.2 Circuit Simulation (Proteus)

Before implementing the physical connections, the control circuit was simulated using Proteus software. The simulation included the Arduino, motor drivers, and all peripheral devices. The Bluetooth module and fan system were also integrated into the simulation, allowing the validation of power flows and signal correctness prior to actual wiring.
as shown in Figure 5-6.

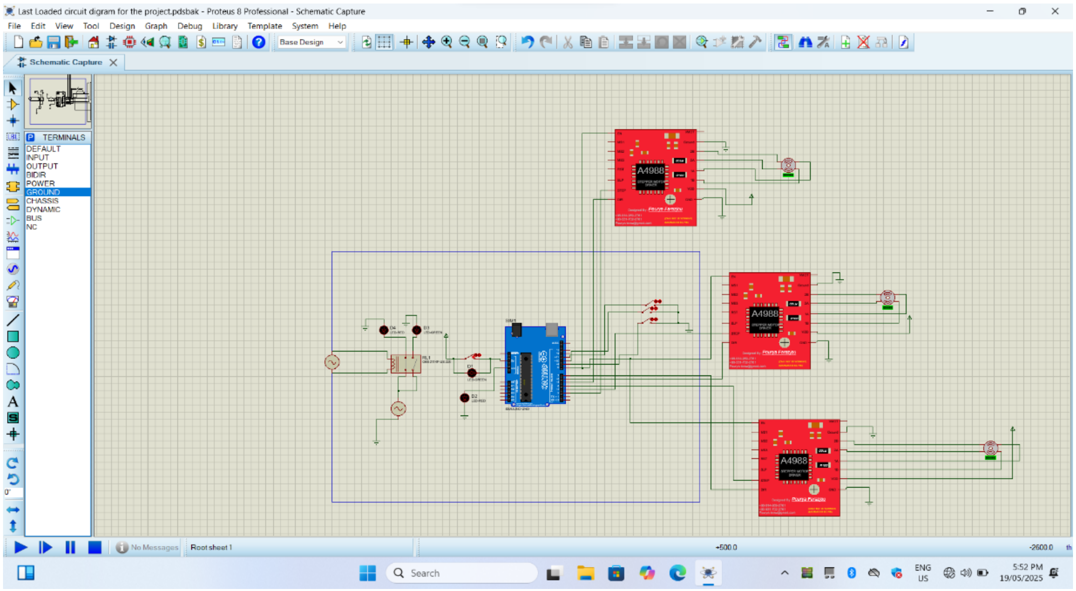

Figure 5-6 Electrical circuit simulation using Proteus.

5.4 Software Environment and Programming

5.4.1 Arduino Environment and Control Code

The Arduino IDE was used to develop firmware that implements the inverse kinematics for the Delta Robot. Serial commands are interpreted to move the robot to specified (X, Y, Z) positions. The control logic includes acceleration, safety checks, and support for external device activation such as the fan. See, Figure 5-7.

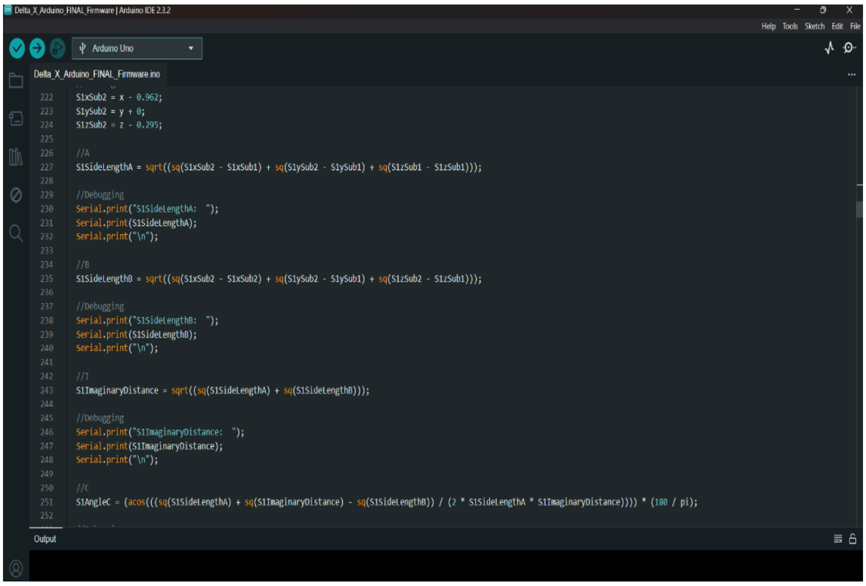

Figure 5-7 Control code by Arduino IDE.

5.4.2 MATLAB Simulation and GUI

A MATLAB-based graphical user interface (GUI) as shown in Figure 5-8. was created to simulate robot movement and interact with the Arduino through serial communication. The GUI includes fields for entering target coordinates, buttons to send commands, and visual feedback of inverse kinematics. A visual simulation window also animates the robot's movement based on input.

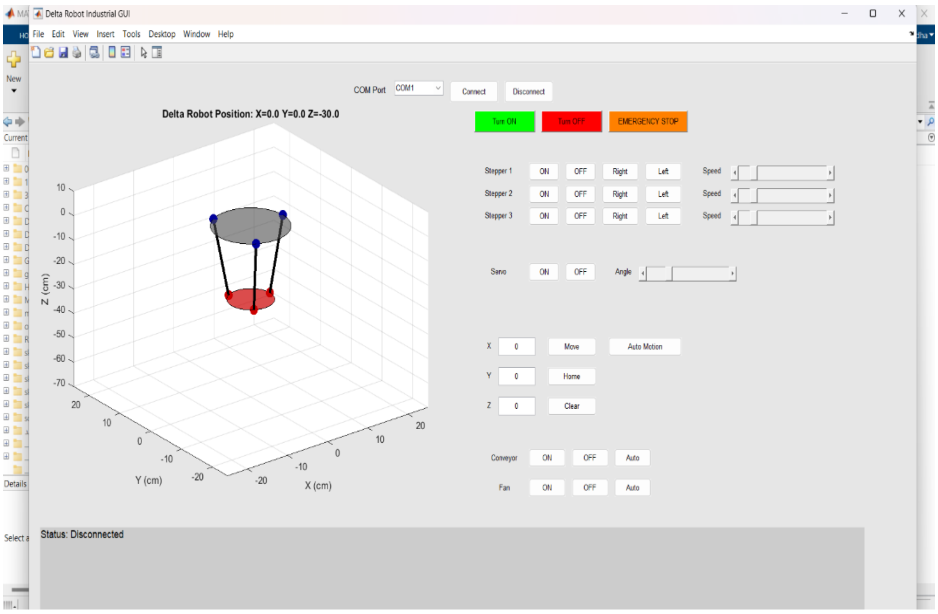

Figure 5-8 MATLAB GUI interface and path simulation.

5.5 Experimental Results, Testing and Observations

The robot was subjected to various motion and pick-and-place tasks look the delta robot block diagram in Figure 5-9. It was observed that the system could move accurately within its designed workspace. See, Figure 5-10. Figure 5-10but not that accurate cause it's a prototype and mechanical problems. Sensor data and command response were recorded to analyze timing and position accuracy. The integration with MATLAB and Arduino functioned as expected, and system behavior was consistent with simulations.

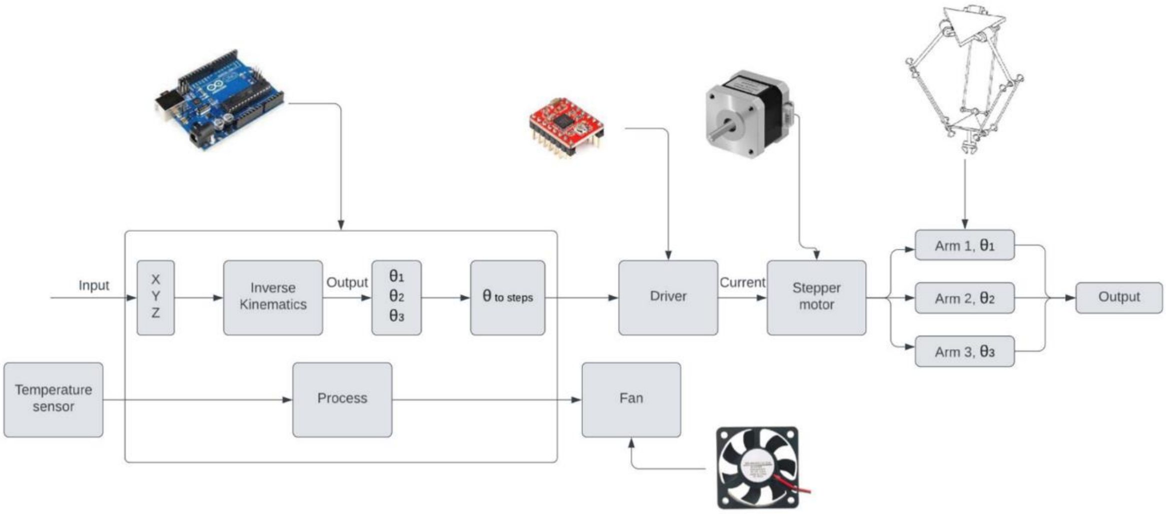

Figure 5-9 Delta robot block diagram.

