MAJOR PROJECT REPORT

(ECN 451)

MERAKI

Pick and Place Machine

Submitted by:

Aditya Agrawal (18105003)

Manik Sardana (18105042)

Yukta Sachdeva (18105086)

Yuganshi Bharti (18105108)

Harsh Pundir (18105117)

Submitted to:

Dr. Divya Dhawan

Department of Electronics and Communication Engineering

Punjab Engineering College (Deemed to be University), Chandigarh

Declaration

We hereby declare that the project work entitled ‘Meraki’ is an authentic record of our own work carried out at Punjab Engineering College (Deemed to be University) for the completion of B. Tech degree in Electronics and Communication, under the course Major Project. The project was carried under the guidance of Dr. Divya Dhawan.

Certified that the above statement made by the students is correct to the best of their knowledge and belief.

Aditya Agrawal (18105003)

Manik Sardana (18105042)

Yukta Sachdeva (18105086)

Yuganshi Bharti (18105108)

Harsh Pundir (18105117)

Dr. Divya Dhawan

Electronics And Communication Engineering Department,
Punjab Engineering College (Deemed to be University)
Sector 12, Chandigarh

Acknowledgement

It gives us immense pleasure to express our profound gratitude and deep regards to our project mentor Dr. Divya Dhawan, for offering invaluable assistance, support and guidance at every step during the advancement of the project. We will carry with us the knowledge and blessings given by her throughout our life.

We are also grateful to other faculty members of our esteemed college, who have bestowed their knowledge and guidance at appropriate times throughout our journey of four years. It is because of their efforts that we were able to understand fundamentals which built the foundation for our project and career. It is because of their motivation and dedication that we were confident enough to dive into a project topic which could be converted into a product.

We are grateful to Mrs. Purnima who helped us in fabricating the PCB in PCB Fabrication Lab; to Dr. Arun Kumar Singh, who reviewed our PCB after it was fabricated; to Mr. Sahil Garg, Senior Research Fellow in ECE Department for his invaluable consultation on Hardware aspects of the project; to Mr. Harshit Singh, 4th year B. Tech. Electrical Engineering student, also IEEE PEC CS chairperson, for providing us with IEEE room, where we worked upon our project comfortably and collaboratively.

We are also grateful to technological advancements and the entire Electronic and Mechanical components supply chain because of which we could acquire knowledge and material to build this project. Finally, we are thankful to God and our parents for providing us with a comfortable life and education because of which we are able to pursue projects like this one.

Aditya Agrawal
Manik Sardana
Yukta Sachdeva
Yuganshi Bharti
Harsh Pundir

Abstract

Computer Numeric Control (CNC) machines are widely used in industries for manufacturing purposes. A Pick-and-Place (PnP) robotic machine is used to place Surface-Mount Devices (SMDs) or through-hole components onto a Printed Circuit Board (PCB). They are used for placement of a broad range of electronic components, like capacitors, resistors, integrated circuits onto the PCBs which are used in computers, consumer electronics as well as industrial, medical, automotive, military and telecommunications equipment. The same process, if done manually, would require delegating a mechanic to fulfil monotonous iterations, which increases the cost and time and reduces the precision associated with the job.

PnP machines currently available in the market for Large-Scale manufacturing applications are associated with high costs (₹3 Lakhs +). A DIY PnP kit for Mid-Scale manufacturing, called LumenPnP costs around $1145 (~₹86,000). The goal of the project is to help Mid-Scale manufacturers bridge the gap between prototyping and mass production. This machine should help with the production process at a moderate scale, with a cost that is reasonable for a business that does not have the resources to invest in expensive contracts or machines.

The push in the Make-In-India campaign has caused a surge in the electronics manufacturing segment in the country. The recent times have seen significant increase in the number of products being manufactured in India and a substantial portion of these products have pre-assembled circuit board, thus, emphasising the need for an affordable, indigenous PnP machine.

The Greek word ‘Meraki’ means to do something with passion, from the heart, with absolute devotion and undivided attention. The word perfectly resonated with the team’s passion towards the project. Thus, the name Meraki was chosen for this project after considering many options.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Motivation

A Pick-and-Place (PnP) robotic machine is used to place Surface-Mount Devices (SMDs) or through-hole components onto a Printed Circuit Board (PCB). PnP machines currently available in the market are for large-scale manufacturing applications and are associated with high costs (range ₹3 Lakhs +). A DIY PnP kit for mid-scale manufacturing, called LumenPnP costs around $1145 (~₹86,000). This is the cheapest one in its domain. There is no practically affordable indigenous PnP machine available in the market for mid-scale and small-scale manufacturing. The ones available have to be imported, which adds to their already high costs. Thus, these manufacturers are left with no choice but to employ manpower to perform operations like pick, place and soldering. These monotonous iterations increase the cost and time and reduce the precision associated with the job.

The goal of the project is to help mid-scale and small-scale manufacturers **bridge the gap between prototyping and mass production** (hundreds of orders per month). This machine should help with the production process at a moderate scale, with a cost that is reasonable for a business that does not have the resources to invest in expensive contracts or machines. This would ultimately help in the growth of such a business because of extra income being generated by fulfilling medium-scale orders. A technological advancement like this would encourage manufacturers to explore a greater variety of products that can be produced domestically.

The idea behind this machine started with a dream- a dream to popularise ‘Made in India’ electronic goods all over the world. To realize this dream, it is important that the Hardware and Electronic design of this successfully functioning, sophisticated machine is made **open source**- so that geeks can build for themselves a machine that will in return build products for them.

1.2 Need for the Project

Stimulated by the government's ₹2.3 lakh crore (₹2.3 trillion) policy push for self-reliant India, the domestic electronics manufacturing industry is expected to see 30 per cent growth in the next fiscal to be worth nearly ₹7 lakh crore (₹7 trillion). This development requires the contribution of all businesses whether small or large scale. Various number of small-scale start-ups have emerged that are solving problems in the Indian Community using hardware-based products, during the Research and Development phase of such products, assembly of complex circuit-boards often becomes a bottleneck in the timeline of the project and also leaves a visible impact on the cost of the product. Hence, it becomes important to remove technological and infrastructure hurdles hampering this development.

Also, there is a lack of industrial level R&D spaces for engineering scholars. Those students who wish to explore the domain of circuit design deserve access to affordable infrastructure which aids their creativity and skills. This machine, if adopted as an open-source design standard and refined to sophistication, has the power to revolutionise domestic electronics manufacturing industry.

To overcome these problems of small-scale manufacturing of circuit boards, a table-top and affordable pick and place is the need of the hour.

1.3 Objectives

- **Pick And Place Circuit Assembly:** To design and assemble the motherboard of the system indigenously with thorough understanding of the circuit and the nitty gritties of the components involved.
- **Pick And Place Structure Assembly:** To design and assemble a 3-Axis CNC Structure with hardware specifically customized for the purposes of a pick and place machine with room for improvement and modularity.
- **4-Axis Head Movement:** X, Y, and Z axes for linear motion, and an auxiliary axis for the pick and place nozzle.
- **Automated:** No human interaction necessary from attaching the paste-applied board to the machine to having a board ready for reflow
    - Integrated up and down vision for fiducial scanning and on-nozzle component alignment
    - Indigenous frame and motherboard design, also capable of future upgrades

1.4 Flow of Documentation

The report broadly approaches the project in two aspects.

1.4.1 Function Units

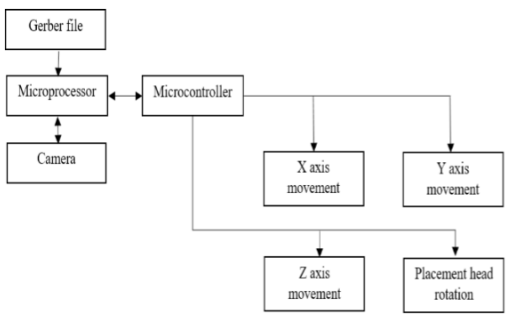
- Chapters 3,4,5 and 6, namely, Mechanical Subsystem Design, System Actuation and Motherboard Design, Firmware and Automation and Integrated System Working focus on the technical design process, the selection of various components and comparison with alternates.
- These chapters contain the technical specification of the components selected for the machine with their reason for selection.
- The flow of these section is analogous to the initial design brainstorming conducted by the development team.

1.4.2 Construction Process Units

- Chapters 7,8 and 9, namely, 3D Printing and procurement, Frame Construction and Assembly, PCB Design and Fabrication have been used to document the build process of the machine with the three sections being crucial to the assembly of the machine.

2 Literature Review

2.1 Research Paper

Aim of the Paper	Proposed Methodology	Result/Conclusion
Gokulnath A R, Chandrakumar S, Sudhakar T D (2018) “Open Source Automated SMD Pick and Place Machine”, International Conference on Robotics and Smart Manufacturing		
To propose a model of an Open Source Automated SMD Pick and Place Machine which is far cheaper than the cheapest one in the market. The steps are as follows: (i) Components are loaded onto the feeder tray (ii) Centroid file is fed to the machine (iii) Component is picked from the feeder tray using vacuum suction (iv) Correction of component’s orientation and alignment using image processing (v) Properly aligned and oriented component is placed on the PCB by releasing the vacuum.	Mechanical system i.e., the proposed SMD machine is built based on the direct shaft-driven XY mechanism as compared to conventional CoreXY and similar systems (H-Bot, D -Bot, etc.). Usage of linear flat bearing has significantly improved mechanical stability by reducing torsional disturbances as compared to conventional usage of circular bearing in P&P machines. Usage of stepper motor without position encoder has shown a significant drop in overall capital price. Vision system is based on contour feature extraction algorithm whereas HAAR training algorithm needs to High capital to train the machine on image processing. 	The machine has been successfully tested for resistor, LED and capacitor. Industrial grade materials are used and build cost is about ₹40,000. Low power consumption as stepper motors are used which require 2A for a motor driver. Machine can reach 240 Components Per Hour (CPH) in current configuration. The machine at times fails to drop the component at the exact position due to presence of partial vacuuming even when the vacuum motor is switched off. Placement head mechanism is not very efficient which needs total redesign.

Limited Literature is available on Pick and Place machines on the web, though extensive literature is available on Pick and Place robotic arms.

2.2 Market Survey

2.2.1 Installer SMD components Borey T15-F30-L4

Figure 2.1: Pick and Place Machine Borey

PRODUCT DESCRIPTION

Key Features:

- Visual identification, automatic empty truck alarm, automatic angle correction.
- Computer control: unlimited memory space for various Windows-based programs, coordinate input for PCB circuit diagrams, visual control and easy to learn.
- Automatic feeding: for reliable feeding systems, avoids careless unreliable gripping.

Main functions:

- Vision system: automatic correction, alignment on the fly, automatic insertion.
- Mounting Heads: automatic angle correction instead of tilt angle correction, more components available.
- Automatic feeding: more reliable with higher feeding accuracy.
- Array Mode: Array settings are available.
- Data Management: Unlimited memory space for files or programs.

Price: ₹15,00,000 +

Remarks: Expensive for mid-scale and small-scale businesses, Russian-origin machine, no after-sales service.

2.2.2 SMT280 Pick and Place Machine

Figure 2.2: Pick and Place Machine SMT280

Technical Details:

- Applicable Components: 0402, 0603, 0805, 1206, diode, triode, BGA SOT, etc
- Feeders: 28
- Feeder size: L = 235 *W = 700 * H = 245 mm
- Max PCB Area: 320*450 mm
- Model Number: SMT280
- Mounting capability: 7500 components per hour
- Nozzle type: Juki
- Placement Head Quantity: 2
- Power Supply: AC220V 10%50Hz
- Vibration Feeder: Optional (Not included)

Price: $2,800.00 = ₹ 2,16,363.28

Remarks: Expensive for mid-scale and small-scale businesses, China-origin machine, no after-sales service.

2.2.3 LPKF ProtoPlace E4

Figure 2.3: LPKF ProtoPlace E4 Pick and Place Machine

The LPKF ProtoPlace E4 is an ergonomically designed, one-hand operation pick & place system for the professional assembly of SMT printed circuit board prototypes and small batch projects. The ProtoPlace E4 quickly assembles SMT boards, with the user controlling each step of the assembly process through an LCD display.

Features:

- Precise fine-pitch component assembly
- Camera system aids component positioning
- Flexible work area via magnetic PCB holders

A camera system coupled with the display ensures easy and accurate component positioning control, so the ProtoPlace E4 can precisely assemble complex circuits. The components are safely removed from the component trays or integrated tape feeders via vacuum needle. The ergonomically formed placement head is guided to the appropriate point above the circuit board, the component is placed, and the vacuum is deactivated – all very easily with just one hand.

Price: € 8000 = ₹ 6,44,757.09

Remarks: Expensive for mid-scale and small-scale businesses, United States-origin machine.

2.2.4 LumenPnP Kit

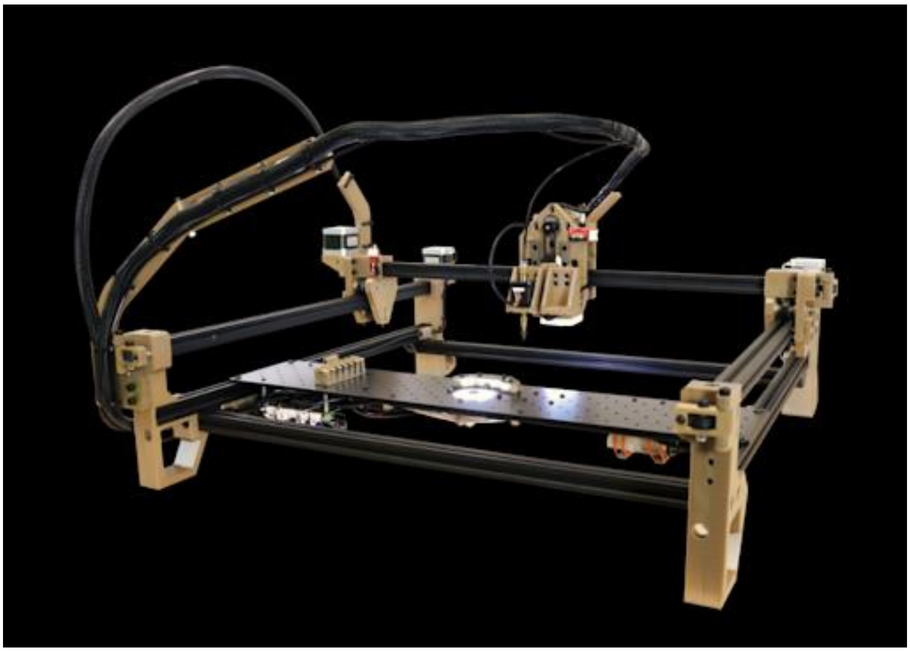


Figure 2.4: LumenPnP

Machine Capabilities:

- Top and Bottom Vision Systems with integrated lighting
- Eliminate time spent populating boards by hand
- Support for dozens of powered feeders over RS-485
- Maximum PCB Size: 225mm x 400mm
- Minimum Component Size: 0603 (0402 in Beta)
- Fully Open Source and constantly improving

Price: $1,145.00 = ₹ 88,477.13

Remarks: Expensive for small-scale businesses, imported, self-assembly

3 Mechanical Subsystem

3.1 Mechanisms Used

Two of the most widely used mechanisms in CNC Machines for actuation of axes linearly are:

- Lead Screw Mechanism
- Timing Belt Mechanism

The following two mechanisms are analysed in detail to assess which would be suitable for the machine in the given constraints like accuracy, repeatability, ease of assembly, procurement and cost.

3.1.1 Timing Belt Mechanism

A belt-driven actuator converts rotary motion into linear motion using a timing belt. The timing belt contains teeth that lock onto toothed pulleys, applying torque and preventing slippage. Often, the belt drive is enclosed within a protective case, and attached to a carriage. The driveshaft and motor are situated perpendicular to either side of the actuator (horizontal motor mount), or perpendicular to the top of the actuator (vertical motor mount).

3.1.2 Lead Screw Mechanism

A lead screw uses a threaded rod to translate its rotational motion into linear motion. There are two versions, captive and non-captive, with both options incorporating a compact and simple design that offers smooth and quiet motion. Both options have various screw leads and diameters that can be selected based on the needs of the application. Short leads offer more precision, while long leads will create more speed, and larger diameters offer more rigidity to actuator systems.

3.1.3 Comparison

Timing Belt Mechanism	*Lead Screw Mechanism*
Advantages	
Long strokes. Typically, up to 6 meters. Optimal for shuttle transport and material handling applications.	Higher accuracy and positional repeatability versus belt drives.
High linear travel speed. Typically, up to 3-5 m/s for long travel distances.	Quick response in short stroke applications. Lead screw possesses agile acceleration and deceleration rates, and a quicker response than belt drive. An aggressive lead screw can be as fast as a belt drive for strokes less than 500 mm.