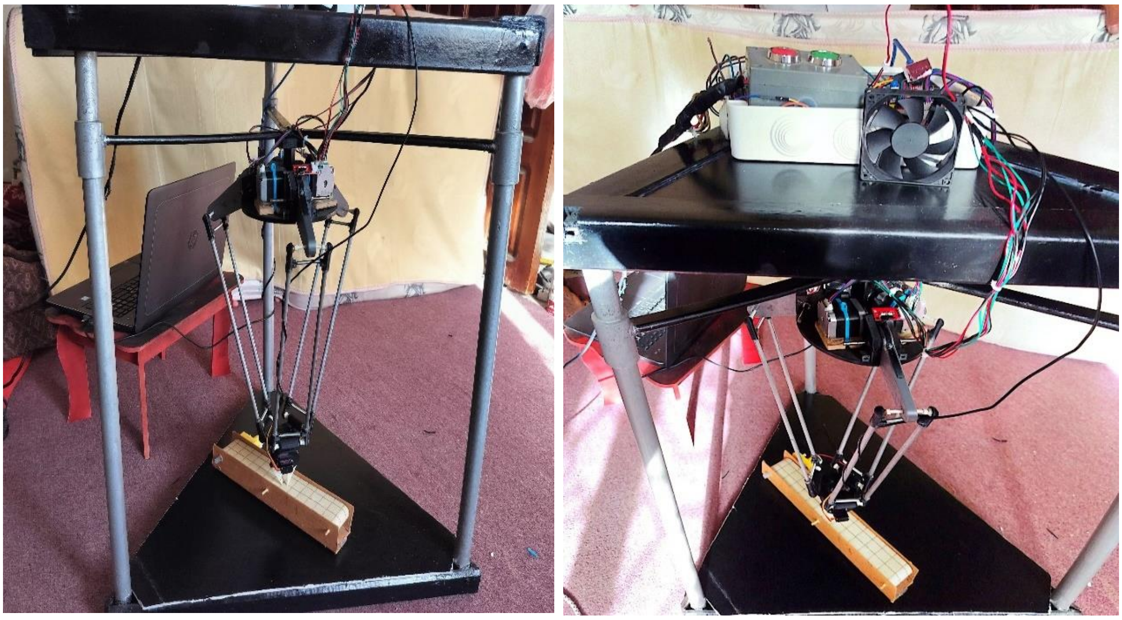

Figure 5-10 Implementation and test delta robot.

5.6 Challenges and Solutions

Several challenges were encountered during implementation: misalignments in the 3D-printed parts, electrical noise affecting motor signals, and inconsistent fan control. These were addressed through redesigning connectors, rerouting wiring, using decoupling capacitors, and refining the control code logic. Mechanical reinforcement and alignment check also contributed to improved stability.

And one of the hardest challenges that we did not find some mechanical parts so we necessary printed them as 3D so they reduce the accuracy.

Another problem faces us when we prepare our project, the mathematical kinematics equations and codes that were difficult to find and write our kinematics analyses and control.

5.7 Conclusion

The implementation of the Delta Robot system was successful across mechanical, electrical, and software domains. The robot demonstrated precise motion, reliable communication, and accurate kinematic control. Testing confirmed the design met its functional goals, and the integrated simulation environment helped verify theoretical behavior before physical execution. These results indicate that the original design and analysis were successfully implemented and validated by the build and tests.

Chapter 6

Conclusions & Future Work

Chapter 6: Conclusions and Future Work

6.1 Introduction

In our project, we have designed and development of a Delta Robot for pick and place operations. We provided an overview of the Delta Robot, including its history, advantages, limitations, and a comparison with other robotic systems. The mechanical design aspects, such as the framework and structure, actuation mechanism, end-effector design, and material selection, were discussed. The study also delved into the kinematics of the Delta Robot, covering forward and inverse kinematics, and workspace analysis. Additionally, we examined the control system, including the controller architecture, feedback sensors, and motion control algorithms. Furthermore, we explored the various applications of Delta Robots.

6.2 Conclusion

In this project, a functional Delta Robot was successfully designed and implemented to perform basic pick-and-place tasks. Through a combination of interdisciplinary engineering skills in mechanical design, electronics, and control systems, the robot demonstrated a high degree of motion accuracy and structural feasibility for lightweight tasks. The kinematic models were verified, and workspace boundaries were clearly identified using MATLAB simulations.

Although the prototype does not meet industrial-grade precision requirements due to inherent mechanical inaccuracies and open-loop control, it effectively fulfills its educational and proof-of-concept purposes. The project provides a foundational platform for exploring robotic system concepts, control algorithms, and automation principles.

6.3 Future Work

Future development of this project may include:

- Enhancing precision by incorporating closed-loop feedback with encoders.
- Integrating a computer vision system for object recognition and improved autonomy.
- Designing a more robust mechanical frame to handle heavier payloads.
- Replacing the open-loop control with advanced trajectory tracking and PID control algorithms.
- Extending the robot functionality for multi-task operations using real-time GUI interfaces.
- Evaluating performance using dynamic simulation and load analysis.

Such improvements would help adapt the Delta Robot for real industrial or research-oriented tasks, transitioning it from a prototype to a scalable automation solution.

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Appendices

Appendix A: ARDUINO UNO

Appendix A: ARDUINO UNO

Arduino® UNO R3

Product Reference Manual
SKU: A000066

Description

The Arduino® UNO R3 is the perfect board to get familiar with electronics and coding. This versatile development board is equipped with the well-known ATmega328P and the ATMega 16U2 Processor.

This board will give you a great first experience within the world of Arduino.

Target areas:

Maker, introduction, industries

Features

- **ATMega328P** Processor
  - **Memory**
    - AVR CPU at up to 16 MHz
    - 32 kB Flash
    - 2 kB SRAM
    - 1 kB EEPROM
  - **Security**
    - Power On Reset (POR)
    - Brown Out Detection (BOD)
  - **Peripherals**
    - 2x 8-bit Timer/Counter with a dedicated period register and compare channels
    - 1x 16-bit Timer/Counter with a dedicated period register, input capture and compare channels
    - 1x USART with fractional baud rate generator and start-of-frame detection
    - 1x controller/peripheral Serial Peripheral Interface (SPI)
    - 1x Dual mode controller/peripheral I2C
    - 1x Analog Comparator (AC) with a scalable reference input
    - Watchdog Timer with separate on-chip oscillator
    - Six PWM channels
    - Interrupt and wake-up on pin change
  - **ATMega16U2 Processor**
    - 8-bit AVR® RISC-based microcontroller
  - **Memory**
    - 16 kB ISP Flash
    - 512B EEPROM
    - 512B SRAM
    - debugWIRE interface for on-chip debugging and programming
  - **Power**
    - 2.7-5.5 volts

CONTENTS

1 The Board

1.1 Application Examples

The UNO board is the flagship product of Arduino. Regardless if you are new to the world of electronics or will use the UNO R3 as a tool for education purposes or industry-related tasks, the UNO R3 is likely to meet your needs.

First entry to electronics: If this is your first project within coding and electronics, get started with our most used and documented board; UNO. It is equipped with the well-known ATmega328P processor, 14 digital input/output pins, 6 analog inputs, USB connections, ICSP header and reset button. This board includes everything you will need for a great first experience with Arduino.

Industry-standard development board: Using the UNO R3 board in industries, there are a range of companies using the UNO R3 board as the brain for their PLC's.

Education purposes: Although the UNO R3 board has been with us for about ten years, it is still widely used for various education purposes and scientific projects. The board's high standard and top quality performance makes it a great resource to capture real time from sensors and to trigger complex laboratory equipment to mention a few examples.

1.2 Related Products

- Arduino Starter Kit
- Arduino UNO R4 Minima
- Arduino UNO R4 WiFi
- Tinkerkit Braccio Robot

2 Ratings

2.1 Recommended Operating Conditions

Symbol	Description	Min	Max
	Conservative thermal limits for the whole board:	-40 °C (-40 °F)	85 °C (185 °F)

NOTE: In extreme temperatures, EEPROM, voltage regulator, and the crystal oscillator, might not work as expected.

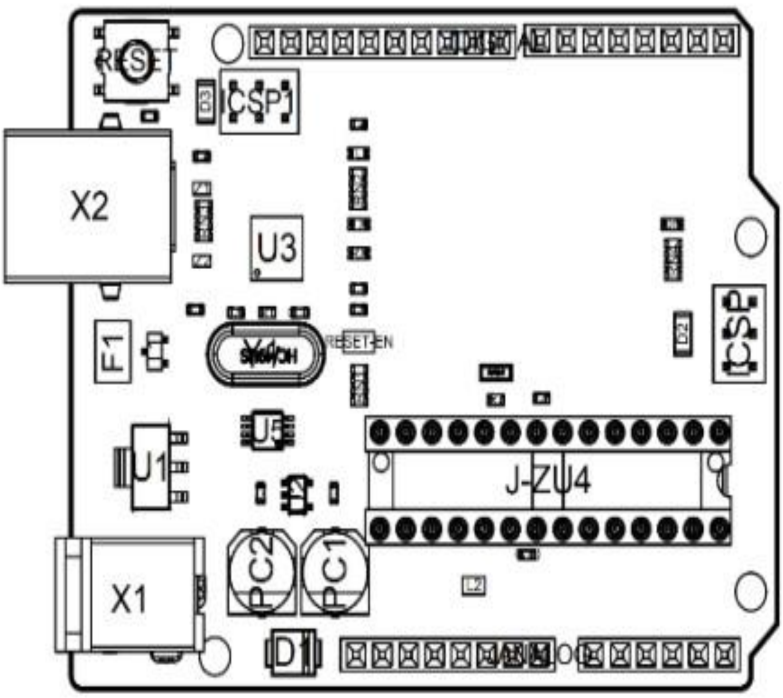
2.2 Power Consumption

Symbol	Description	Min	Typ	Max	Unit
VINMax	Maximum input voltage from VIN pad	6	-	20	V
VUSBMax	Maximum input voltage from USB connector		-	5.5	V
PMax	Maximum Power Consumption	-	-	xx	mA

3 Functional Overview

3.1 Board Topology

Top view



Board topology

Ref.	Description	Ref.	Description
X1	Power jack 2.1x5.5mm	U1	SPX1117M3-L-5 Regulator
X2	USB B Connector	U3	ATMEGA16U2 Module
PC1	EEE-1EA470WP 25V SMD Capacitor	U5	LMV358LIST-A.9 IC
PC2	EEE-1EA470WP 25V SMD Capacitor	F1	Chip Capacitor, High Density
D1	CGRA4007-G Rectifier	ICSP	Pin header connector (through hole 6)
J-ZU4	ATMEGA328P Module	ICSP1	Pin header connector (through hole 6)
Y1	ECS-160-20-4X-DU Oscillator		

3.2 Processor

The Main Processor is a ATmega328P running at up to 20 MHz. Most of its pins are connected to the external headers, however some are reserved for internal communication with the USB Bridge coprocessor.

4 Board Operation

4.1 Getting Started - IDE

If you want to program your UNO R3 while offline you need to install the Arduino Desktop IDE [1] To connect the UNO R3 to your computer, you'll need a USB-B cable. This also provides power to the board, as indicated by the LED.

4.2 Getting Started - Arduino Cloud Editor

All Arduino boards, including this one, work out-of-the-box on the Arduino Cloud Editor [2], by just installing a simple plugin.

The Arduino Cloud Editor is hosted online, therefore it will always be up-to-date with the latest features and support for all boards. Follow **[3]** to start coding on the browser and upload your sketches onto your board.

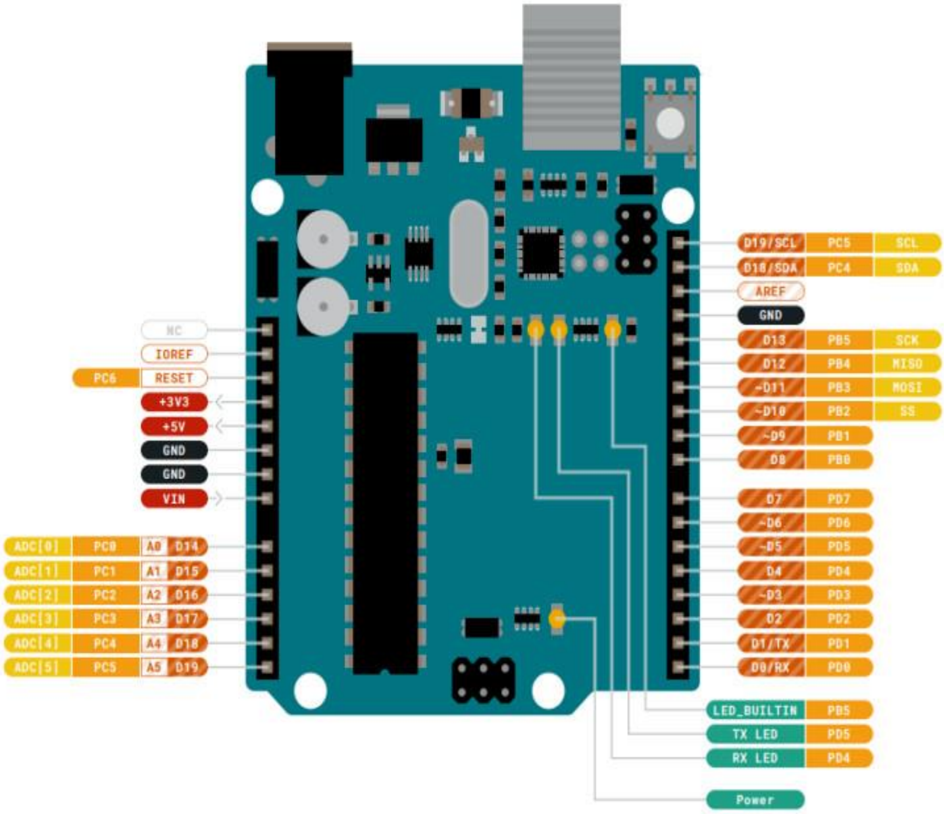
4.3 Sample Sketches

Sample sketches for the UNO R3 can be found either in the "Examples" menu in the Arduino IDE or in the "Documentation" section of the Arduino website [4].

4.4 Online Resources

Now that you have gone through the basics of what you can do with the board you can explore the endless possibilities it provides by checking exciting projects on Arduino Project Hub [5], the Arduino Library Reference [6] and the online Arduino store [7] where you will be able to complement your board with sensors, actuators and more.

5 Connector Pinouts



Pinout

5.1 JANALOG

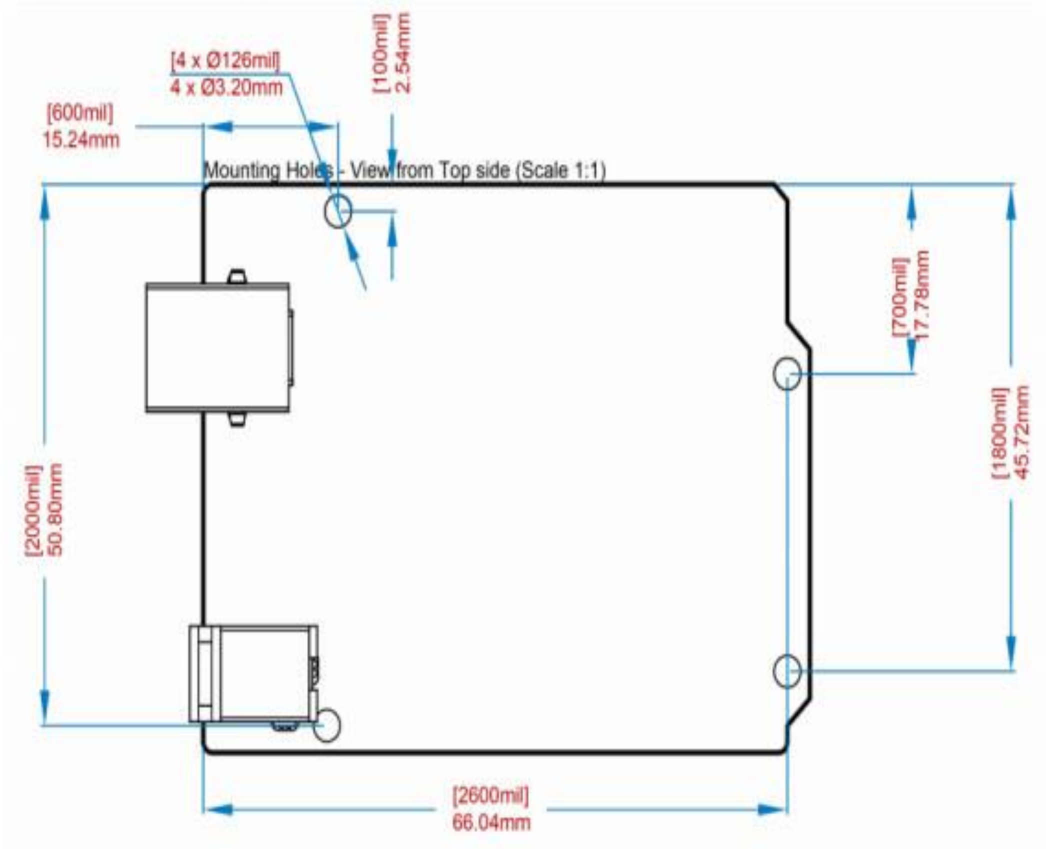
Pin	Function	Type	Description
1	NC	NC	Not connected
2	IOREF	IOREF	Reference for digital logic V - connected to 5V
3	Reset	Reset	Reset
4	+3V3	Power	+3V3 Power Rail
5	+5V	Power	+5V Power Rail
6	GND	Power	Ground
7	GND	Power	Ground
8	VIN	Power	Voltage Input
9	A0	Analog/GPIO	Analog input 0 /GPIO
10	A1	Analog/GPIO	Analog input 1 /GPIO
11	A2	Analog/GPIO	Analog input 2 /GPIO
12	A3	Analog/GPIO	Analog input 3 /GPIO
13	A4/SDA	Analog input/I2C	Analog input 4/I2C Data line
14	A5/SCL	Analog input/I2C	Analog input 5/I2C Clock line

5.2 JDIGITAL

Pin	Function	Type	Description
1	D0	Digital/GPIO	Digital pin 0/GPIO
2	D1	Digital/GPIO	Digital pin 1/GPIO
3	D2	Digital/GPIO	Digital pin 2/GPIO
4	D3	Digital/GPIO	Digital pin 3/GPIO
5	D4	Digital/GPIO	Digital pin 4/GPIO
6	D5	Digital/GPIO	Digital pin 5/GPIO
7	D6	Digital/GPIO	Digital pin 6/GPIO
8	D7	Digital/GPIO	Digital pin 7/GPIO
9	D8	Digital/GPIO	Digital pin 8/GPIO
10	D9	Digital/GPIO	Digital pin 9/GPIO
11	SS	Digital	SPI Chip Select
12	MOSI	Digital	SPI1 Main Out Secondary In
13	MISO	Digital	SPI Main In Secondary Out
14	SCK	Digital	SPI serial clock output
15	GND	Power	Ground
16	AREF	Digital	Analog reference voltage
17	A4/SD4	Digital	Analog input 4/I2C Data line (duplicated)
18	A5/SD5	Digital	Analog input 5/I2C Clock line (duplicated)

5.3 Mechanical Information

5.4 Board Outline & Mounting Holes



Board outline

6 Certifications

6.1 Declaration of Conformity CE DoC (EU)

We declare under our sole responsibility that the products above are in conformity with the essential requirements of the following EU Directives and therefore qualify for free movement within markets comprising the European Union (EU) and European Economic Area (EEA).