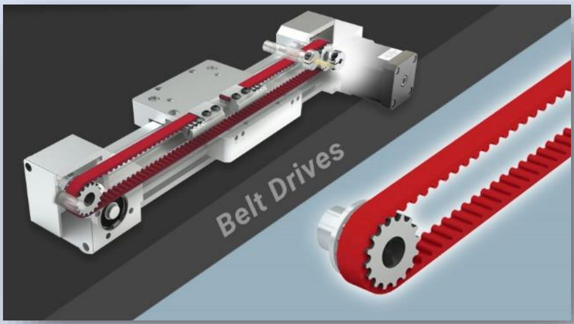
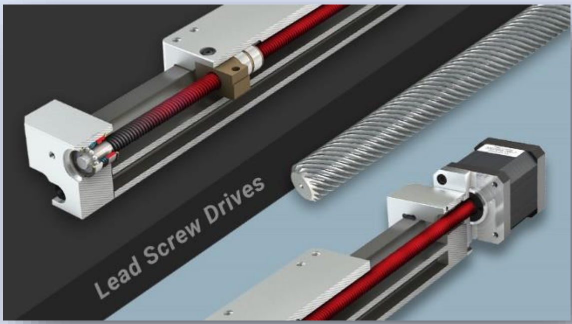
Higher efficiency. Typically, 90-percent. Benefits high-speed and continuous power applications.	Smoother and quieter linear motion.
Lower input RPM versus screw drives.	Large range of diameters (6-16 mm) or (3/16” - 1/2”) with several leads available to match application requirements.
Disadvantages	
Lower accuracy and positional repeatability versus screw drives.	Limited load capacities due to polymer nuts and anti-backlash nut styles.
More input torque required versus screw drives. Typically requires additional expense of gear reducer.	Limited speed. Typically, <= 1,000 rpm. This limit can be exceeded for lighter payloads.
Belt re-tensioning may require preventative periodic adjustments.	Limited screw accuracies are available.
Belt materials that can be adversely affected by corrosive environments.	Not recommended for applications requiring the combination of high load, high speed and continuous duty. Ambient and friction generated heat are primary concerns.
	

Table 3.1: Comparison between Timing Belt and Lead Screw Mechanism

Final Selection: On all the Three Axes, a ‘Timing Belt’ Mechanism is chosen

Criteria For Selection:

- **Integration into the Frame Design**: The Timing belt mechanism does not require any additional hardware setup and the linear rails required for the system can be same as that of the frame which greatly reduces system cost and complexity.
- **Higher Speeds:** Due to lower gear and pulley ratios, higher speeds can be achieved in the belt pulley mechanism which will provide a huge advantage to pick and place machines.
- **3D Printable Parts:** Various parts of the timing belt mechanism can be 3D Printed without any substantial compromise on the system performance, this helps in reducing the machine cost monumentally in terms of capital as well as procurement time.

3.1.4 Gantry Design

Depending on the axes and the placement of the timing belts (vertical or horizontal), different configurations of the plate carrying the head/components is designed. This plate is referred to as the 'Gantry Design'.

In the project, 4-V Wheel and 3-V Wheel gantry designs are used which are common solutions to the specific problem statement. Also, a hybrid design is fabricated for the Z-axis movements.

- 4-V Wheel Gantry for Y-Axis Rail:

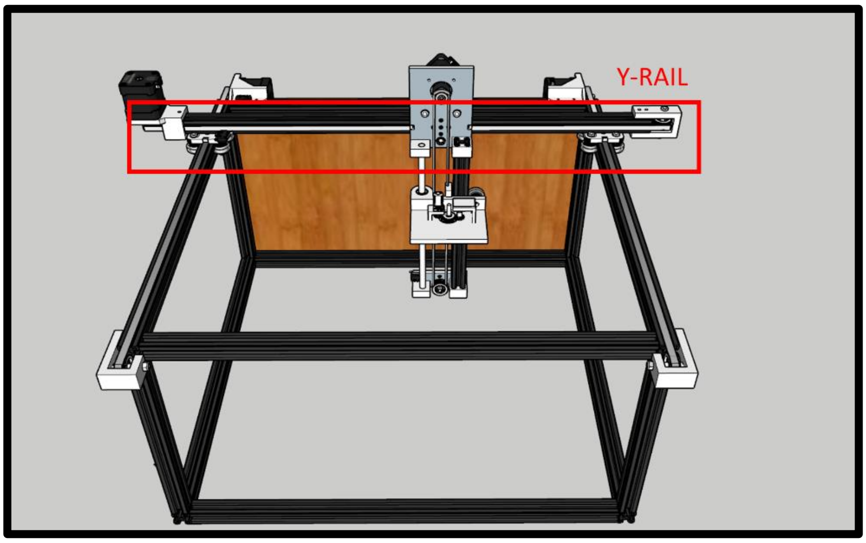


Figure 3.1: Rail mounted on Y-axes

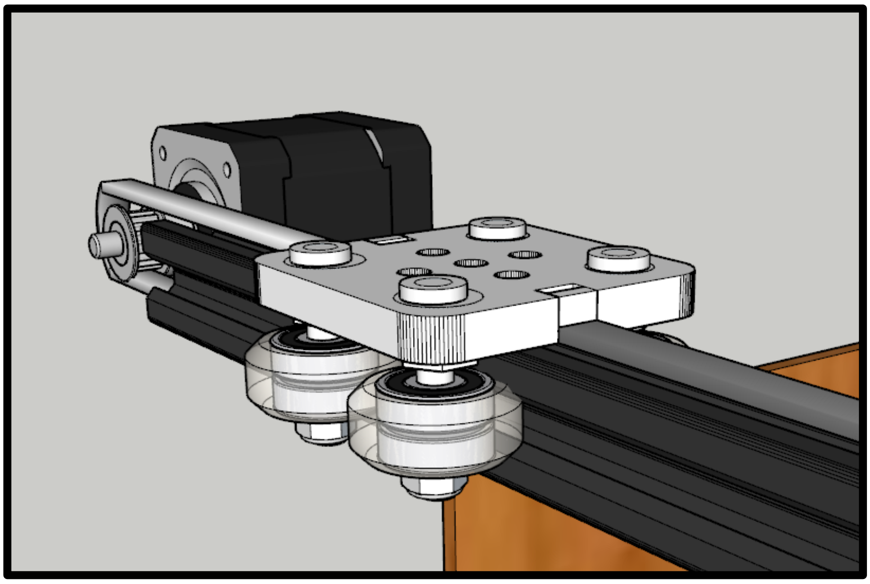


Figure 3.2: 4-V Wheel Gantry on Y-axis

The 4-V Wheel Gantry consists of following parts:

- M5 Screws: 4 units
- M5 Loc Nuts: 4 units
- Delrin V-Wheels: 4 units
- M5 Eccentric Nuts: 2 units
- M5 Spacers: 2 units

- 3-V Wheel Gantry for X Axis:

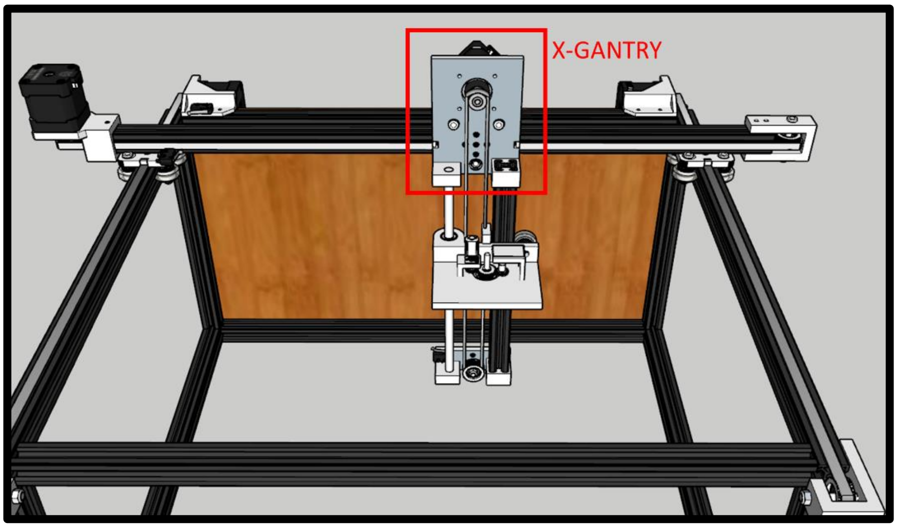


Figure 3.3: X-Gantry: To move Head on X-axis

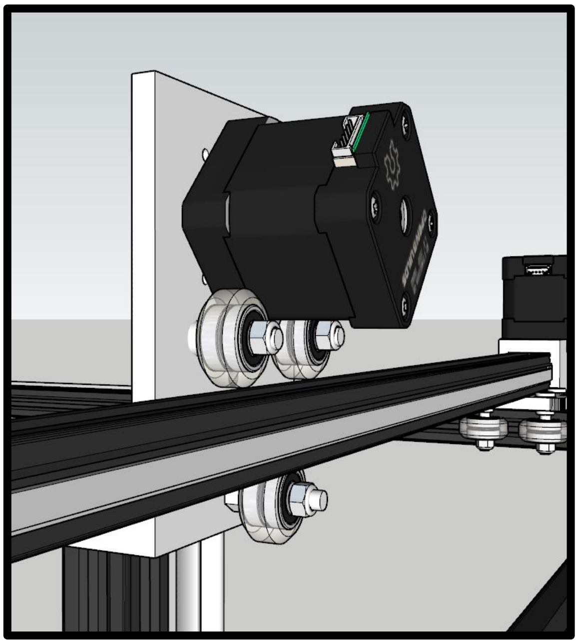


Figure 3.4: 3-V Wheel Gantry on X-axis

The 3-V Wheel Gantry consists of following parts:

- M5 Screws: 3 units
- M5 Loc Nuts: 3 units
- Delrin V-Wheels: 3 units
- M5 Eccentric Nuts: 1 unit
- M5 Spacers: 2 units

Hybrid Design for Z Axis:

- To optimize for least cost and smooth functionality, a custom Z-Axis design is opted.
- The Z-Axis plate is also controlled by Timing Belt Mechanism.
- The plate slides smoothly on the Stainless-Steel smooth rod using the linear bearing on the left and uses the V-Wheel to slide on the Extrusion Rod.
- The Steel rod and the extrusion rod also provide structure to the frame.

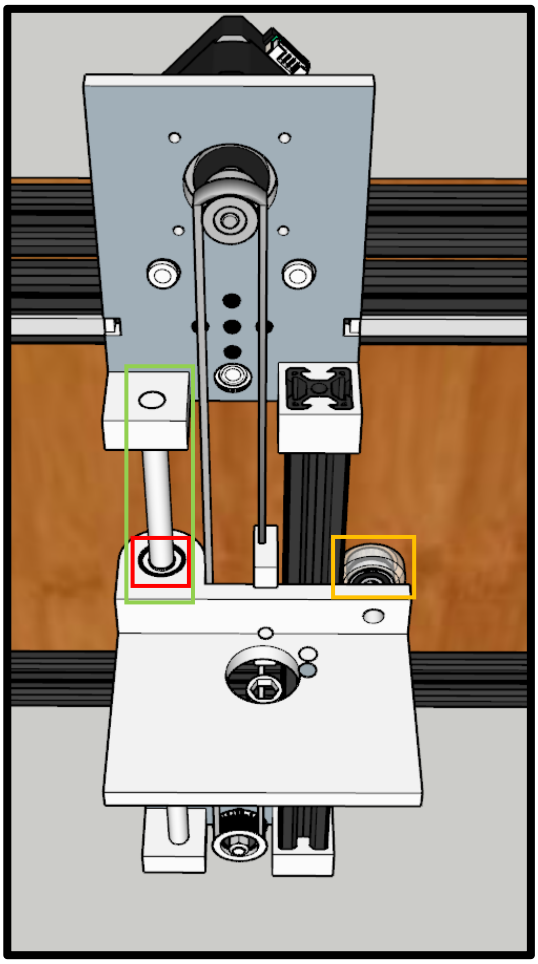


Figure 3.5: Z-Axis Design

3.1.5 Rotatory Movement

To provide the final axis to the machine, that is the rotation axis, a set of gears is employed with the micro motors coupled with the rotary encoder.

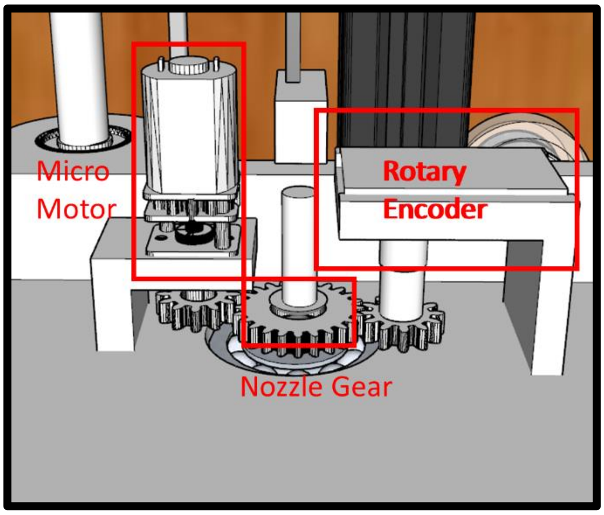


Figure 3.6: Mechanism of Rotatory Axis

3.2 Structural Parts of the Machine

3.2.1 Procured Parts

- 2020 Aluminium Extrusions- 6 meters

Figure 3.7: Aluminium Extrusion Rod

- Features:
  - Black anodized, durable and excellent corrosion resistance.
  - 2020 V slot profile support linear motion.
- These are the main structural pillars of the project, all the components are mounted over these aluminium extrusions which provide stability and stiffness to the project, also used as rail strips for the movement of gantries.

- 8mm Diameter Stainless Steel Smooth Rod

Figure 3.8: Stainless Steel smooth rod

- Used in providing strength to the z-axis
- Nuts and screws

Fasteners are used to secure or fasten materials together. There are many types of bolts and hardware nuts. Most, if not all, bolt types have machine threads. A threaded bolt screws into nuts to hold or fasten materials together. The machine assembly uses the following type of screws and nuts:

  - M3 nuts and screws for motor mounting and power supply mounting
  - M4 nuts and screws for L-clamps, T-nuts
  - M5 nuts and screws for gantry, pulleys
  - T-nuts: for fastening parts with the V-Slot Extrusions

3.2.2 3D Printed Parts

- T-Nuts

Due to the high price of metallic T-Nuts, 3D Model of the T-Nuts were designed with cavities to hold standard M4 Screw. This is to allow the development team to leverage the cost and procurement benefits of 3D Printing without compromising on the mechanical strength provided by Metal Nuts.

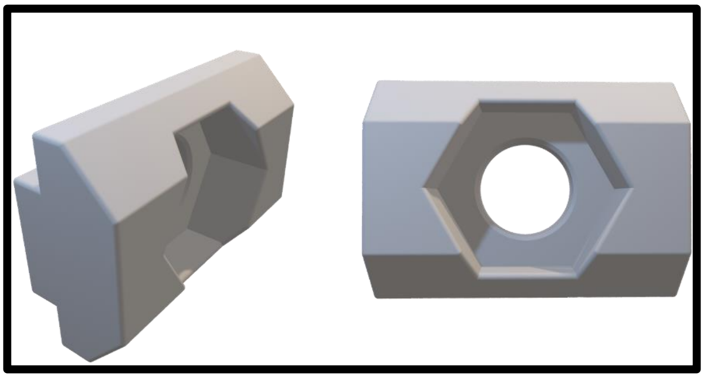


Figure 3.9: 3D Model of T-nuts

- L-Clamps

90^{o} Clamps used to hold together the machine frame.

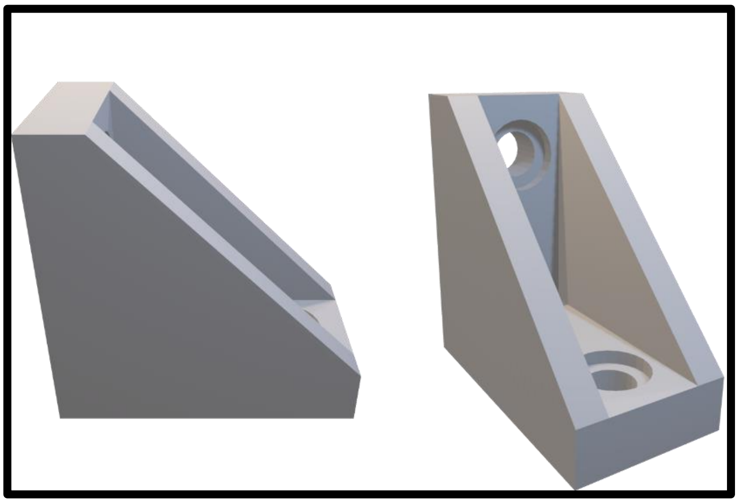


Figure 3.10: 3D Model of L-clamps

3.3 Moving Parts of the Machine

3.3.1 Procured Parts

- Timing belt:

Timing belt drives are a cost-effective, low-maintenance drive alternative that is especially suited for linear movement and positioning applications such as those used in 3D printers.