ROHS 2 Directive 2011/65/EU	
Conforms to:	EN50581:2012
Directive 2014/35/EU. (LVD)	
Conforms to:	EN 60950-1:2006/A11:2009/A1:2010/A12:2011/AC:2011
Directive 2004/40/EC & 2008/46/EC & 2013/35/EU, EMF	
Conforms to:	EN 62311:2008

6.2 Declaration of Conformity to EU RoHS & REACH 211 01/19/2021

Arduino boards are in compliance with RoHS 2 Directive 2011/65/EU of the European Parliament and RoHS 3 Directive 2015/863/EU of the Council of 4 June 2015 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Substance	Maximum limit (ppm)
Lead (Pb)	1000
Cadmium (Cd)	100
Mercury (Hg)	1000
Hexavalent Chromium (Cr6+)	1000
Poly Brominated Biphenyls (PBB)	1000
Poly Brominated Diphenyl ethers (PBDE)	1000
Bis(2-Ethylhexyl} phthalate (DEHP)	1000
Benzyl butyl phthalate (BBP)	1000
Dibutyl phthalate (DBP)	1000
Diisobutyl phthalate (DIBP)	1000

Exemptions: No exemptions are claimed.

Arduino Boards are fully compliant with the related requirements of European Union Regulation (EC) 1907 /2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). We declare none of the SVHCs (https://echa.europa.eu/web/guest/candidate-list-table), the Candidate List of Substances of Very High Concern for authorization currently released by ECHA, is present in all products (and also package) in quantities totaling in a concentration equal or above 0.1%. To the best of our knowledge, we also declare that our products do not contain any of the substances listed on the "Authorization List" (Annex XIV of the REACH regulations) and Substances of Very High Concern (SVHC) in any significant amounts as specified by the Annex XVII of Candidate list published by ECHA (European Chemical Agency) 1907 /2006/EC.

6.3 Conflict Minerals Declaration

As a global supplier of electronic and electrical components, Arduino is aware of our obligations with regards to laws and regulations regarding Conflict Minerals, specifically the Dodd-Frank Wall Street Reform and Consumer Protection Act, Section 1502. Arduino does not directly source or process conflict minerals such as Tin, Tantalum, Tungsten, or Gold. Conflict minerals are contained in our products in the form of solder, or as a component in metal alloys. As part of our reasonable due diligence Arduino has contacted component suppliers within our supply chain to verify their continued compliance with the regulations. Based on the information received thus far we declare that our products contain Conflict Minerals sourced from conflict-free areas.

7 FCC Caution

Any Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

(1) This device may not cause harmful interference

(2) this device must accept any interference received, including interference that may cause undesired operation.

FCC RF Radiation Exposure Statement:

1. This Transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.
2. This equipment complies with RF radiation exposure limits set forth for an uncontrolled environment.
3. This equipment should be installed and operated with minimum distance 20cm between the radiator & your body.

English: User manuals for license-exempt radio apparatus shall contain the following or equivalent notice in a conspicuous location in the user manual or alternatively on the device or both. This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions:

(1) this device may not cause interference

(2) this device must accept any interference, including interference that may cause undesired operation of the device.

French: Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes :

(1) l' appareil nedoit pas produire de brouillage

(2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

IC SAR Warning:

English This equipment should be installed and operated with minimum distance 20 cm between the radiator and your body.

French: Lors de l' installation et de l' exploitation de ce dispositif, la distance entre le radiateur et le corps est d 'au moins 20 cm.

Important: The operating temperature of the EUT can't exceed 85℃ and shouldn't be lower than -40℃.

Hereby, Arduino S.r.l. declares that this product is in compliance with essential requirements and other relevant provisions of Directive 2014/53/EU. This product is allowed to be used in all EU member states.

8 Company Information

Company name	**Arduino S.r.l**
Company Address	Via Andrea Appiani 25 20900 MONZA Italy

9 Reference Documentation

Reference	Link
Arduino IDE (Desktop)	https://www.arduino.cc/en/Main/Software
Arduino Cloud Editor	https://create.arduino.cc/editor
Arduino Cloud Editor - Getting Started	https://docs.arduino.cc/arduino-cloud/guides/editor/
Arduino Website	https://www.arduino.cc/
Arduino Project Hub	https://create.arduino.cc/projecthub?by=part&part_id=11332&sort=trending
Library Reference	https://www.arduino.cc/reference/en/
Arduino Store	https://store.arduino.cc/

10 Revision History

Date	Revision	Changes
25/04/2024	3	Updated link to new Cloud Editor
26/07/2023	2	General Update
06/2021	1	Datasheet release

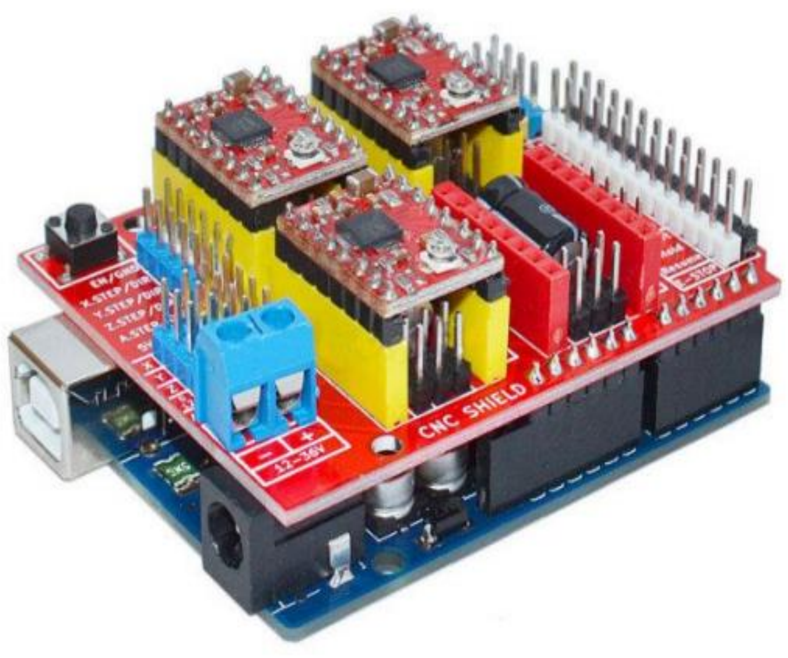
Appendix B: CNC SHIELD V3

Appendix B: CNC SHIELD V3

Cnc Shield V3

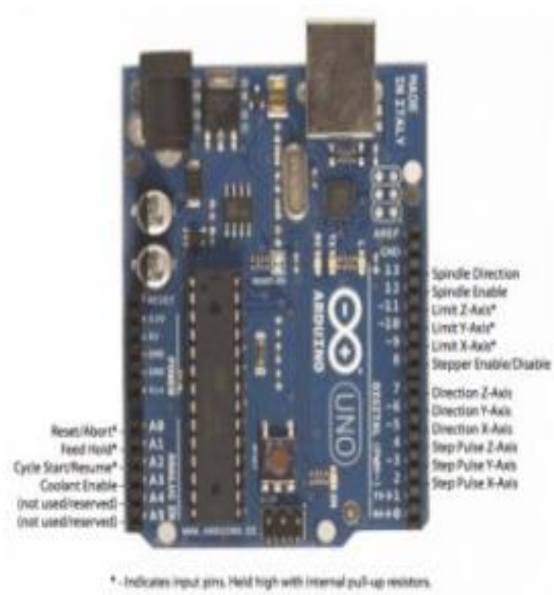
Overview:

CNC Shield V3.0 can be used as drive expansion board for engraving machine, 3D printer and other devices. There're 4 slots in the board for stepper motor drive modules, can drive 4 stepper motors, and each step stepper motor only need two IO port, that is to say, 6 IO ports can quite well to manage three stepper motor, it's very convenient to use. After insert Arduino CNC Shield V3.0 into Arduino UNO, and installed GRBL firmware then you can quickly DIY a CNC engraving machine.