Figure 3.11: Timing Belt

- Motor Pulley:

A pulley is a wheel on an axle or shaft that is designed to support movement and redirect tension. They are simple, yet powerful devices that can make small forces move large objects. Pulleys are used to make heavy work more manageable.

Figure 3.12: Motor Pulley

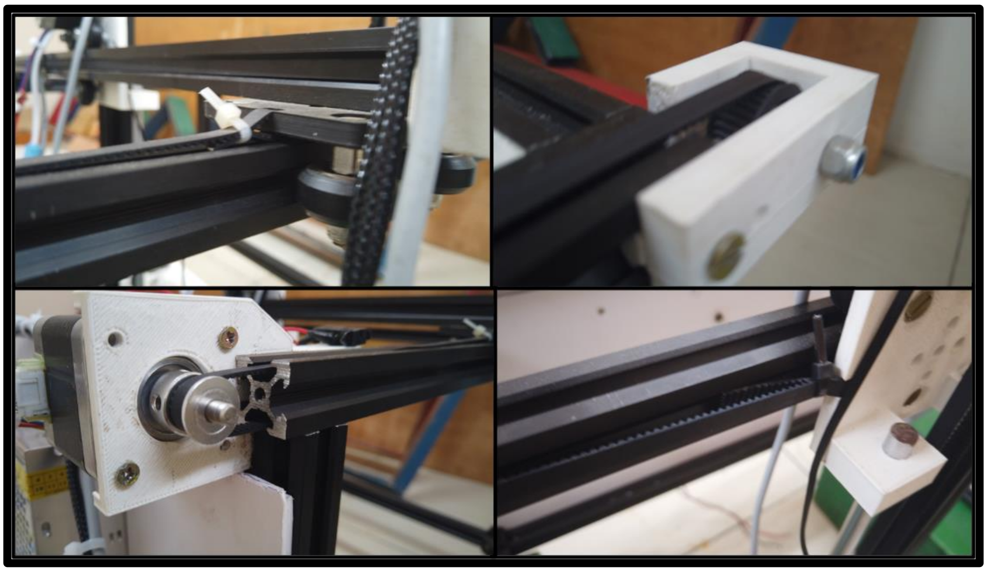


Figure 3.13: Use of Timing Belt and Motor Pulley in the Project

- V-Wheels:

V-Slot wheels are made of Delrin or Polycarbonate, which have extreme strength. These wheels are used on Gantry Plates to develop movement systems for 3D Printers CNC Machines and Laser Engravers.

Figure 3.14: V-Wheels

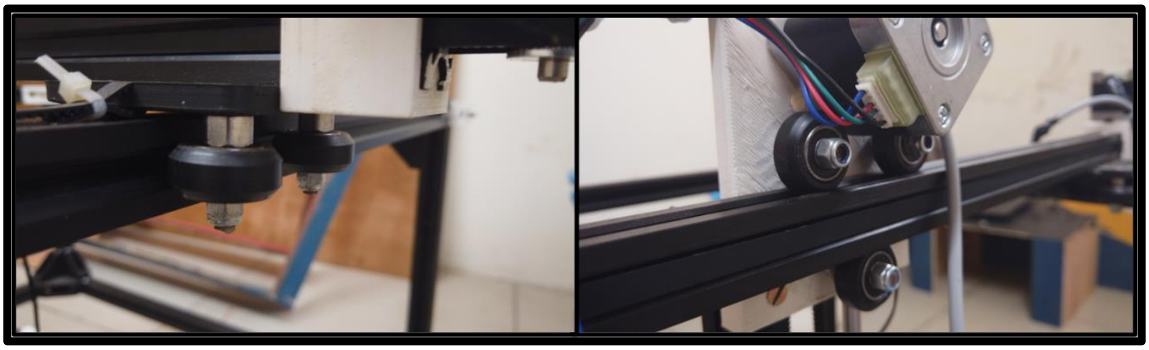


Figure 3.15: Use of V-Wheels in the Project

- Spacers:

Spacers are fasteners used to connect, separate, or position parts in assemblies. They provide sturdy support, alignment and spacing to a variety of applications such as circuit board assemblies, panels and doors.

Figure 3.16: Spacers

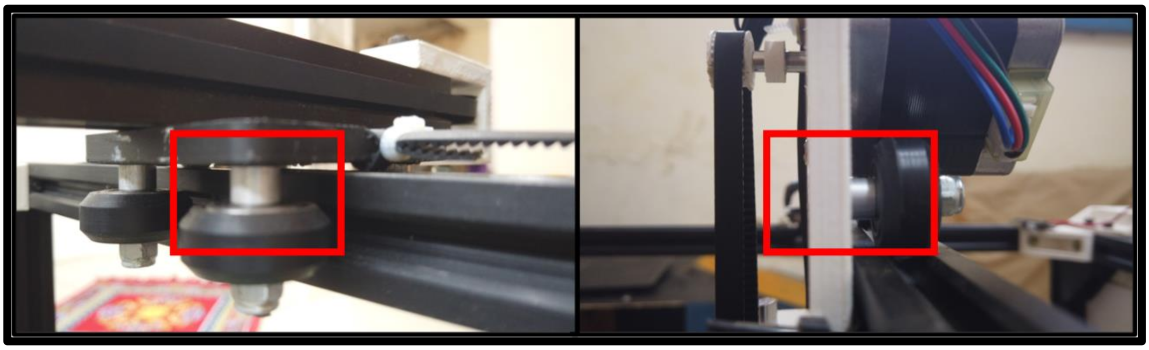


Figure 3.17: Use of V-Spacers in the Project

- Loc nuts:

Bearing loc nuts, sometimes called shaft locknuts or bearing retaining nuts, are utilized to secure bearings onto a shaft and are designed to prevent the loosening of components due to vibration and rotation.

Figure 3.18: Loc Nuts

Figure 3.19: Use of Loc Nuts in the Project

3.3.2 3D Printed Parts

- 4-V Wheel Gantry (1st iteration):

Used standard design for 4-V wheel gantry

Figure 3.20: Standard Design for 4-V Wheel Gantry

- Y-axis Motor Mount (1st adjustment):

Used the standard design with lower end manually removed by cutting to avoid time wastage.

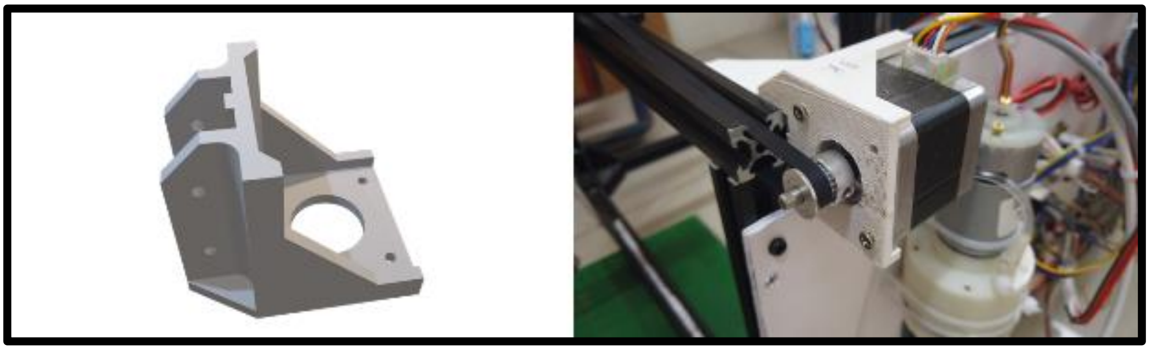


Figure 3.21: Y-axis Motor Mount

- X-axis Motor mount (1st iteration):

Used an end/cap design modification to hold motor on extended end of extrusion over gantry.

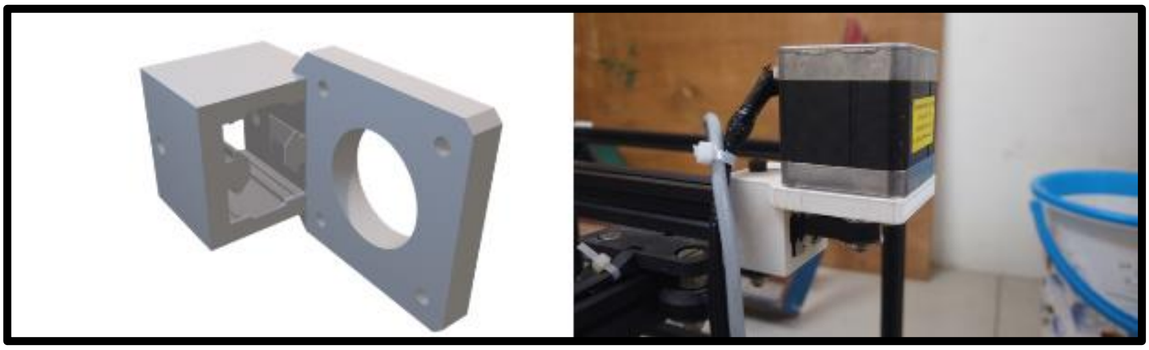


Figure 3.22: X-axis Motor mount

- Pulley Holder (2 iterations):

Using 2 different designs for X-axis and Y-axis depending on the length of extrusion rods.

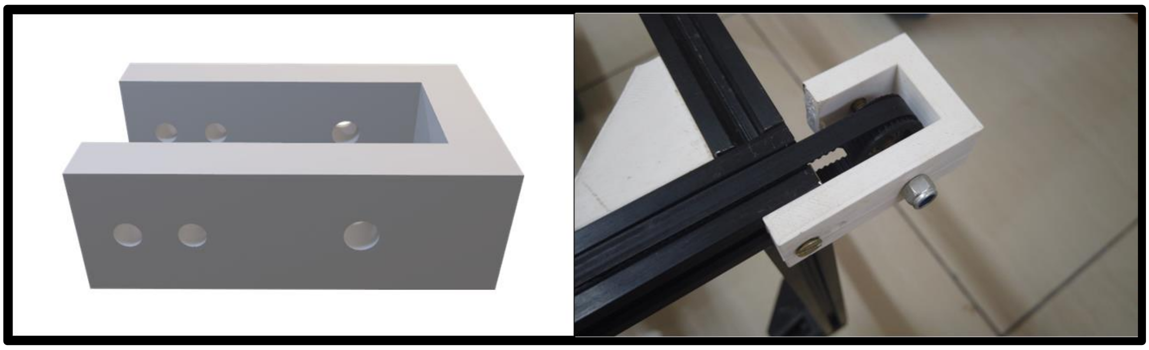


Figure 3.23: Pulley Holder

- Z-axis Base Plate:

To uphold all the 4th axis components and nozzle along with Z-axis movement compatibility with design- a flaw was later detected while mounting the timing belt, which was later resolved.

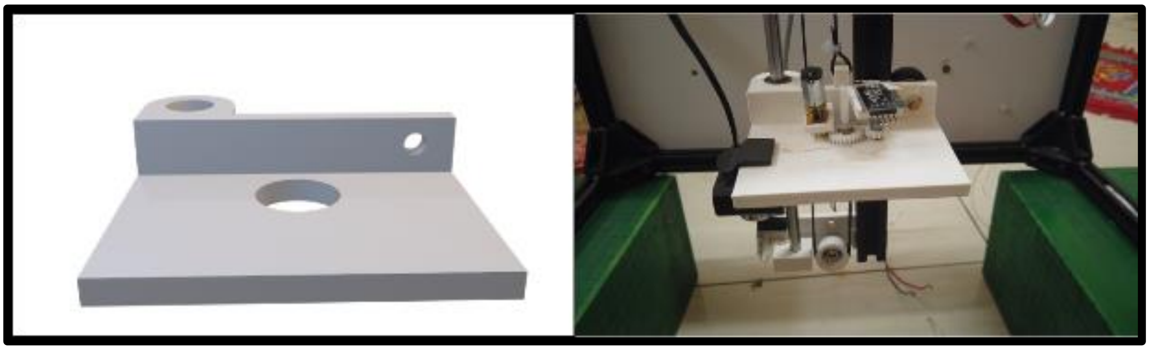


Figure 3.24: Z-axis Base Plate

- Z-axis Lower End:

To uphold pulley, rod and extrusion used in Z-axis movement.

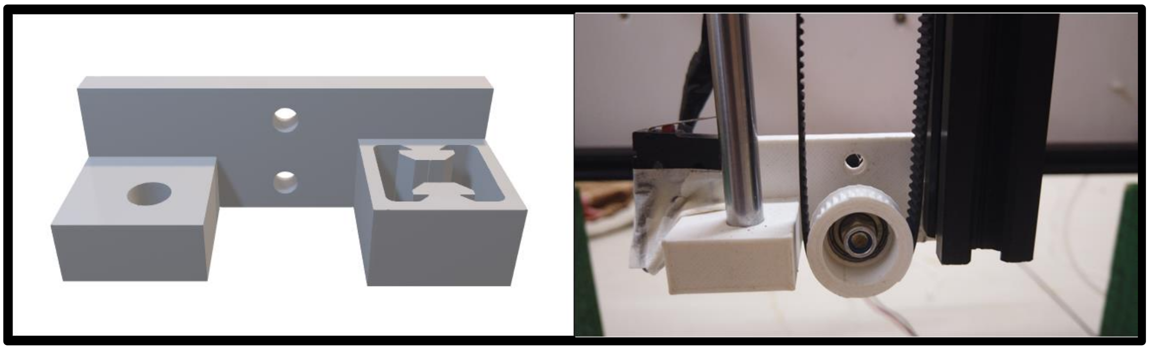


Figure 3.25: Z-axis Lower End

- Z -axis motor-mount + X-axis Gantry (2 adjustments):

With the unique design, motor mount and gantry requirement was combined for the X-axis, which also acts as an upper-end holder for the z-axis supports.

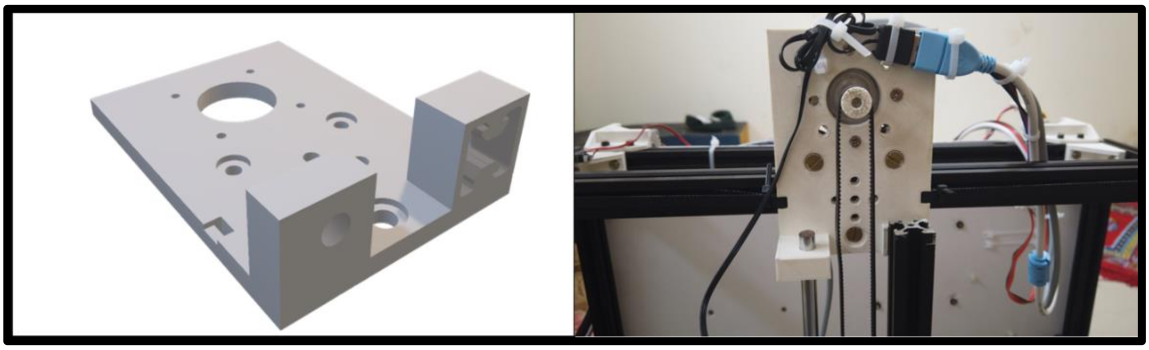


Figure 3.26: Z -axis motor-mount and X-axis Gantry

- Z-axis Timing Belt Connector:

Due to a lack of resources and to avoid any other iteration in the z-axis, another part was printed to connect the timing belt with the plate as discussed earlier.

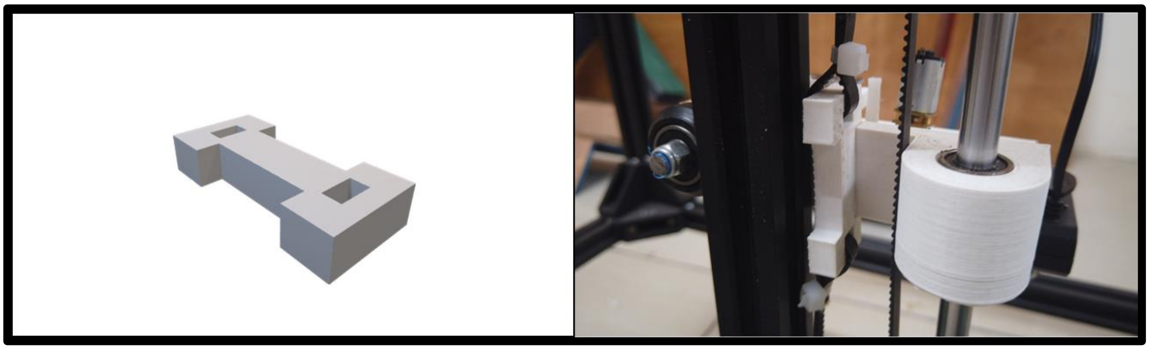


Figure 3.27: Z-axis Timing Belt Connector

- Z-Axis Stepper Motor Timing Belt Gear:

Since the timing belt didn't have to take much load, to avoid any further procurement of another motor pulley the part was 3d-printed to maintain the tension in the timing belt.

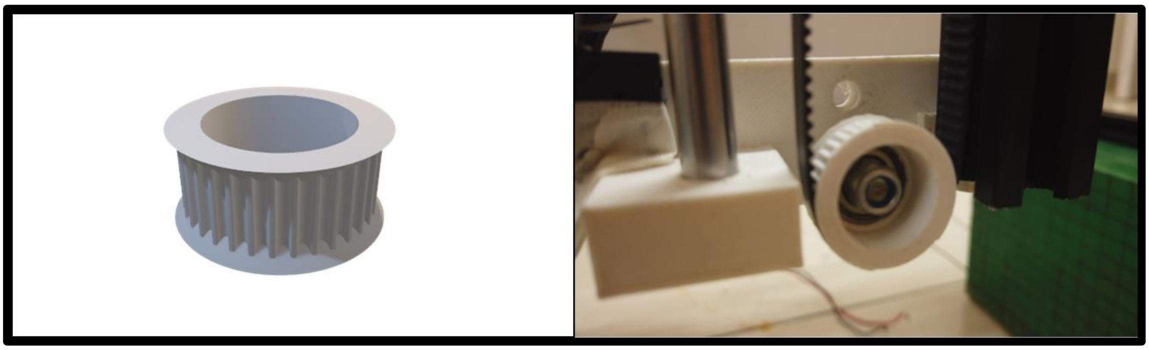


Figure 3.28: Z-Axis Stepper Motor Timing Belt Gear

3.4 Final 3D Model of the Machine

Once all the components are finalized, a 3D model is rendered to act as a guide during assembly as well as to ensure that the design has no missing components or functionality.

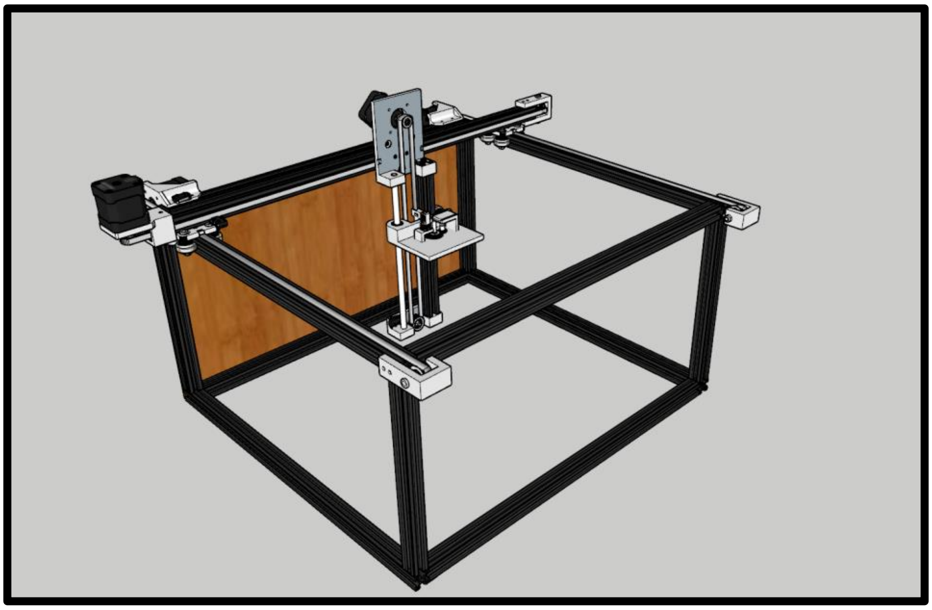


Figure 3.29: Final 3D Model of the Machine

4 System Actuation and Motherboard Design

While the mechanical portion of the machine is integral to the design. The electronics of the system are crucial in running the system autonomously or semi-autonomously.

The following section covers in details all the different aspects regarding the brainstorming and final design selections of the Electronic Sub-System of the machine. It goes on to cover the selection of motors to actuate the three axes, the corresponding motor driver circuitry, the microcontroller selected for the system, the miscellaneous electronic components and concludes the unit with the complete motherboard design.

4.1 Motor Selection

The three commonly available motors for the control of a mechanical system are:

- Brushless DC Motor (BLDCs)
- Servo Motors
- Stepper Motors

A comprehensive study was done on each of these motor types and their respective drivers, the comparison between the three can be summarised as:

Parameter	Stepper Motor	Servo Motor	BLDC Motor
Configuration	Open Loop	Open Loop	Open Loop
Feedback	No Feedback to The Driver/Controller, More Prone to Error	Has an Internal Feedback System, Less Prone to error	No Feedback to The Driver/Controller, More Prone to Error
Cost*	450 INR /-	1800 /-	1200 /-
Size*	42 X 42 X ~42 mm^3	55 X 20 X 43 mm^3	33 X 27 x 35 mm^3
Torque*	5.6 Kg-cm	1.2 Kg-cm	0.95 Kg-cm
Hold Position Vibration	No Vibration When Motor Is at Standstill	Motor Tends to Pulsate or Vibrate in Standstill position	No Vibrations When at Standstill.

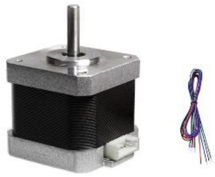
Minimum Angle of Rotation	0.1125 Degrees	1.41 Degrees	Variable, Depends on External Feedback Mechanism
Degree Of Freedom	360^{o} Bidirectional Control	180^{o} Bi Directional Control	360^{o} Unidirectional Control
Driver Complexity	Fairly Simple Driver Circuit Design. Requires Only 2 digital pulses.	No Additional Drivers needed. But Require Independent PWM Signals for Control	Very Complex Driver Design, needs precise encoders for positioning.
Image			

Table 4.1: Comparison of Motors

*Specifications taken from Robu.in, based on the torque-speed requirement of the system.

Final Selection (for X, Y and Z axes) – Stepper Motor (Product Name: Nema-17)

Criteria For Selection:

- The primary reason for selecting the Stepper Motor is the Higher Torque Rating of the Stepper Motors available in the Indian Market. These motors come by the name of ‘Nema-17’.
- Nema-17 Models come in a range of torque ratings with varying price. Since the form factor of these motors are standardized and fixed in dimensions, these can be easily replaced without significant change in driving circuitry. This offers a modularity and upgradability to the machine.
- Stepper Driver Circuits are available at low cost and in different current ratings. These drivers are easy to configure and can easily be replaced in case of component failure.
- Although the price of the motors can be comparable, the difference quicky adds when the quantity of motors required is taken into account. Thus, to maintain the affordability factor, the cost of motors is given significant importance as well.
- The motors in the machine will be tasked with converting rotational motion to linear motion and for precise motion control will require higher resolution as well as 360^{o} bi-directional control.

- All these constraints are checked by the Nema-17 Motors.

4.2 Motor Driver Selection

The stepper motors require high amounts of synchronized current. The output pin of the traditional microcontrollers run on 5V or 3.3V Logic Levels which are in-sufficient to the drive the motor.
For the purposes for converting signals from the controller into high voltage high current signals, we require stepper motor driver. The three most commonly available drivers ICs are compared to select the driver IC for the circuit.

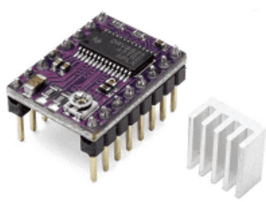
Parameters	A4988	DRV8825	TMC2208
Manufacturer	Allegro	Texas Instruments	Trinamic
Swappable Module	Available	Available	Available
Availability	Available on both offline and online vendors	Available on both offline and online vendors	Available only on online vendors
Max Current	2 A	2.5 A	2 A
Max Load Voltage	24V	36V	36V
Operating Voltage	3.3V, 5V	3.3V, 5V	5V
Micro stepping	1/16	1/32	1/256
Thermal Protection	Yes	Yes	Yes
Cost	78 INR /-	199 INR /-	850 /-
Image			

Table 4.2: Comparison of Motor Drivers

Final Selection – A4988

Criteria For Selection:

- Sufficient Current Draw and Load Voltage – The power requirement of the selected Nema-17 motors for optimal performance do not exceed the max current and max load voltage ratings of the A4988 Driver.
- Driving Voltage – The A4988 Driver can be driven at 3.3V as well as 5V Logic levels, this gives the user the opportunity to use a 3.3V logic level microcontroller like STM32 Series or the ESP32 Series.
- Cost – The primary reason for selection the A4988 driver is the low price of the module, since the machine is in R&D phase, damage of components during development is inevitable, to ensure that there is minimal capital wasted, A4988 Drivers are chosen.

Note: Hot-Swappable Nature of Modules, since all the three stepper driver modules come in the same 16-pin form factor, it is possible to simply replace the module with a different one without any change in firmware or hardware. Thus, leaving scope for future upgradability.

4.3 Controller Selection

To control the selected motors as well as the miscellaneous electronics with precision, based on the user commands, A microcontroller is required that could act as the brains of the system.
Since the controllers is tasked with controlling 4 axes independently along with various other features like GPIO Control, Homing, Motor acceleration control. The selected controller must have enough of the following features (resources):

- 6 to 7 Timers to generate precise timing signals for stepper motors
- Interrupt Functionality
- Hardware Serial Port (UART)
- SPI Port for Future Upgradability.

Due to the ongoing global pandemic, the supply for chips has been disrupted which includes development boards as well as low and mid-range micro-controllers. Along with unexpected delays and long shipment times, the price of these development boards has grossly inflated.
Hence, the controller development boards already available in the development team's inventory have been analysed and the prospective controllers that can satisfy the given hardware requirements are shortlisted. Namely:

- STM32 Blue Pill Board
- ESP32 – WROOM – 32
- Raspberry Pi Pico

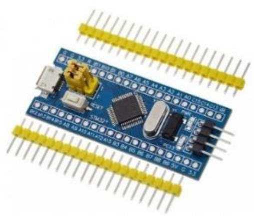
Parameters	STM32 BluePill	ESP32-WROOM32	R-Pi Pico
Controller	STM32F103C8T6 (Based On ARM Cortex M3)	Tensilica Xtensa LX6	RP2040 (Based On ARM Cortex M0)
CPU Cores	1	2	2
Architecture	32 Bit	32 Bit	32 Bit
Max CPU Frequency	72 MHz	240 MHz	133 MHz
SRAM	20 KB	512 KB	264 kB
Flash	64 KB	4 MB	2 MB
GPIO Pins	37	36	26
MCU Voltage	3.3V	3.3V	3.3V
PWM Capable Pins	15	16	16
SPI Ports	2	4	2
UART Ports	3	3	2
I2C Ports	2	2	2
Wi-Fi	No	Yes, Both as an access point and as Station	No
Bluetooth	No	Supports Both, Classic Bluetooth and BLE	No
Ethernet	No	Yes, up to 10 Mbps	No
Current Price (as of 1st May 2022)	929 INR /-	549 INR /-	349 INR /-
Pre-Pandemic Price	199 INR /-	349 INR /-	349 INR /-
Image			

Table 4.3: Comparison of Various Controllers

Final Selection – ESP32 WROOM32

Criteria For Selection:

- The primary reason for selection is the SRAM and Flash Memory Size, ESP32 offers the maximum Flash Memory in the given price range. A large flash memory is essential to ensure that the selected firmware is conveniently loaded onto the controller without requiring heavy optimizations.
- The Controller has a large number of GPIO Pins that can offer the user the ability to attach multiple axes as well as other peripherals.
- Has high operating frequency offering fast processing on its dual core system.
- Sufficient number of PWM Channels, SPI, I2C and UART Ports.
- Supports connectivity features like Bluetooth Low Energy, Wi-Fi and Ethernet that can be used for future upgrades.

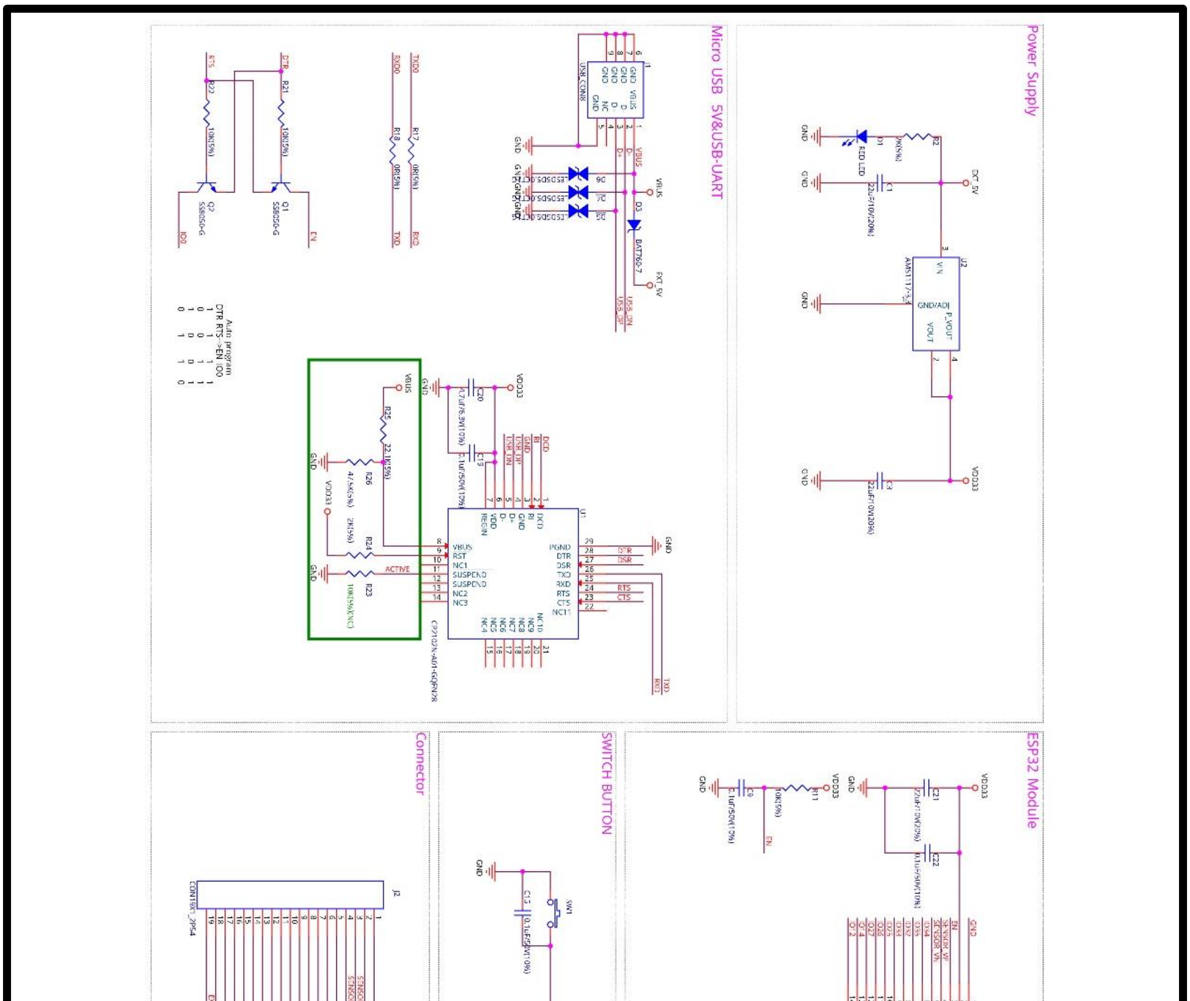


Figure 4.1: Circuit Diagram of the ESP32-WROOM32 DEV Board

4.4 Miscellaneous Electronics

The Controller, Motors and Motor Driver make up the core of the electronics subsystem but need additional components to integrate together with the machine and to perform the necessary tasks. Since these components have limited number of options and product variants, they are chosen on the basis of non-technical criteria like Cost and Availability.