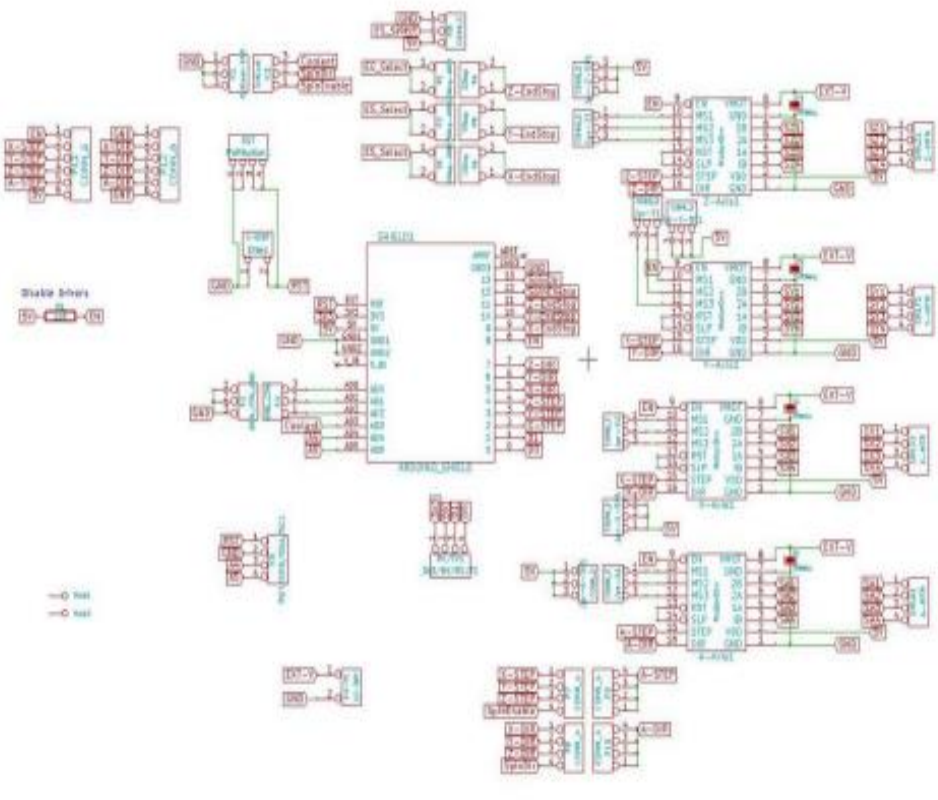
Board Layout

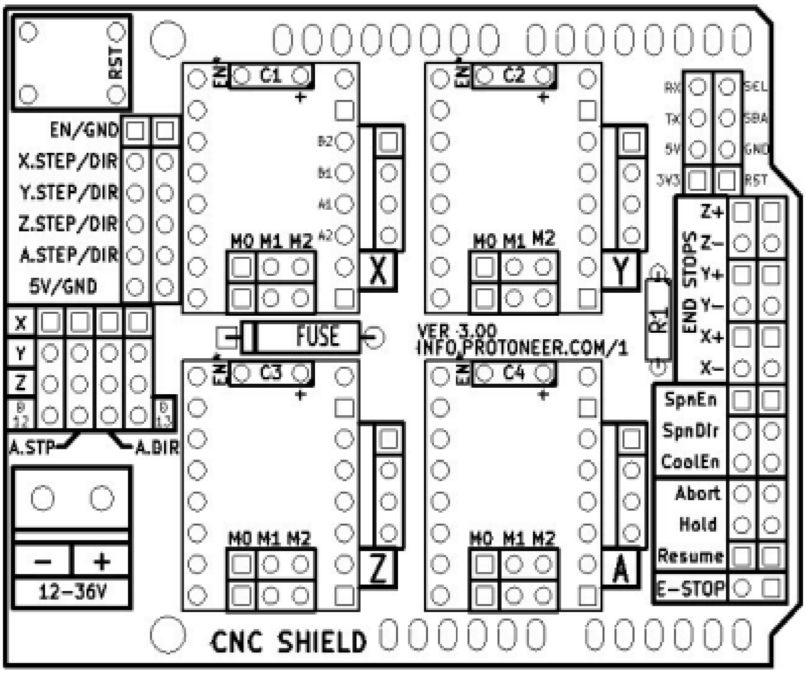
GRBL Pin Layout:



GRBL Pin Layout:

In addition to have all the GRBL function pin, Arduino CNC Shield V3.0 also have some additional pins to achieve more features:





Extra pins:

Limit switch pins have been doubled up so that each axis has a "Top/+" and "Bottom/-". This makes it easier to install two limit switches for each axis. (For use with a normally open switch)

EStop – These pins can be connected to an emergency stop switch. This does the same as the RESET button on the Arduino board. (We do advice that an extra emergency button also be installed that cuts power to all machinery. A REAL EMERGENCY BUTTON)

Spindle and coolant control has their own pins.

External GRBL Command Pins have been broken out allowing you to add buttons for Pause/Hold , Resume and Abort.

Serial Pins (D0-1) and I2C Pins (A4-5) have their own break out pins for future extensions. I2C can later be implemented by software to control things like spindle speed or heat control.

Version 3.00 of the board added a jumpers to configure the 4th axis(Clone the other axis's or run from Pin D12-13), Comms Header(RX+TX , I2C) and a Stepper Control Header(All Pins needed to run 4 steppers)

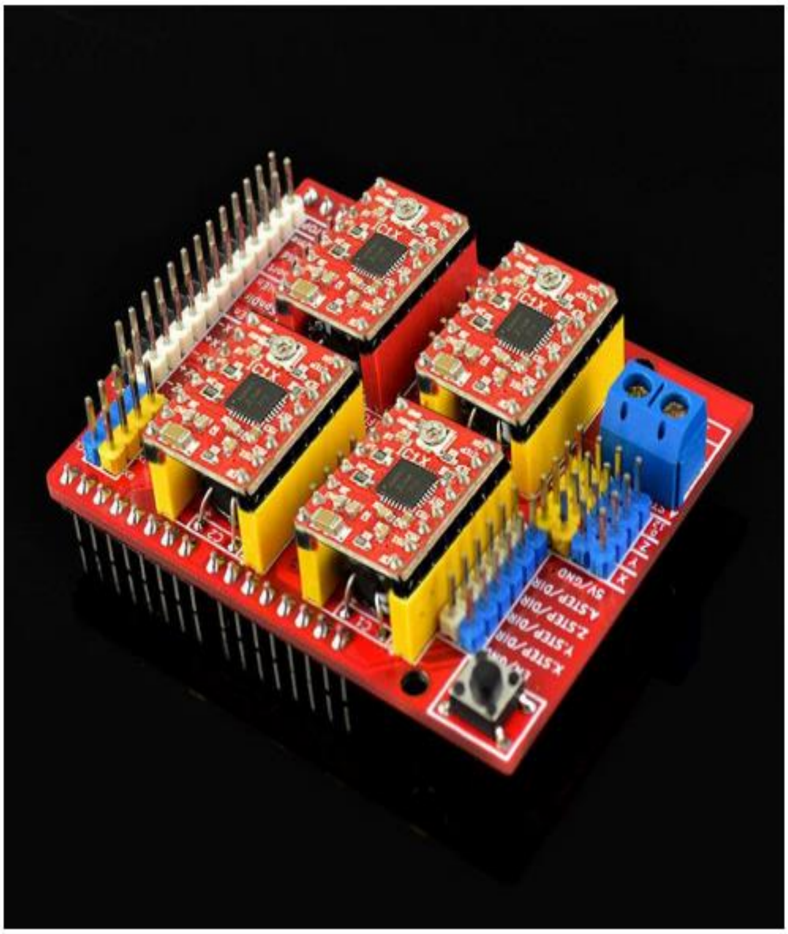
Hardware installation

Connect the components according to the actual situation, such as motors, limit switches, lasers, motor drives and so on.

When installing the hardware, please pay attention to the following points:

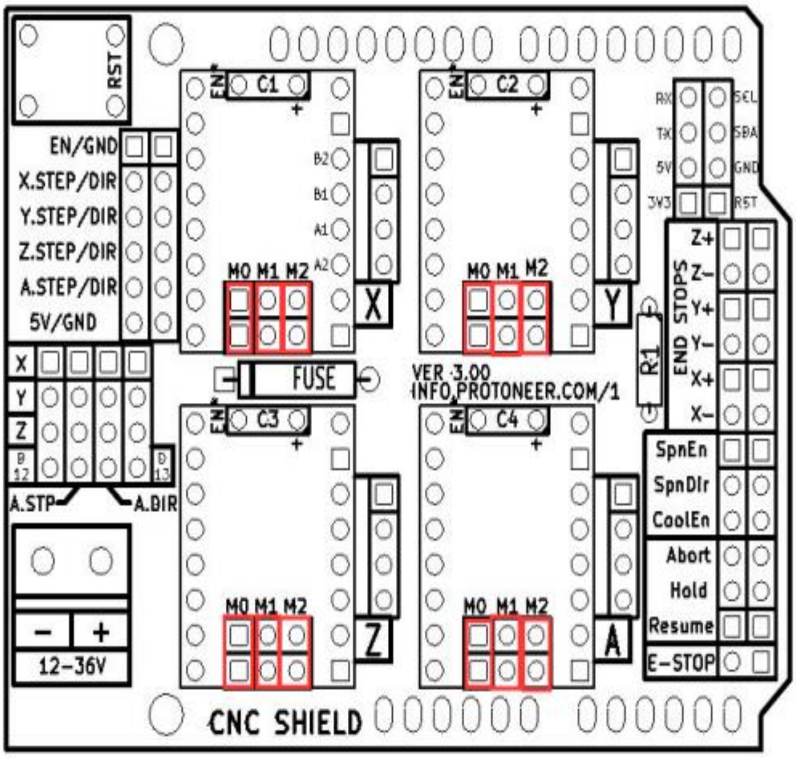
1) Incorrect connection of +/- may destroy your devices, even cause fire.

2) Please make sure to insert drivers in correct direction, or it may burn the mainboard and drivers, specific installation direction please integrating Arduino CNC Shield V3.0, refer to the data sheet of motor drive. The picture shows the connection of A4988 motor drivers and Arduino CNC Shield V3.0.



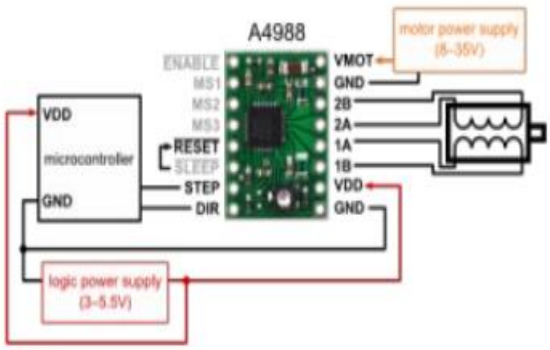
A4988 support 1 segment, 1/2 segment, 1/4 segment, 1/8 segment, 1/16 segment. Each segment is set by the M0, M1, M2 pin header in the Arduino CNC Shield V3.0, cover the jumper cap to the pin header represents high level, do not cover the jumper cap represents low level.