S.No.	Component	Image	Specifications	Requirement
1	Limit Switches		Lifetime: 30 million Clicks Rated Voltage: 125V Rated Current: 5A	For Determining Absolute Zero of The Cartesian.
2	Relay Modules		No. of Channel: 4 Trigger Voltage: 5VDC Pull-down circuit for the avoidance of malfunction	For Controlling LEDs and PUMP
3	DC Air Pump		Operating voltage: 12 VDC Rated current: 800mA Minimum pressure: 53.33KPa Maximum pressure: 100KPa	For Picking Up Components using Air Pressure
4	12 V Power-Supply		Input Voltage: AC 100 - 264V 50/60Hz Output Voltage: 12V DC, 20A Output voltage Adjustment Range: ±20%	Supplying Power to The Complete System
5	LM2596 Step-Down Converter		Input voltage: 3-40V Output voltage: 1.5-35V(Adjustable) Output current: 2A, maximum 3A	Stepping Down 12V From the Power Supply to 5V

6	Capacitors		Working Voltage: 25 V Capacitance: 100 uF Pitch: 2.54 mm	Used as decoupling capacitors to prevent spike rise and drop in voltages.
7	12V LED Strips		Glow Colour: Warm White Operating Voltage: 12V DC Strip width: 10 mm Protection Level: IP20 (Not Waterproof)	Illuminating the PCB For Better View in Camera
8	Resistors		Resistance: 10 K Ohm Power Rating: 0.5 Watt	Mostly used as pull up and pull-down resistors
9	Jumpers		N/A	Used for configuring the PCB
10	Camera		Sensor: ¼ Inch CMOS Supports 300k pixels, Resolution: 640×480, Dimension: 40mm × 15mm × 30mm;	Bottom Facing Camera to Place Components precisely.

Table 4.4: Miscellaneous Electronics Description

4.5 Schematic Design

Post the finalisation of components, the selected components’ datasheets are studied to determine the circuit configuration for optimal performance. Most of the components have minimal constraints in terms of circuit design and have self-explanatory pin outs.

The following attributes are kept in mind while designing the circuit.

1. The selected motor drivers (A4988) require a STEP and DIRECTION Signal Each.
2. The Y Axes is driven by two Nema-17 Stepper Motors and hence must have two stepper drivers on the circuit board sharing the same STEP and DIRECTION Signals for synchronisation.
3. To Make the circuit modular and easy to debug, no actual connections are made on the ESP 32 Pins, Header Pins are used instead so the circuit can be reconfigured with the help of jumpers.
4. The Limit Switches require external pulldown resistors to ensure that the signal does not stay on a floating condition when the switches are open.
5. The Power Supply is required to supply 12V Power to the following components
    a. Motor Driver (VMOT)
    b. Step-Down Converter
    c. Relay Module (JDVCC)
    d. DC Pump (Via Relay)
    e. 12V LED (Via Relay)
6. The Step-Down Converter is required to supply a 5V Power to the following components
    a. A4988 Motor Driver (VCC)
    b. ESP32 WROOM32 (VIN)
    c. Relay Module (VCC)

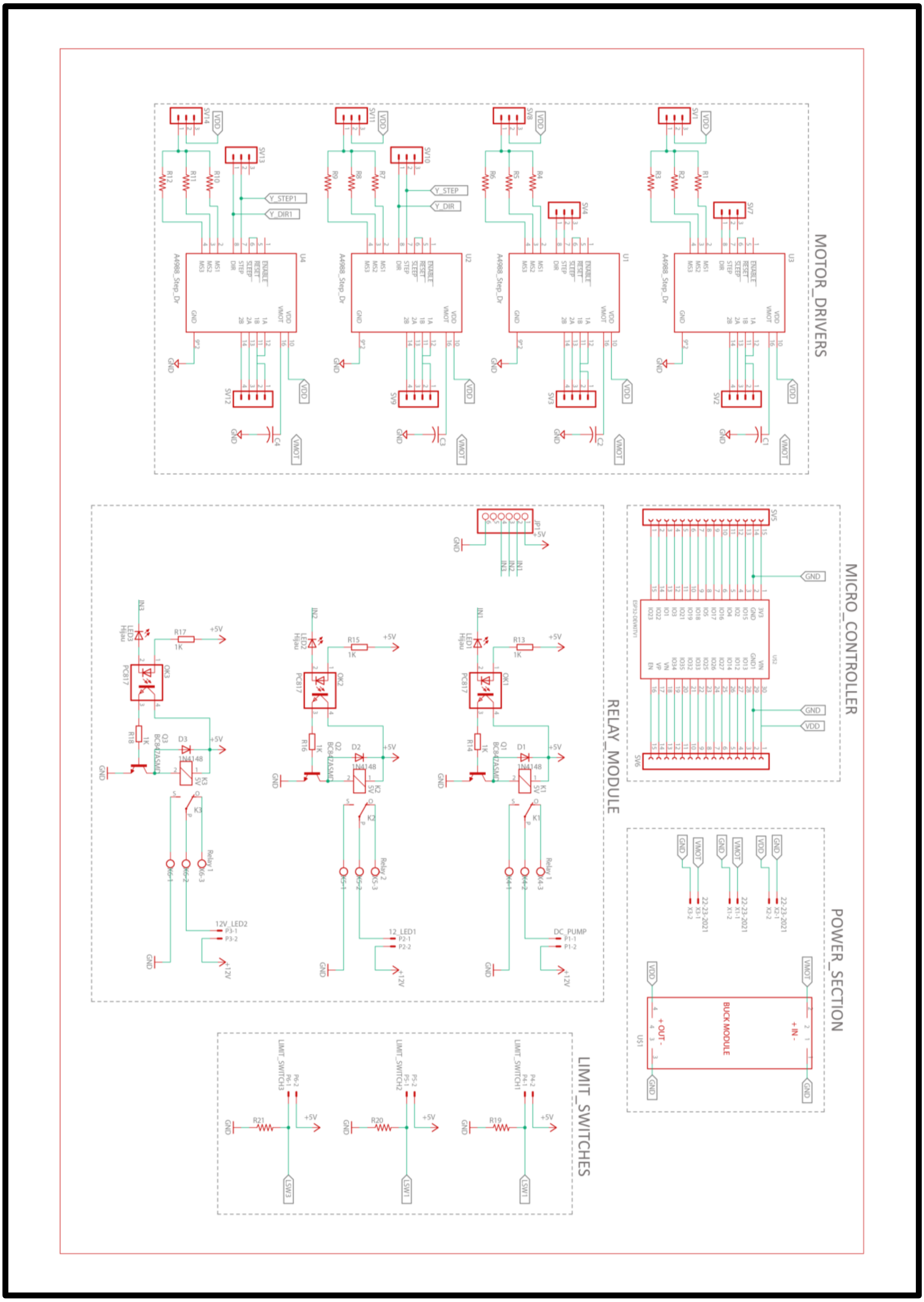


Figure 4.2 Final Schematic of the Machine Electronic Components

4.6 PCB Design

The aforementioned schematic is used to generate a PCB Design using EAGLE Design Tool.

- Since the circuit has very less complexity the design is adopted on a single layer PCB to reduce the prototyping time as well as cost of fabrication.
- The PCB Routing has been done manually with the following constraints:

Varying 'Trace Width' for various signal types

Depending on the current values, the PCB Traces generate heat and EMI that can cause the circuit to malfunction and in worse cases even lead to permanent damage of the circuit board as well the components. To prevent such a scenario, PCB traces are given enough tolerance in their thickness to mitigate all the aforementioned phenomenon.

The IPC (Institute of Printed Circuit Boards) has given standard Trace-Width specifications for different current values. These standards are:

IPC Recommended Track Width For 1 oz cooper PCB and 10 °C Temperature Rise

Current/A	Track Width(mil)	Track Width(mm)
1	10	0.25
2	30	0.76
3	50	1.27
4	80	2.03
5	110	2.79
6	150	3.81
7	180	4.57
8	220	5.59
9	260	6.60
10	300	7.62

Figure 4.3: Trace-Width Specifications

Taking reference from the given values, the trace width selected for different signals are:

- High Voltage and High Current Signals are kept at a thickness of **30 mil** (1 mil = 0.001 Inch = 0.0254 mm)
- 5 Volt supply lines are kept at a trace width of **24 mil**.
- Rest Signal lines are kept at a trace width of **16 mil.**

Trace to Trace clearance:

- The minimum distance between two nearby traces is an important constraint that must be taken into account to avoid cross signal interference as well as to ensure that the fabrication technology is capable of producing the design.
- Under the IPC 2221 standards, the minimum PCB clearance (really, the clearance between any two conductors) is 0.1 mm for general purpose devices, or 4 mils. For power conversion devices, this minimum PCB trace spacing is 0.13 mm or 5.1 mils.
- For A Liberal design with minimal noise and interference the Minimum Clearance is set to 12 mils.

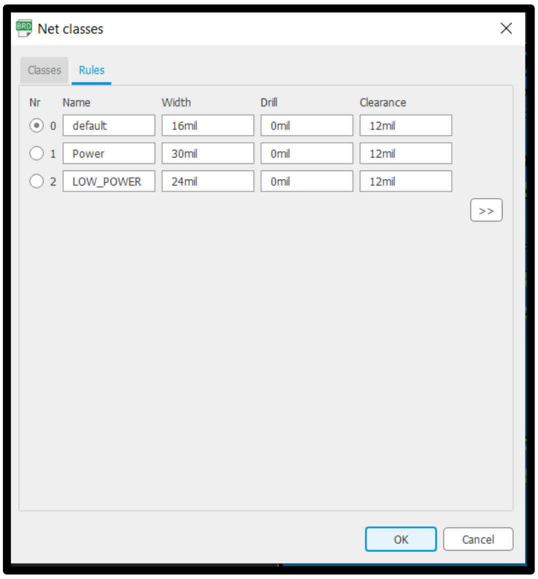


Figure 4.4: Net Widths

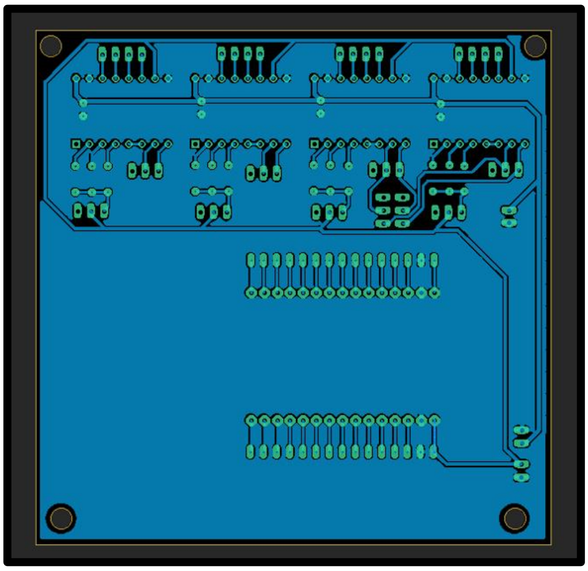


Figure 4.5: Traces on PCB

5 Firmware and Automation

5.1 GCODE: The standard for CNC Machines.

G-code is the most widely used computer numerical control (CNC) programming language. It is used mainly in computer-aided manufacturing to control automated machine tools, and has many variants. G-code instructions are provided to a machine controller that tells the motors where to move, how fast to move, and what path to follow. The two most common situations are that, within a machine tool such as a lathe or mill, a cutting tool is moved according to these instructions through a toolpath cutting away material to leave only the finished workpiece and/or an unfinished workpiece is precisely positioned in any of up to nine axes around the three dimensions relative to a toolpath and, either or both can move relative to each other. The same concept also extends to noncutting tools such as forming or burnishing tools, photo plotting, additive methods such as 3D printing, and measuring instruments.

Since the pick and place machine is analogous to a 4-Axis CNC Machine, The Standardized GCODE instructions are used to control the machine.

Examples of some G-Codes with their functions are:

Command	Function
G1	Linear movement at specified Feed rate (F)
G2, G3	Movement in an arc at specified Feed rate (F)
G20	Select Imperial units
G21	Select metric units
G28	Go to Pre-Defined Position
G28.2	Run homing cycle
G90	Absolute distance mode
G91	Relative distance mode
G91.1	Arc radius mode

Table 5.1: G-Codes and their Functions

5.2 Firmware to Process G-Code

G-Code commands like the ones mentioned in Table 5.1 are generated by the software being used to run the machine, we can also feed the commands manually to the controller *(this control software is discussed in later sections of the unit)*. The controller then processes the G-Code Commands and accordingly controls the motors and actuators. To perform the said processing task, a firmware is required to manage the resources of the microcontroller effectively as well as communicate with the user/control software about the status of the machine.

Since CNC Machines and 3D Printers have been present in the DIY community for over a decade, there are multiple open-source firmware and repositories available that offer great customisations and learning curve to the developer.

On doing research regarding the firmware, two of the most well maintained and active opensource firmware are shortlisted.

1. GRBL

GRBL is a no-compromise, high-performance, low-cost alternative to parallel-port-based motion control for CNC milling. The controller is written in highly optimized C utilizing every clever feature of the AVR-chips to achieve precise timing and asynchronous operation. It is able to maintain up to 30kHz of stable, jitter-free control pulses.

It accepts standards-compliant g-code and has been tested with the output of several CAM tools with no problems. Arcs, circles and helical motion are fully supported, as well as, all other primary g-code commands. Macro functions, variables, and most canned cycles are not supported, but we think GUIs can do a much better job at translating them into straight G-code anyhow.

GRBL includes full acceleration management with look ahead. That means the controller will look up to 18 motions into the future and plan its velocities ahead to deliver smooth acceleration and jerk-free cornering.

2. Marlin

Marlin is open-source firmware primarily designed for RepRap project based FDM (fused deposition modelling) 3D-printers using the Arduino platform.

The firmware runs G-code formatted coded commands and instruction sets as robot software on the 3D printer's control board which manages all of the machine's real-time activities including sending movement coordinates to stepper motors through the stepper drivers, controlling heater elements, sensors, lights, tracking bed levelling, LC displays and buttons.

Marlin supports many different boards and many designs of 3D printer robot platforms, including Cartesian (including Core XY), Delta and SCARA printers, as well as some other less conventional designs like Hangprinter.

Other than for 3D printing, Marlin is also used for many other types of machines including SLA and SLS 3D printers, CNC mills, laser engravers (or laser beam machining), laser cutters, vinyl cutters, pick-and-place machines, and egg painting robots.

After comparing the two firmware, the final firmware GRBL is selected and further tests are done using the same.

Reasons for selecting GRBL:

- While Marlin can only offer up to 4-Axis Control, GRBL offers up to 9 Axis control giving greater room for future improvement.
- Marlin Firmware is designed specifically for 3D Printer and porting the firmware to run a Pick and Place would require a large number of customizations.
- Since GRBL is widely used in CNCs, a substantial number of control software are available that specially offer support for GRBL.
- For Functionalities like LCD Screen, SD Card control, Heated Bed, Thermistors and various parts that are specific to 3D Printers, Marlin Firmware greatly reduces the availability of usable pins on the controller, GRBL on the other hands gives the user complete control of the peripherals.

5.3 Customizing, Compiling and Uploading GRBL onto ESP32

A port of the GRBL Firmware that is specifically designed for the ESP32 Hardware can be found here: https://github.com/bdring/Grbl_Esp32

The said GRBL Port has been used and uploaded onto the ESP32 Development Board using the process discussed below.

1. Visual Studio Code is installed to the host system. The software is available under freeware licencing and can be found in the download section of the official website of VS Code (https://code.visualstudio.com/download).

2. Once the installation is successfully completed, open VS Code and click on the “Extensions” button on the left panel.
3. Search the PlatformIO extension and instal the PlatformIO IDE Extension.

PlatformIO IDE Extension allows the user to use VSCode as a development platform for various AVR and 32-Bit controllers. It also provides the functionality to verify, compile and flash the required code on the desirable micro-controller.