In order to improve the precision of engraving, use 1/16 segment, it needs 3 jumper caps to cover M0, M1, M2. As shown in picture:

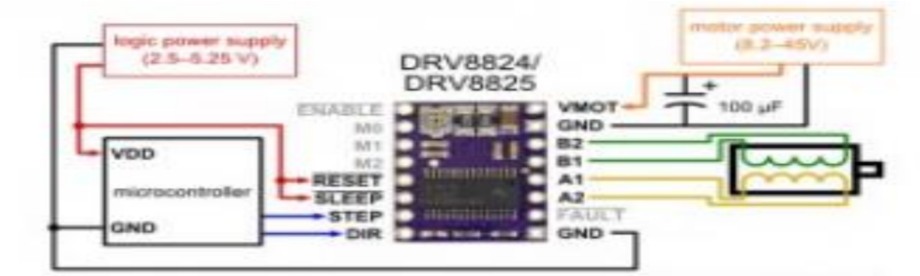


3) The input voltage of Arduino CNC Shield V3.0 is DC 12V-36V, do not input more than 36V voltage. Although the input voltage supports power supplies up to 36V, does not mean that you can use 36v under any circumstances, because some motor drivers supply voltage (VMOT) is less than 36V, such as A4988, its supply voltage is 8-35V, if you use 36V power supply, it will burn the motor driver. So when you select the power supply, please refer to the corresponding the motor driver's data sheet. Here are a few supply voltage parameters for commonly motor driver:

A4988

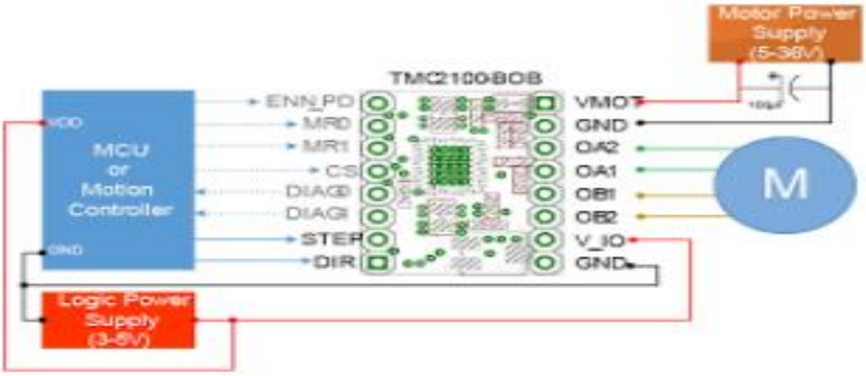


DRV8824/DRV8825



Minimal wiring diagram for connecting a microcontroller to a DRV8824/DRV8825 stepper motor driver carrier (full-step mode).

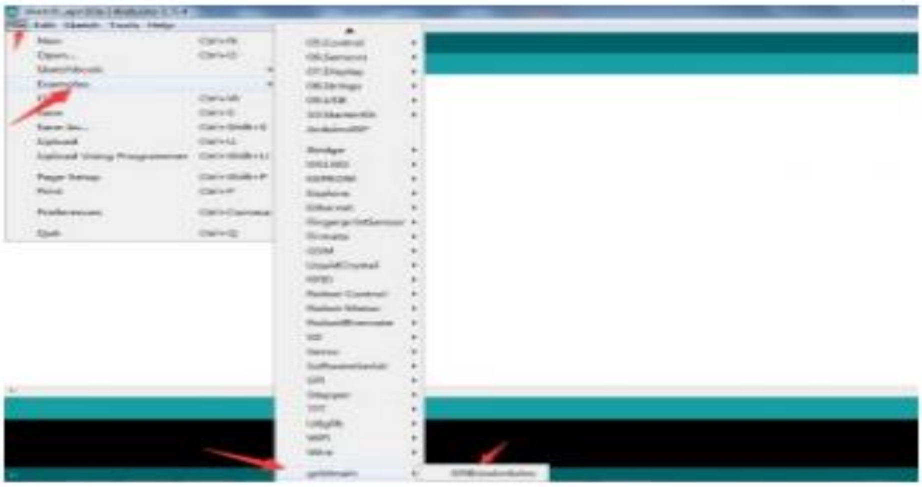
TMC2100

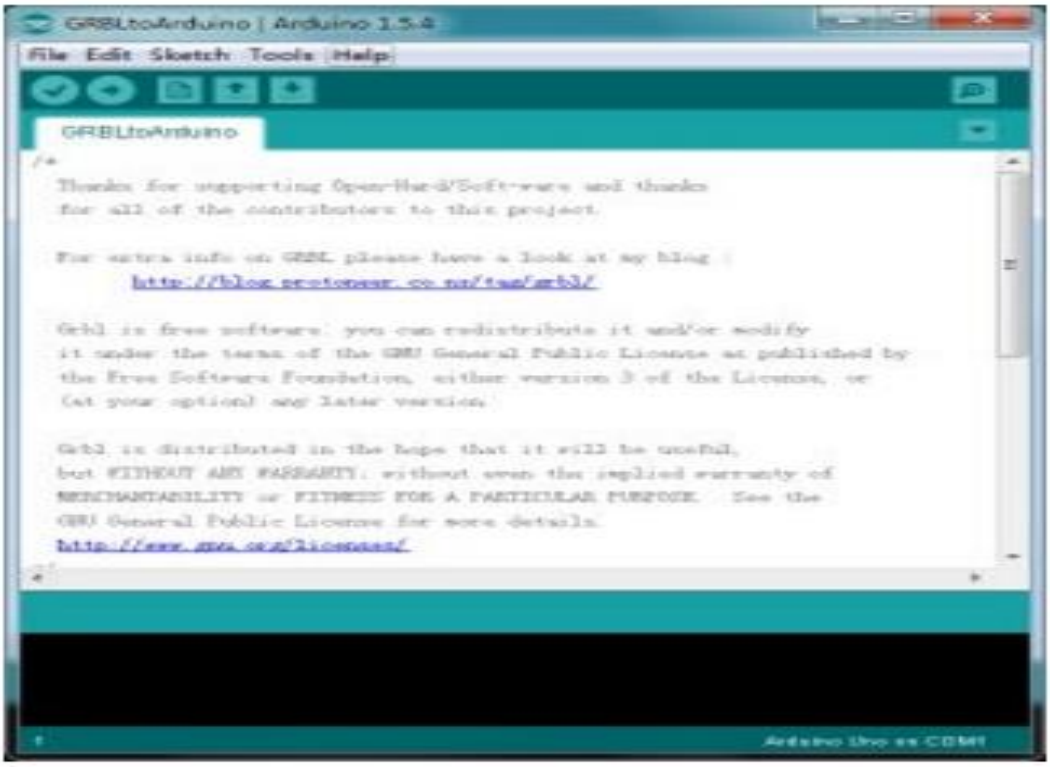


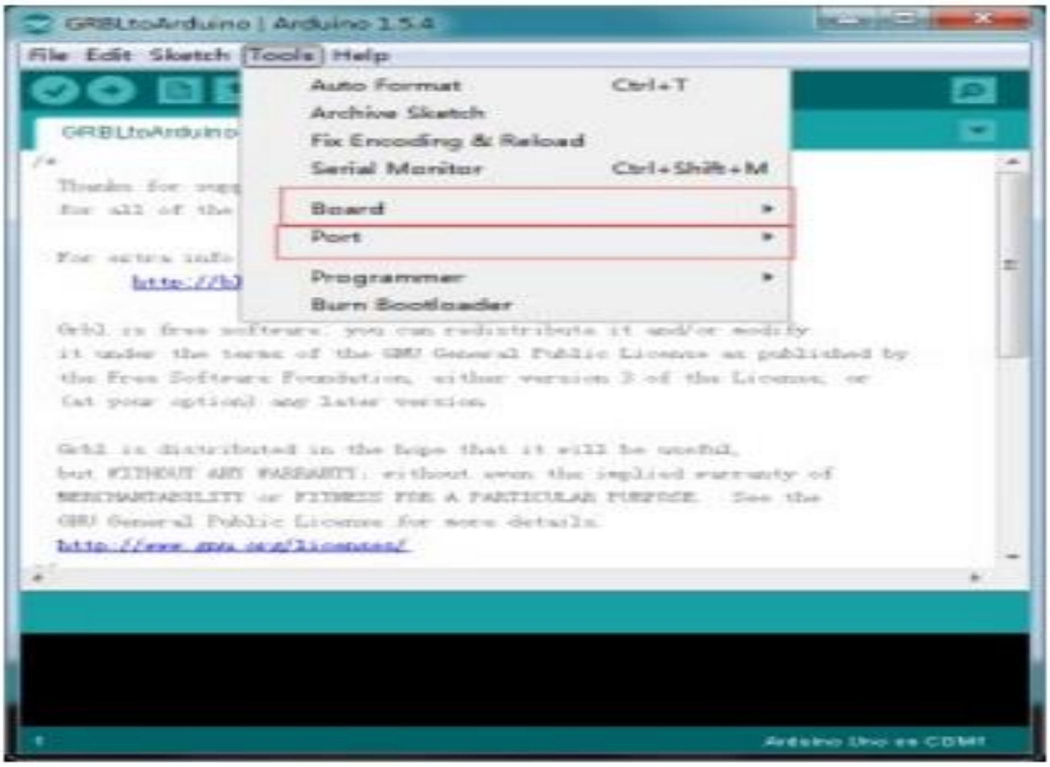
Software installation

1) GRBL Library Installation:

Download and unzip grblmain.zip, put it to libraries folder of Arduino choose File->Examples->grblmain->GRBLtoArduino, then you'll ope board type, burn this grbl sample program to Arduino UNO.