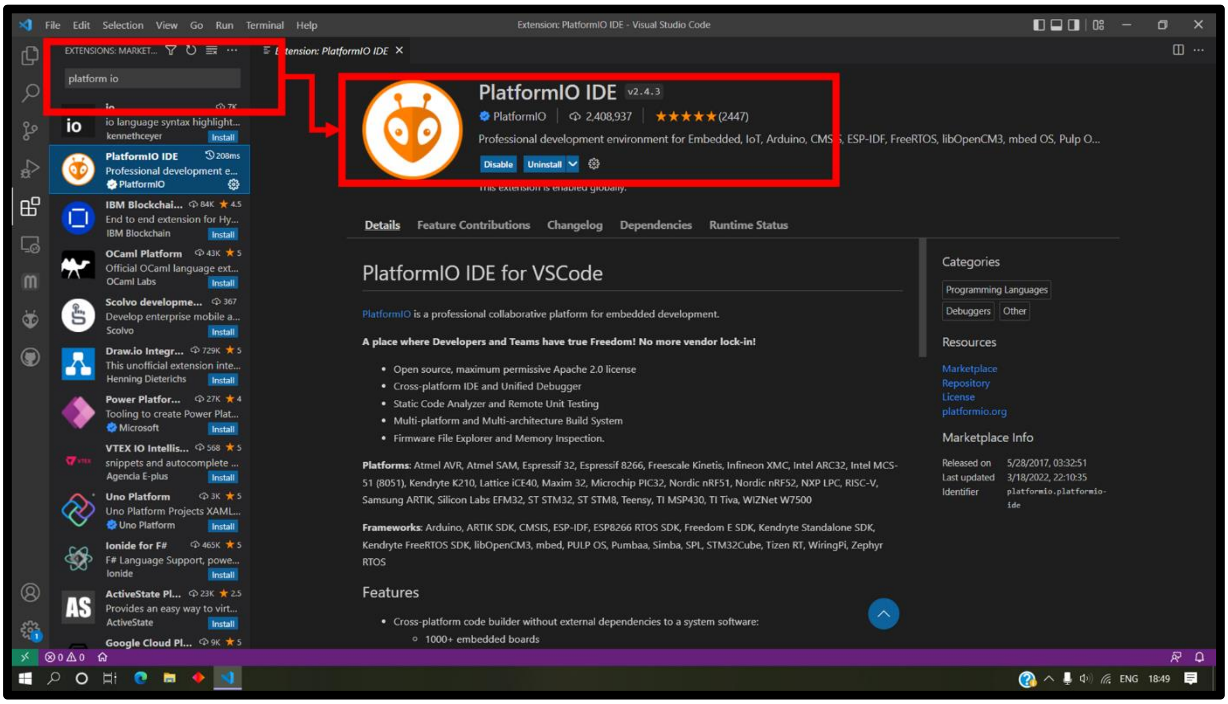


Figure 5.1: PlatformIO

4. Once the PlatformIO extension is installed our development environment is ready for testing the GRBL firmware and making necessary changes in it.
5. Open the GRBL firmware by cloning the GitHub repository and opening the folder from VSCode.
6. Open the 3Axis_V4.h file in the machines folder and make necessary changes to the code. This involves setting the right pin for the required motor control as well as disabling functions that are not required. Additionally, GPIO Pins are setup to provide user functionality to control Relays that would in turn control the Air Pumps and The Lights.
7. Once this is done, upload the code on the ESP32. Simply connect the development board to the Host PC and click on the verify and upload button present on the bottom left corner of the VS Code Terminal. Once the Firmware is uploaded, successfully move towards the next step of working on the control software.

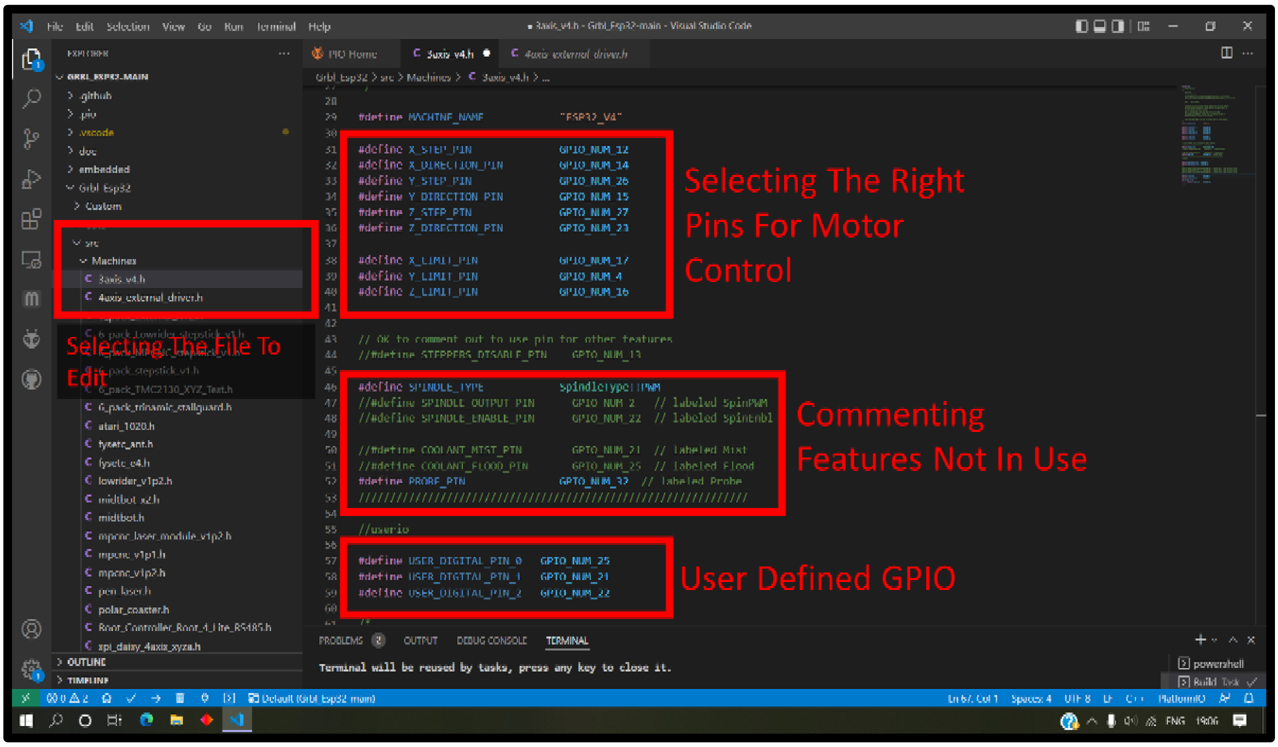


Figure 5.2: Firmware Settings

5.4 UGS Software to Control PnP

The controller can now successfully process G-Code Commands and control the machine movements as per the user’s needs.

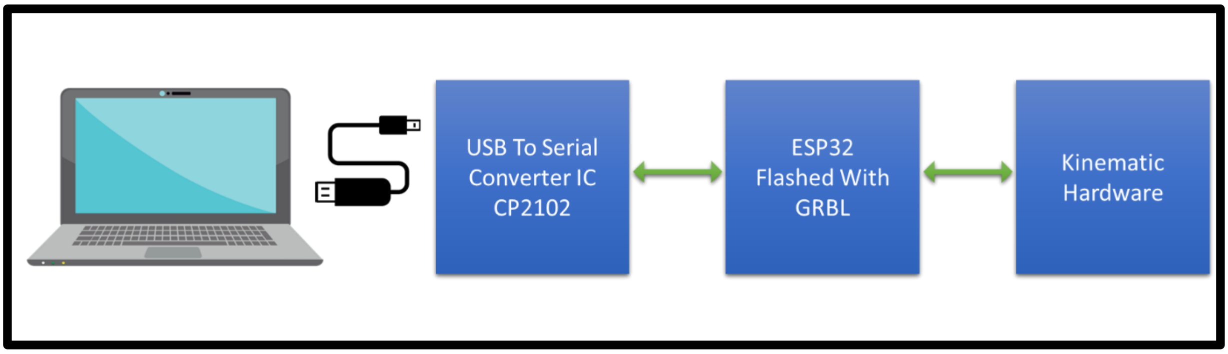


Figure 5.3: Pick and Place control Block Diagram

Thus, a control software is needed on the system connected to the machine which can be used to visualise the machine movements and send GCODE Commands to the machine

The software selected here is UGS i.e., Universal G-Code Sender, which is the most widely used opensource software in the CNC realm.

Steps to configure UGS with the Machine:

- Start off by connecting to the controller hardware.
- Select the correct hardware in the firmware combo box as GRBL.
- Refresh the serial ports list and select the correct port for hardware.
- To start the Setup Wizard, open the menu *Machine* > *Setup wizard…*

  The setup wizard will allow the user to configure limit switches, homing, soft limits and calibrating the machine.
- On the *Motor Wiring* configuration page, test the direction of the motors and change its direction if needed.

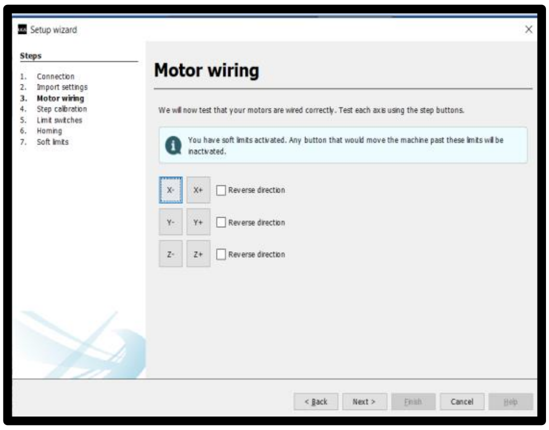


Figure 5.4: Testing Motor Directions

- On the *Step Calibration* page, move the machine and measure the actual distance using a Vernier Callipers. It will then recommend a step setting for the machine.

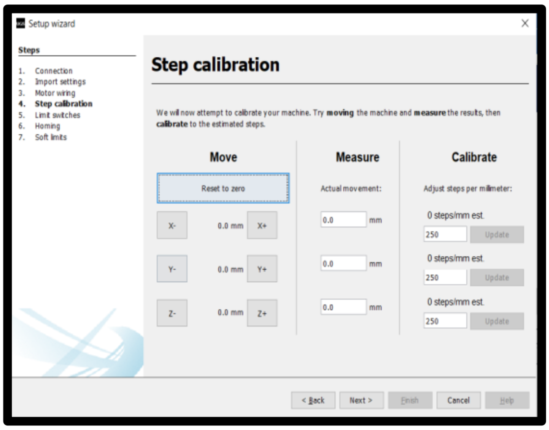


Figure 5.5: Step Calibration

- Limit switches are enabled on this page and tested if they are firing correctly:

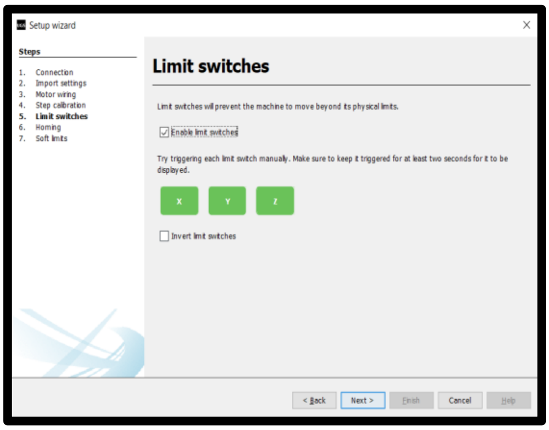


Figure 5.7: Configuring Limit Switches

- Homing is a method of finding the absolute machine coordinates. If limit switches are used, homing may be enabled. This page helps figure out the direction in which homing should be made:

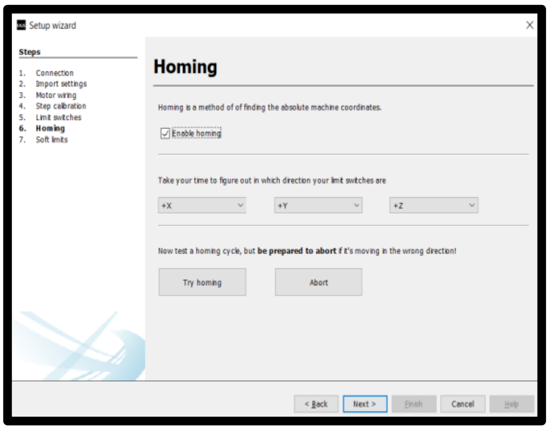


Figure 5.6: Enable Homing

- If Homing is enabled, soft limits may also be configured so that the controller knows if it can process a command without triggering limit switches. This completes the setup wizard and the machine can be run.

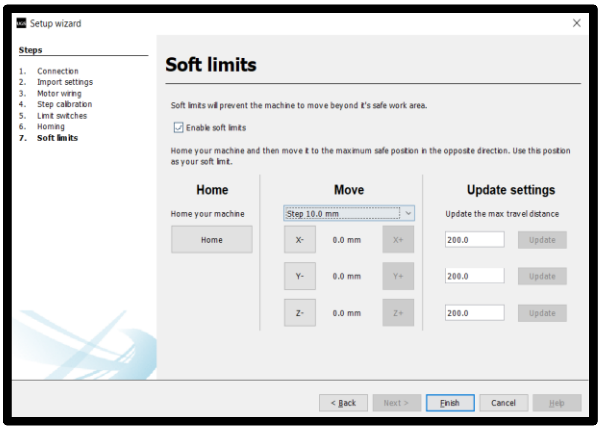


Figure 5.8: Configure Soft Limits

- The machine can be controlled via the Jog Controller Buttons present on the *Jog Panel* on the bottom left.

Figure 5.9: Jog Panel

Digital Read-Out

The Digital read-out (or Controller state) panel displays the current status of the machine.

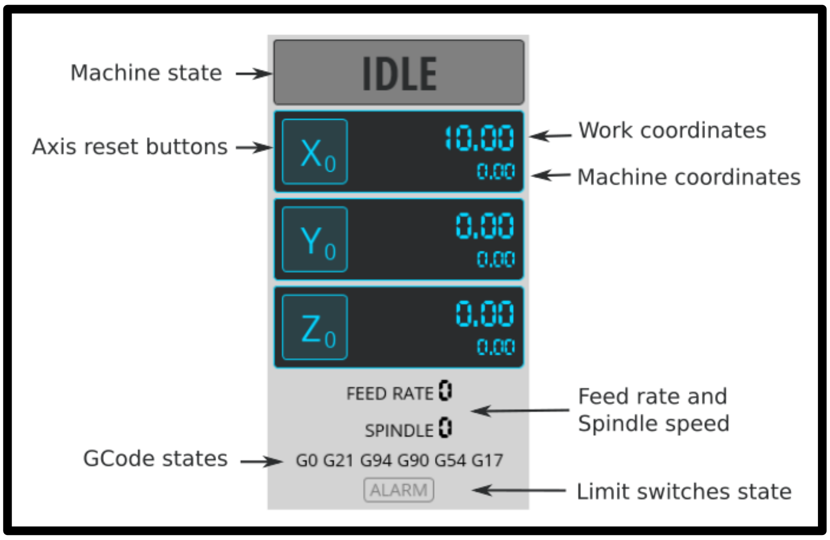


Figure 5.10: Controller State Panel

The panel provides the following functions:

- Coordinates of the machine and the current work
- Buttons for resetting the work coordinates for each axis
- Changeable work coordinates using simple mathematical expressions
- Display the current machine state (Idle, Run, Jog, Alarm, etc.)
- Display the different GCODE states
- Display alarm with the triggered limit switches

6 Integrated System Working

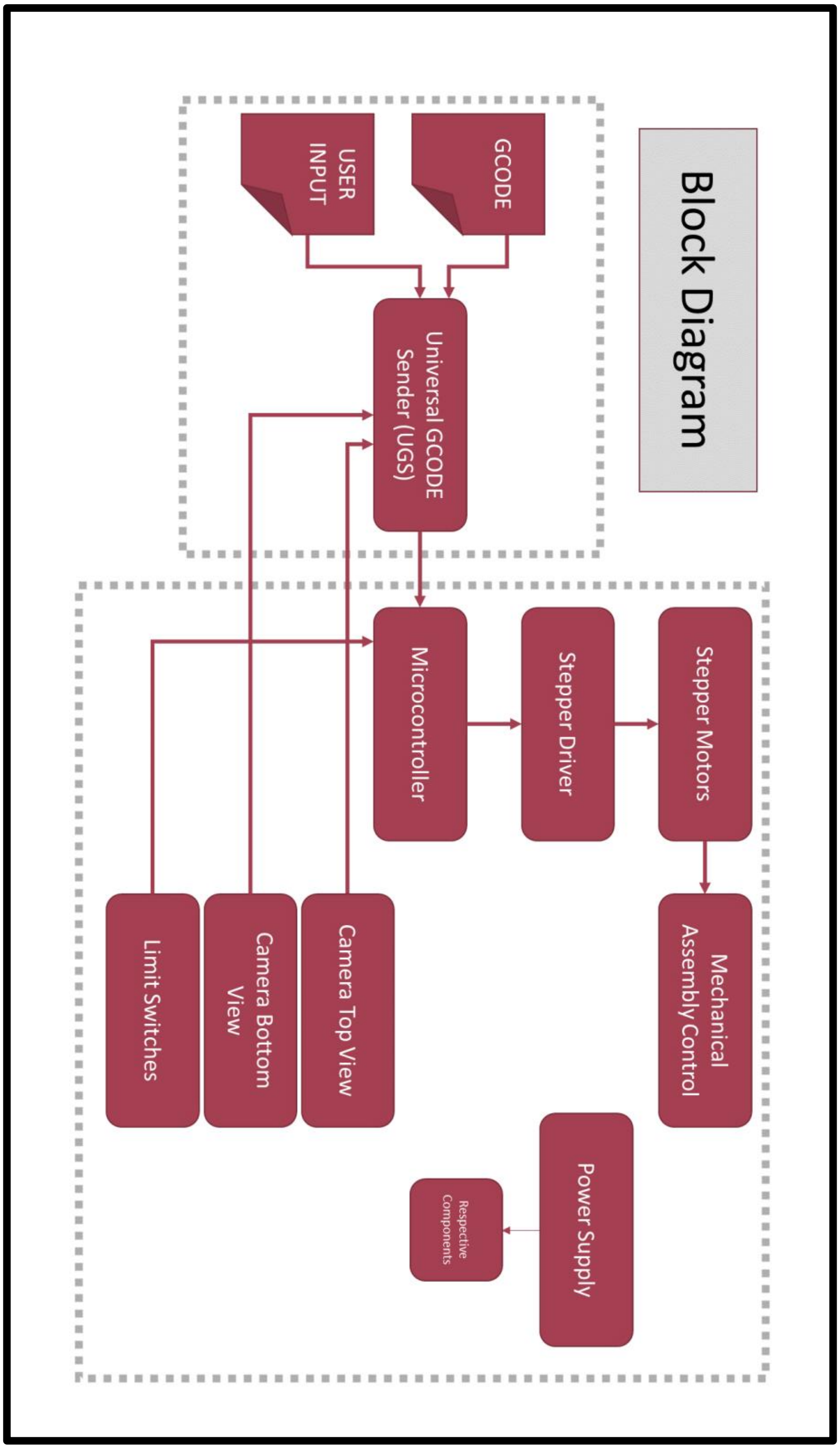


Figure 5.1: Block Diagram of Integrated System Working

7 3D-Printing and Procurement

7.1 Printing Technology Selection

The following section presents a brief comparison between the most common and economically available printing technologies, namely FDM (Fused Deposition Modeling) and SLA (Stereolithography).