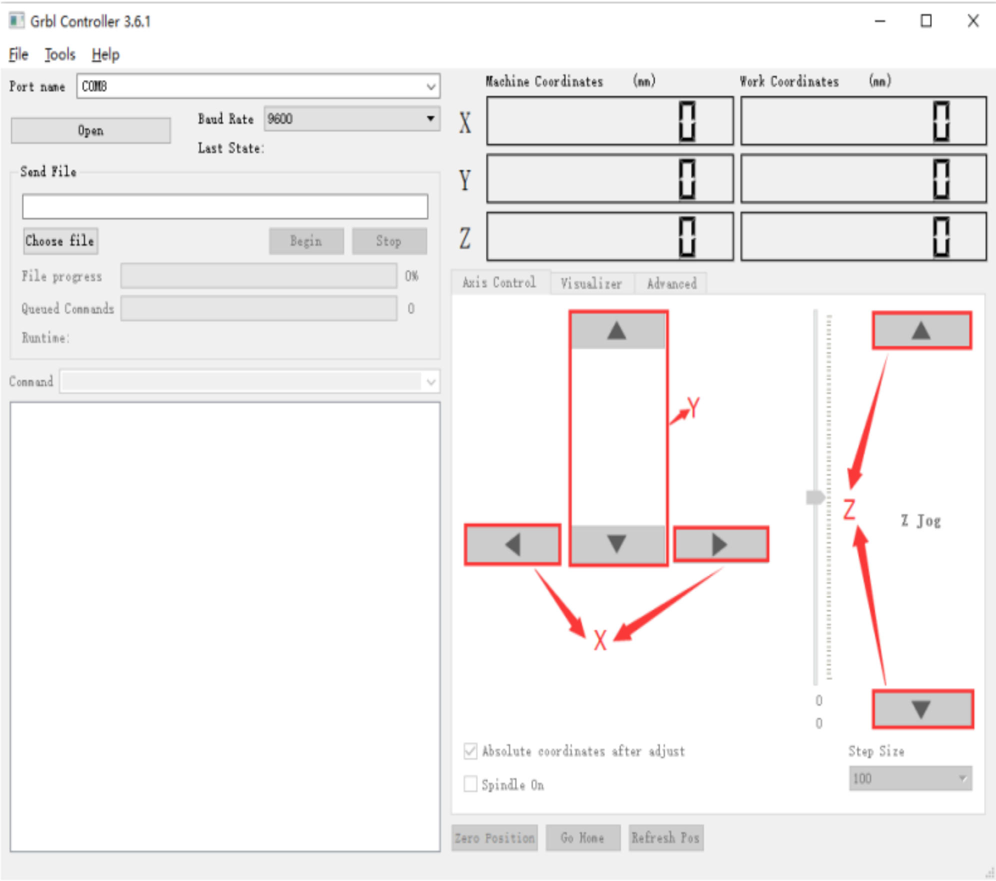






2) Install GRBL Controller:

Download and install Grbl Controller, open it, interface



Use the USB cable to connect your PC and Arduino UNO, select the port and select the baud rate as 9600. Click "Open", if it connected, "Open" will be "Close/Reset ", the background is red. Click "Choose File" to choose the graphy you want to engrave, after selected click "Begin" to engrave.

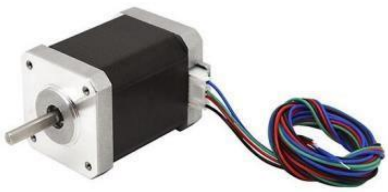
Appendix C: NEMA 17 STEPPER MOTOR

Appendix C: Nema 17 Stepper Motor

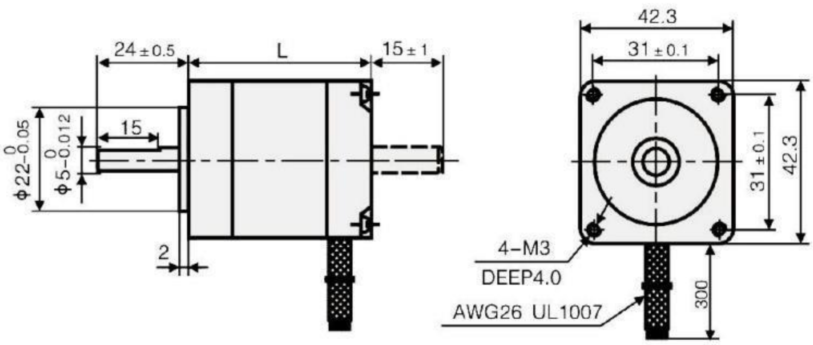
Nema 17 Stepper Motor

Nema 17 stepper motor, including open loop and closed loop, is a permanent magnet stepper motor with an end face size of 1.7 inches x 1.7 inches (42mm x 42mm). 2 phase hybrid bipolar stepper motor is simple structure, small size and easy assembly. ATO high torque stepper motor at factory price, and can be controlled by AC or DC digital stepper drivers for precise position control.

Open Loop Stepper Motor



Specification

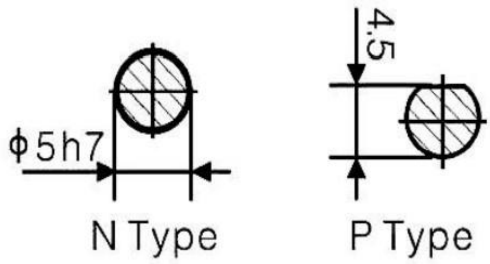


Model	Step Angle (°)	Motor Length (mm)	Rated Current (A)	Holding Torque (N.m)	Phase Resistance (Ω)	Phase Inductance (mH)	Rotor Inertia (g.cm²)	Lead Wires (NO.)	Motor Weight (Kg)
FY42EX080A		30	0.8	0.16	3.8	4.5	30	4	0.2
FY42ES150A		34	1.5	0.28	2.4	4.5	34	4	0.22
FY42EM150A	1.8	40	1.5	0.40	2.5	5.0	54	4	0.28
FY42EL180A		48	1.8	0.50	1.8	3.2	68	4	0.35
FY42EC200A		60	2.0	0.65	1.4	2.5	80	4	0.45

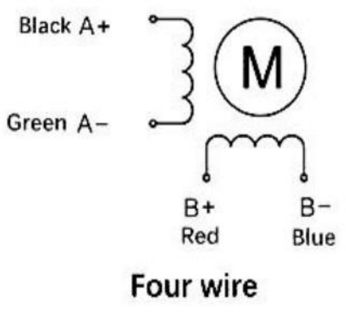
Nema 17 Stepper Motor

Technical Specification	
Shaft Diameter	5mm
Step Angle Accuracy	±5% (Full Step, No Load)
Resistance Accuracy	±10% (20℃)
Inductance Accuracy	±20% (1KHz)
Temperature Rise	80℃ Max. (rated current, 2 phase on)
Ambient Temperature	-20℃~+50℃
Insulation Resistance	100MΩ Min. 500VDC
Dielectric Strength	1Min. 500VAC
Shaft Radial Play	0.02Max. 450g Load
Shaft Axial Play	0.08Max. 450g Load
Radial Max. Load	28N
Axial Max. Load	10N
Warranty Period	12 months
Certificate	CE, ROHs, FCC