Parameter	Stereolithography	Fused Deposition Modeling
Method	UV Curing	Extrusion of Melted Filament
Material Printed	Resin/ Photocurable liquid materials	Thermoplastic polymer string (Filament) i.e PLA, ABS
Advantages	High Print Resolution	Low Cost
	High Process Automation	Less Printing Time
Disadvantages	Narrow Material Variety	Need for support structures
	High Maintenance Cost	Thermal Shrinkage of Filament
Applications	Complex internal geometry prototypes	Fast Prototyping
		Education
	Dental Prototypes	Low Volume Production
Layer Thickness	0.05mm – 0.15mm	0.1mm – 0.30mm

Table 7.1: Selecting Printer Technology

Final selection: Fused Deposition Modelling (FDM)

Criteria for selection:

- One major reason for selection of FDM is its low procurement, maintenance and running costs.
- FDM Raw materials are major PLA and ABS which are not only more economical but also carbon friendly. Especially with PLA which is easy to recycle as well as degradable, thus ensuring that the machine leaves minimal carbon footprint.
- FDM Printers have higher printing speeds.

- Since the project required no micro parts or parts with micro-meter precision, FDMs offering a resolution of 0.1mm were sufficient for the prototypes.

7.2 Material Used

Once the printing technology was finalized as FDM, the selection of filament was done. The most commonly available filament materials are:

- ABS (Acrylonitrile Butadiene Styrene)
- PLA (Poly-Lactic Acid)

Properties	ABS	PLA
Tensile Strength	27 MPa	37 MPa
Elongation	3.55 – 50%	6%
Flexural Modulus	2.1 – 7.6 GPa	4 GPa
Density	1.0 – 1.4 g/cm^3	1.3 g/cm^3
Melting Point	N/A (amorphous)	173º C
Biodegradable	No	Yes
Glass Transition Temperature	105º C	60º C
Spool Price	₹1,199	₹799
Common Products	LEGO, Electronic Housing	Cups, Plastic Bags, Cutlery

Table 7.2: Comparison between the Two Materials

Final Selection: PLA Filament Spool (Poly-Lactic Acid)

Reasons for selection:

- More Tensile Strength
- Density Similar to PLA
- Fixed Melting Point, giving consistent results even with low end 3D printers.
- Biodegradable and easily recyclable.
- Very economic for non-moving structural parts.

7.3 Printer Used

As observed in the previous sections, a substantial number of parts of the project were designed from scratch and often required multiple iterations with numerous trial and errors. To ensure that there is a swift development cycle followed, the 3d printing was done using a personal table-top 3D Printer, namely the Ender 3.

NOTE: *The reason for selections for the ENDER 3 Printer have been omitted since the selection was purely on the basis of non-technical parameters like **cost** and **availability** in India and presence of a wide online community based on this printer which is often termed as a "Hobby 3D Printer".*

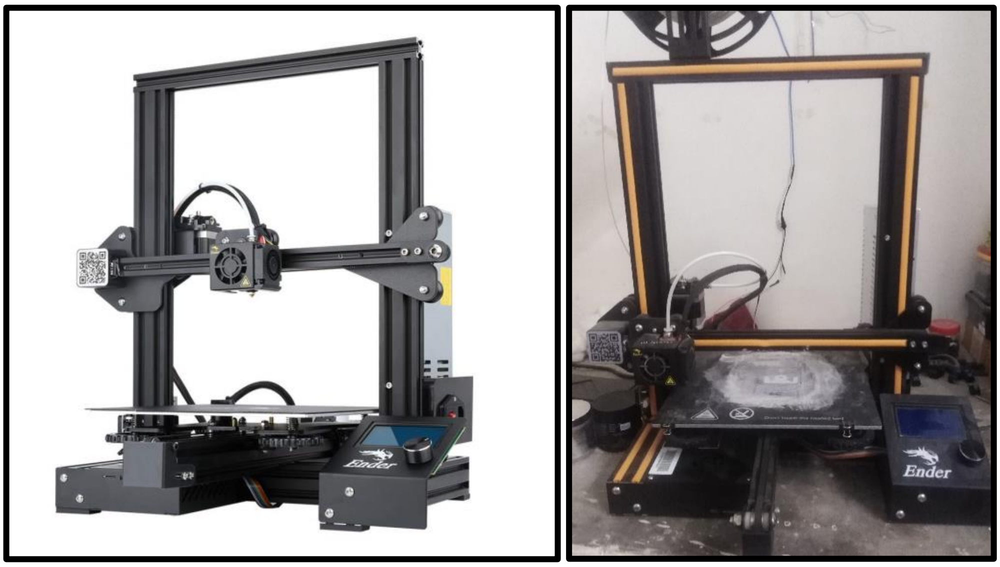


Figure 7.1: Ender 3 Printer

The Ender 3 is a low-cost printer from Creality. It is based on the extremely popular CR10 design from the same company, but in a smaller footprint. It uses aluminium extrusions to build a solid frame to attach all the parts, and V-Slot wheels to move bed, gantry and print.

Printing Technology	FDM
Build Volume	220 x 220 x 250mm
Chassis Size (Desk Space Required)	440 x 410 x 465mm
Filament Diameter Compatibility	1.75mm
Extruder Style	Bowden-Style
Stock Nozzle	0.4mm MK8 Nozzle

Stock Hotend Assembly	Creality MK10 Hotend Assembly (24V Version)
Maximum Hotend Temperature	260°C
Print Platform Style	Aluminium Bed with Creality BuildTak
Print Platform Max Temperature	110°C
Printing Speed (Stable)	50mm/s
Printing Speed (Max)	70mm/s
Layer Height (Resolution)	0.1 to 0.4mm
Motherboard / Primary Controller	Creality3D V1.1.2 Mainboard
User Interface	LCD Display with Rotary Encoder
Slicing Software Compatibility	Cura / Simplify3D / Slic3r / Repetier Host
File Format Compatibility	STL / OBJ / DAE / AMF
File Transfer Method	Micro SD Card / Micro USB
Bed Levelling System	Manual / Large Adjustable Corner Screws
Print Resume Functionality	Included
Filament Runout Sensor	Not Included
Chassis Materials	Black Anodised Aluminium / V-Slot Extrusion
Included 3D Printing Filament	±5m Test Filament - Silky White
Weight (Printer)	8kg
Weight (Package)	8.6kg
Operating Voltage	24V
Power Supply Input	110V/220V AC
Power Supply Output	24V, 15A, 360W

Table 7.3: Printer Specifications

7.4 Slicing Software Used

All the parts were modelled in Sketchup 2022 and Fusion 360, to process these parts in the 3D printer, and STL file is generated and then processed through a “Slicing” Software.

The Slicer converts the said STL file to a 3D-Printer compatible file, known as a GCODE File. This GCODE File can be processed by the motherboard of the 3D Printer and accordingly control the machine to process the print.

The Slicer most efficient with the Ender 3 is the “Ultimater Cura Slicer”.

Cura is an open-source slicing application for 3D printers. Cura is available under LGPLv3 license. Cura was initially released under the open source Affero General Public License version 3, but on 28 September 2017 the license was changed to LGPLv3. This change allowed for more integration with third-party CAD applications. Development is hosted on GitHub. Ultimaker Cura is used by over one million users worldwide and handles 1.4 million print jobs per week. It is the preferred 3D printing software for Ultimaker 3D printers, but it can be used with other printers as well.

Ultimaker Cura works by slicing the user's model file into layers and generating a printer-specific g-code. Once finished, the g-code can be sent to the printer for the manufacture of the physical object.

The open-source software, compatible with most desktop 3D printers, can work with files in the most common 3D formats such as STL, OBJ, X3D, 3MF as well as image file formats such as BMP, GIF, JPG, and PNG.

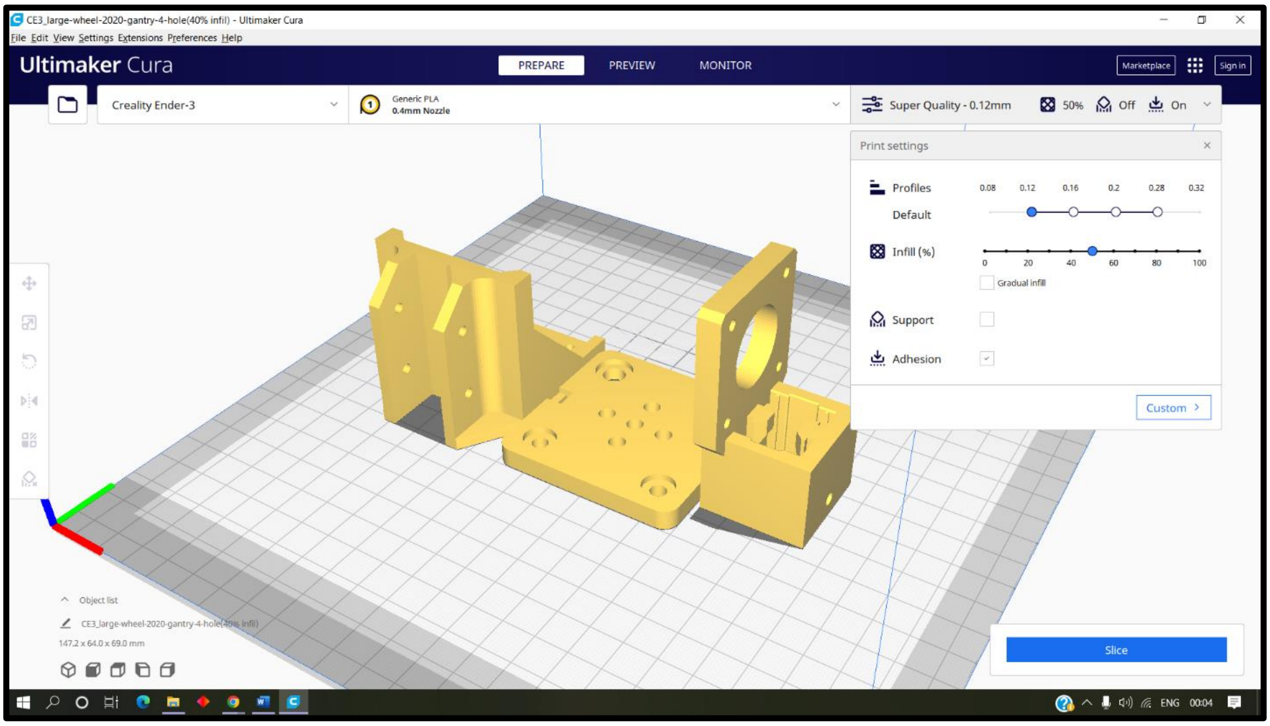


Figure 7.2: Preview of 3D Model of Motor Mounts and Gantry in Cura Slicer

7.5 Print settings for 3D printed parts

Cura offers the user to customize on a plethora of print settings, while most of the settings are only adjusted when fine tuning of the printer is required, the major settings to be adjusted while slicing the model are "INFILL Density" and Layer Height. Both the settings greatly affect the print time and strength of the print.

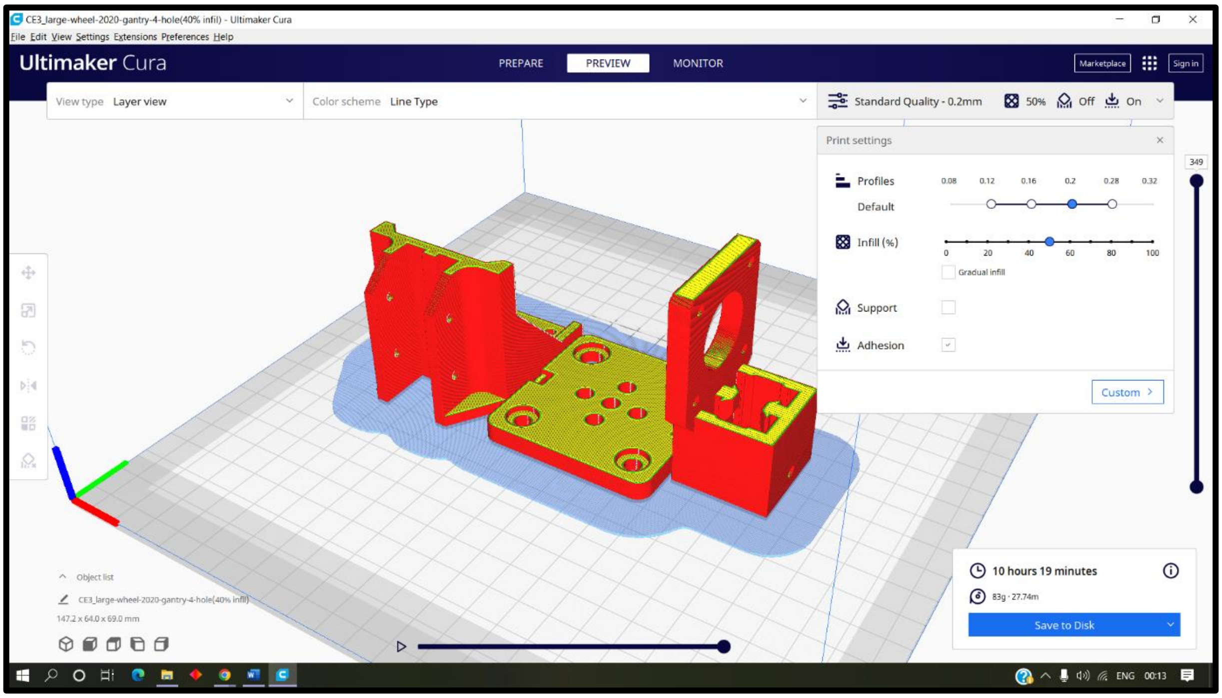


Figure 7.3: GCODE Preview in Slicer

For larger parts a **50% infill density** has been opted to ensure optimal usage of the filament. And a large **layer height of 0.2mm** to increase the print speed and reduce the time required for reprints in the scenario of multiple iterations.

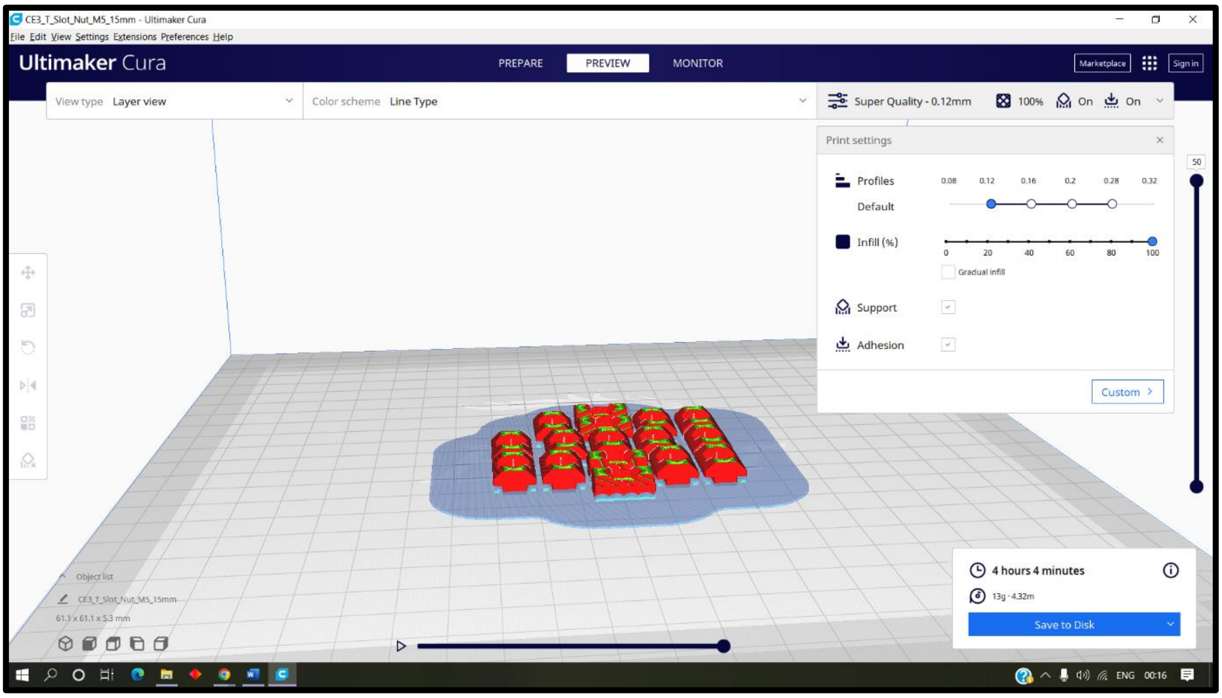


Figure 7.4: GCODE Preview of T-Nuts

For Smaller parts, a **100% infill density** was selected to maintain strength of the parts. Along with this, a minimal **layer height of 0.12mm** was opted. Using the specified print settings on the slicer, the G-Code for all the required parts was fed into the Ender 3 printer.