Shaft Type

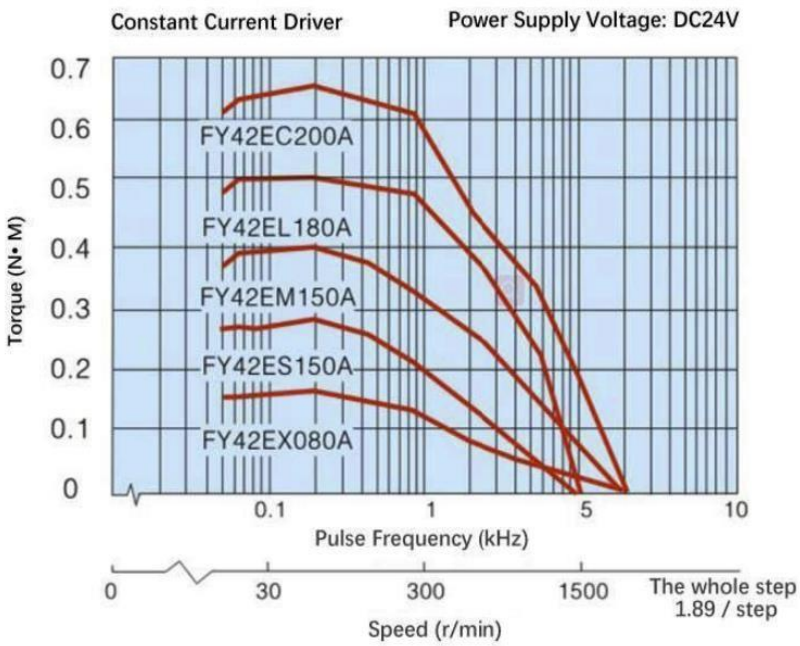


Wiring Diagram



ATO Nema 17 Stepper Motor

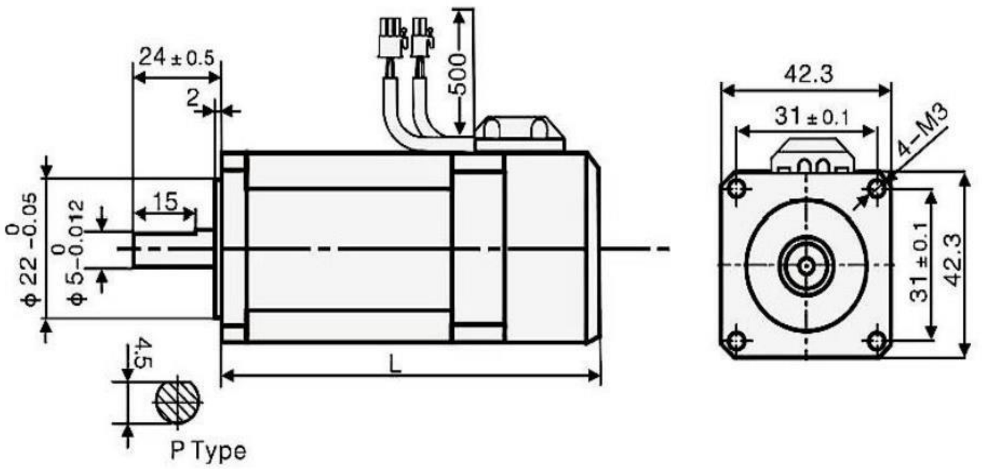
Speed-Torque Curve Diagram



ATO Nema 17 Stepper Motor

Closed Loop Stepper Motor

Specification



Model	Step Angle (°)	Motor Length (mm)	Rated Current (A)	Holding Torque (N.m)	Phase Resistance (Ω)	Phase Inductance (mH)	Rotor Inertia (g.cm²)	Lead Wires (NO.)	Motor Weight (Kg)
FY42EM200BC1	1.8	60	2.0	0.4	0.8	1.9	57	4	0.24
FY42EL200BC1		68	2.0	0.5	1.35	2.8	77	4	0.36
FY42EC200BC1		80	2.0	0.72	1.75	4.0	110	4	0.50

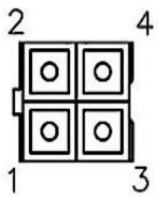
ATO

Nema 17 Stepper Motor

Technical Specification	
Shaft Diameter	5mm
Step Angle Accuracy	±5% (Full Step, No Load)
Resistance Accuracy	±10% (20℃)
Inductance Accuracy	±20% (1KHz)
Temperature Rise	80℃ Max. (rated current, 2 phase on)
Ambient Temperature	-20℃~+50℃
Insulation Resistance	100MΩ Min. 500VDC
Dielectric Strength	1Min. 500VAC
Shaft Radial Play	0.02Max. 450g Load
Shaft Axial Play	0.08Max. 450g Load
Radial Max. Load	28N
Axial Max. Load	10N
Warranty Period	12 months
Certificate	CE, ROHs, FCC

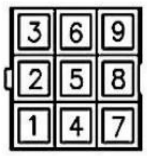
Motor & Encoder Wiring Diagram

Motor Wiring



Motor End	Color	Function
1	Blue	B-
2	Red	B+
3	Green	A-
4	Black	A+

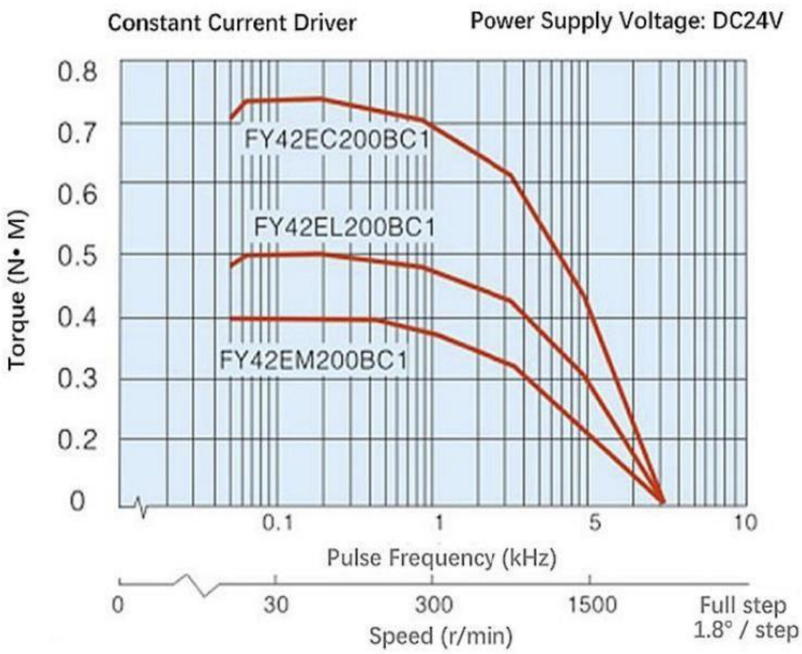
Encoder Wiring



Encoder	Color	Function
1	Blue	EA+
2	—	—
3	Blue/White	EA+
4	Orange	EB+
5	—	—
6	Orange/ White	EB-
7	Red	VCC
8	Black	GND
Encoder	Shield	

ATO Nema 17 Stepper Motor

Speed-Torque Curve Diagram



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Appendix D: DRV8825

Appendix D: Drv8825

STEPSTICK DRV8825 v1.0 DATASHEET

Author

Date

Document version 1.0

PRODUCT OVERVIEW

The stepstick DRV8825 is a breakout board for the Texas Instruments DRV8825 stepper motor controller. You can use this board to act as interface between your microcontroller and stepper motor. The DRV8825 is able to deliver up to 2.5A and can be controlled with a simple step/direction interface. The controller has a resolution of min. 1/32 step and protective features for over-current, short circuit and over-temperature. See the DRV8825 Datasheet for details on the DRV8825 controller.

The stepstick DRV8825 supersedes the stepstick A4988, which has been discontinued. The aim is for the stepstick DRV8825 to be a drop-in replacement for Stepstick A4988.

SAFETY WARNINGS

Always disconnect the power source from the board before unplugging the stepper motor and/or adjusting the current. Failure to do so may result in permanent damage to the board and/or injuries due to high voltage spikes.

The stepper driver may get **HOT**, do not touch the device until it had a few minutes to cool down after operation.

It is recommended to drive the stepper motor on current as low as possible to reduce power consumption and increase lifespan.

It is **NOT** recommended to turn the stepper motor while connected to the electronics. While turning the stepper motor, large voltages may be emitted through the VMOT pin, which can damage the electronics.

TECHNICAL SPECIFICATION

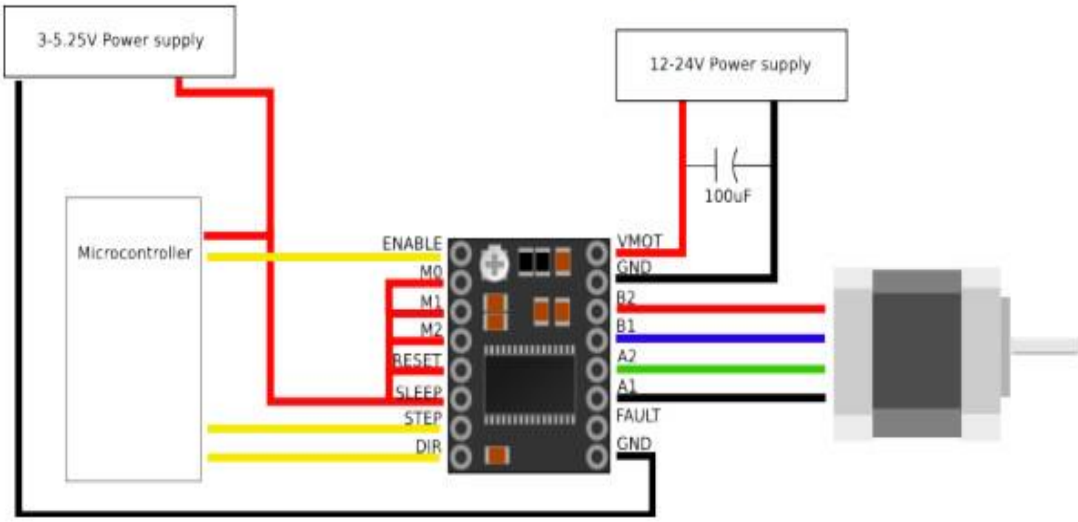
Controller	DRV8825
Operating Voltage (logic)	3-5.25V
Operating Voltage (vmot)	12-24V
Max current	2.5A
Dimensions	20.4x15.6mm

MAJOR FEATURES

	**DRV8825** Powerful DRV8825 with • High current driver capable up to 2.5A • Six different step resolutions: full-step, half-step, 1/4-step, 1/8-step, 1/16-step, and 1/32-step • Protection against over-temperature and over-current • No logic voltage required
	**Adjustable current** Using the trimpot on the board you can easily turn the current up or down. Turn left to lower the current, right to output a higher current.

EXAMPLE CIRCUIT

The following diagram lists the pins and show an example circuit.



Name	Description
Enable	Enable/disable the stepper driver HIGH – Disable LOW – Enable *
M0 – M2	Step resolution setting, see chapter 'step resolution configuration'
RESET	Enable/disable the H-bridge output * LOW – Disable * HIGH – Enable
SLEEP	Enable/disable low-power sleep mode LOW – Sleep * HIGH – Active
STEP	LOW → HIGH, move one step
DIR	LOW / HIGH switches direction
VMOT	Motor power (12-24V)
GND	System ground
FAULT	LOW when the stepper driver is in fault condition. You can provide 5V on this pin for compatibility with stepstick A4988

* this is the default state when the pin is not connected

STEP RESOLUTION CONFIGURATION

The DRV8825 had six step resolution modes, which can be configured using the M0-M2 pins on the stepstick DRV8825. The following table lists the step resolution settings:

M0	M1	M2	Resolution
Low	Low	Low	Full step
High	Low	Low	Half step
Low	High	Low	1/4 step
High	High	Low	1/8 step
Low	Low	High	1/16 step
High	Low	High	1/32 step
Low	High	High	1/32 step
High	High	High	1/32 step