After multiple batches of print, several design iterations, all the 3D printed parts have been finalized.

7.6 Procurement of Pre-Fabricated Components

To reduce the cost of the overall machine as well as to adopt and indigenous design approach, a number of parts of the machine were 3D printed. In various instances 3D printing the required part was seen as an unviable option, due to the one or more of the following reasons: -

- Limited strength of the 3D Printed material especially in structural requirements like Extrusion Rods making up the frame.
- Precision, Smoothness and Consistency Requirements in parts like bearings, wheels.
- High Strength requirements in parts like screws and nuts.

A major portion of this hardware procurement was from the following Suppliers

- Novo3D.in, based in Coimbatore
- Robu.in, based in Pune

Invoices of the purchases made have been attached in Annexure 3.

The Hardware Parts thus ordered were:

1.	Delrin V Wheels	12 units
2.	Aluminium Extrusions	6 Meters
3.	Eccentric Spacers	6 units
4.	M5 Spacers	7 units
5.	GT2 Timing Belt	4 Meters
6.	GT2 Pulley	3 units
7.	M8 Linear Bearing	1 units
8.	M5 Loc Nuts	15 units
9.	PLA Filament Spool	1 KG
10.	M8 Smooth Steel Rod	380 mm
11.	M10 Bearing	1 units
12.	M5 Bearing (625)	5 units
13.	M4 T-Nuts	10 units
14.	Misc. Screws and Nuts	

8 Frame Construction and Assembly

Based on the design of the machine, the 3D printed and the procured parts are assembled using various mechanical tools. These tools have been listed in this section as well as photographs of the machine assembly have been attached.

8.1 Tools Used

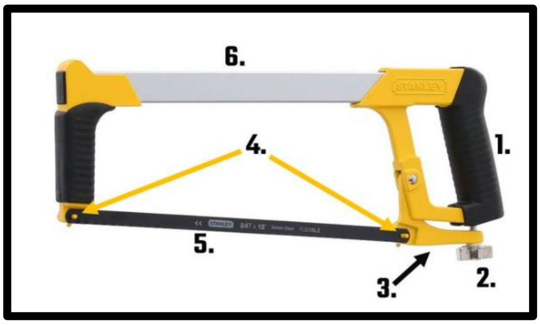


Figure 8.2: Hand Hex Saw

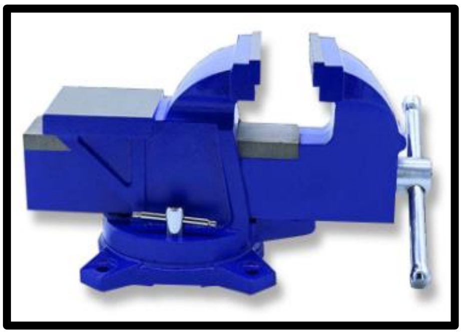


Figure 8.1: Bench Vice

Figure 8.3: Allen keys

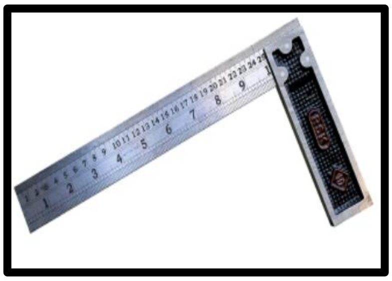


Figure 8.4: Tri-Square

8.2 Images Of the Assembly

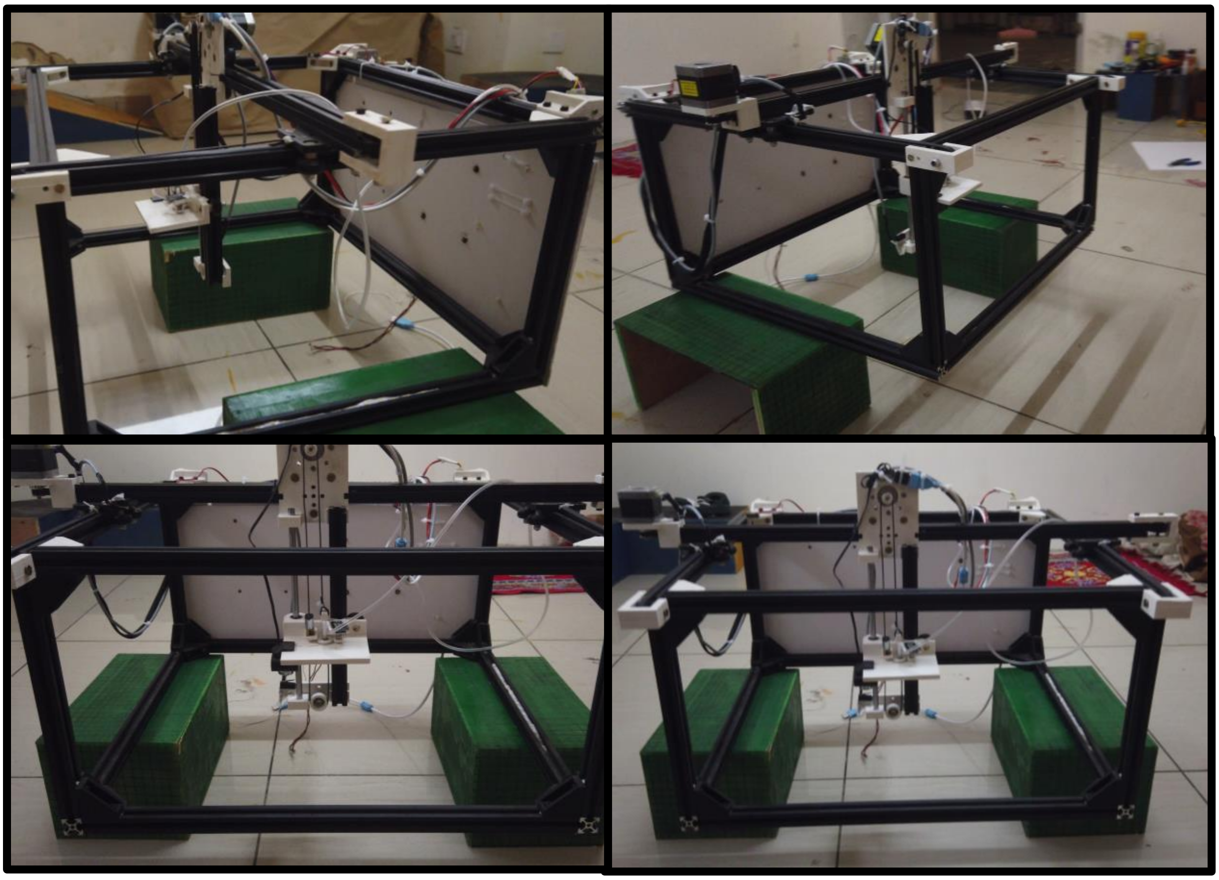


Figure 8.3: Images of the Assembly

9 PCB Design and Fabrication

9.1 PCB Design

Software Used: EAGLE

EAGLE is an electronic design automation (EDA) software that lets printed circuit board (PCB) designers seamlessly connect schematic diagrams, component placement, PCB routing, and comprehensive library content.

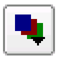
EAGLE's Layers

The EAGLE board designer has layers just like an actual PCB, and they overlap too. A palette of colours is used to represent the different layers. Layers worked upon in the board designer are:

Colour	Layer Name	Layer Number	Layer Purpose
	Top	1	Top layer of **copper**
	Bottom	16	Bottom layer of **copper**
	Pads	17	Through-hole pads. Any part of the green circle is exposed **copper** on *both* top and bottom sides of the board.
	Vias	18	Vias. Smaller copper-filled drill holes used to route a signal from top to bottom side. These are usually covered over by soldermask. Also indicates **copper** on both layers.
	Unrouted	19	Airwires. Rubber-band-like lines that show which pads need to be connected.
	Dimension	20	Outline of the board.
	tPlace	21	**Silkscreen** printed on the top side of the board.
	bPlace	22	**Silkscreen** printed on the bottom side of the board.
	tOrigins	23	Top origins, which is clicked to move and manipulate an individual part.
	bOrigins	24	Origins for parts on the bottom side of the board.
/ / **Hatch**	tStop	29	Top stopmask. These define where **soldermask** should *not* be applied.
\ \ **Hatch**	bStop	30	Absent0020**soldermask** on the bottom side of the board.

	Holes	45	Non-conducting (not a via or pad) holes. These are usually drill holes for stand-offs or for special part requirements.
	tDocu	51	Top documentation layer. Just for reference. This might show the outline of a part, or other useful information.

Table 9.1: Layers in EAGLE Software

To turn any layer off or on, the "Layer Settings" button  is selected and then a layer's number is selected or deselected.

Steps:

- *Schematic Design*

The schematic design as discussed in the Section 4.5 has been used for the fabrication of the PCB.

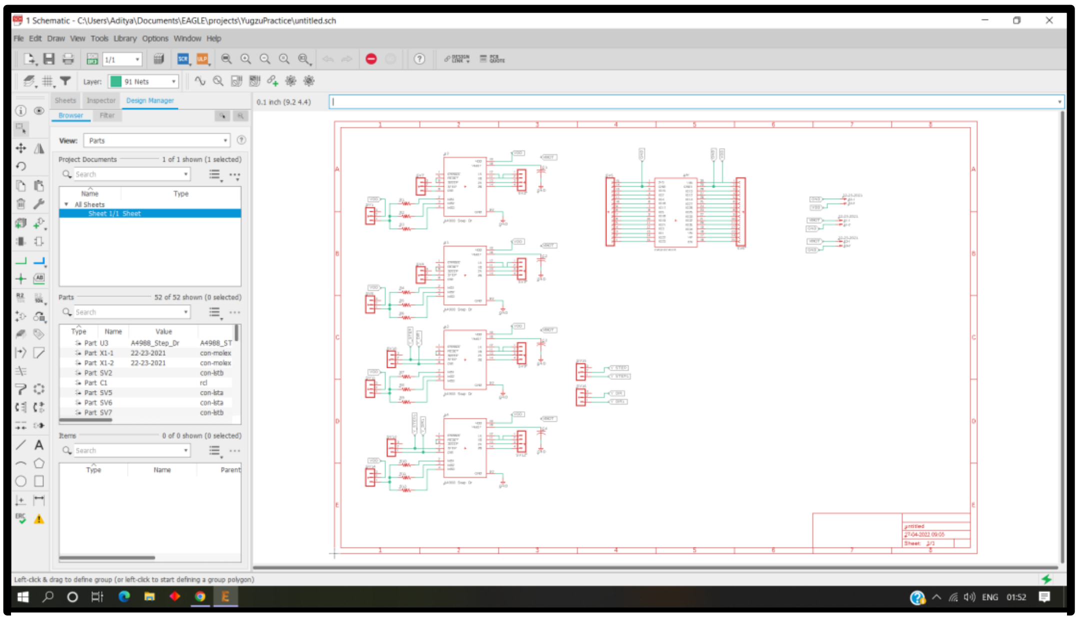
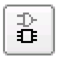


Figure 9.1: Schematic

- *Board Layout from Schematic*

Generate/Switch to Board icon --  -- in the schematic editor is used to create a new PCB design based on schematic. The new board file shows all of the parts from the schematic. The black space is the board area. The gold lines, called airwires, connect between pins and reflect the net connections made on the schematic.

- *Setting Granularity of Grid:*

Grid size is important because EAGLE forces the parts, traces, and other objects to snap to the grid defined in the *Size* box. If finer control is desired, ALT key is pressed to access the **alternate grid**, which is defined in the *Alt* box. The grid is visible in the board editor.

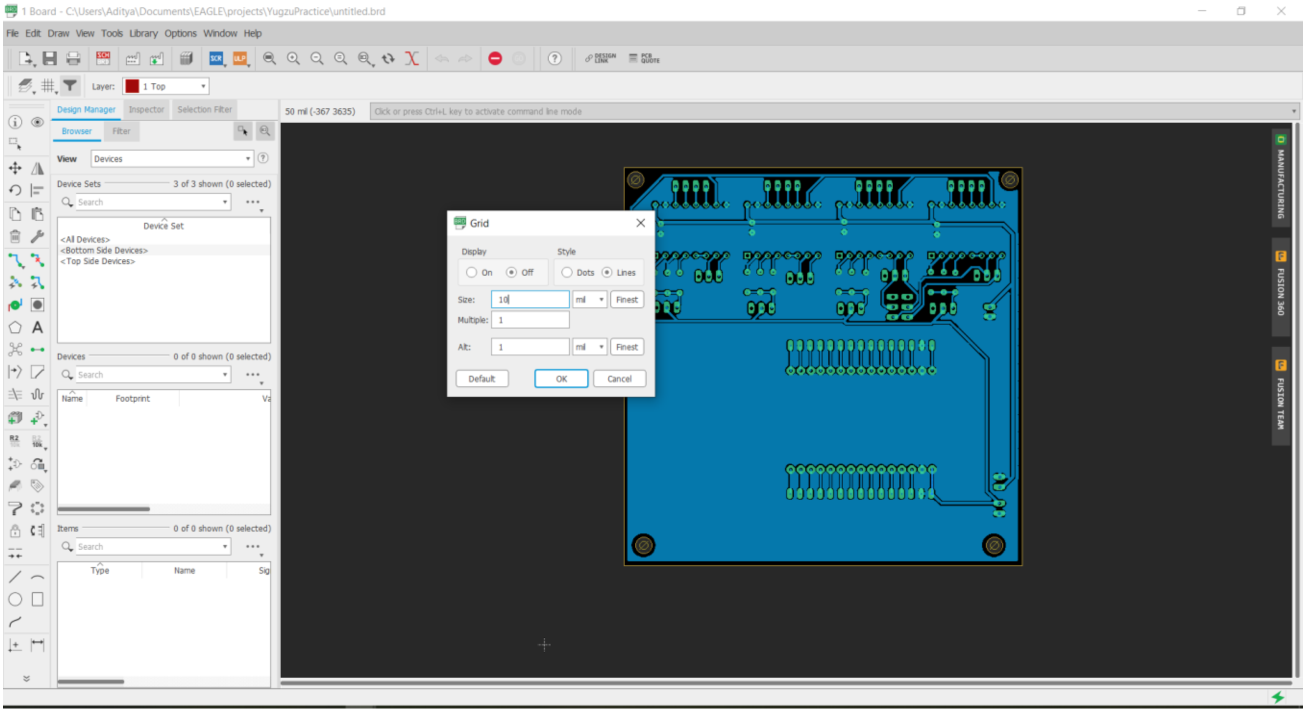


Figure 9.2: Granularity of Grid

Grid Size used: 10 mil

Alternate Grid Size used: 1 mil

Reason For the Grid Size: 10 mil is equivalent to 0.254 mm, since most of the design has through hole components with a pin distance of 2.54 mm, the gird size is kept in its multiples for ease of design symmetry.

- *Placement of Parts*

Using the MOVE tool -- -- parts are moved within the dimension box. While moving parts, they can be rotated by either right-clicking or changing the angle in the drop-down box near the top. Factors taken into consideration while moving, rotating and placing parts:

- Overlapping of parts avoided: All components need a good amount of clearance between them.
- Intersecting airwires minimized: The airwires move with moving parts. Limiting criss-crossing airwires as much as possible makes routing easier. While relocating parts, RATSNEST button -- – is pressed to recalculate the airwires.

- Part placement requirements: Some parts require special consideration during placement. For example, decoupling capacitors are placed just below the stepper drivers.

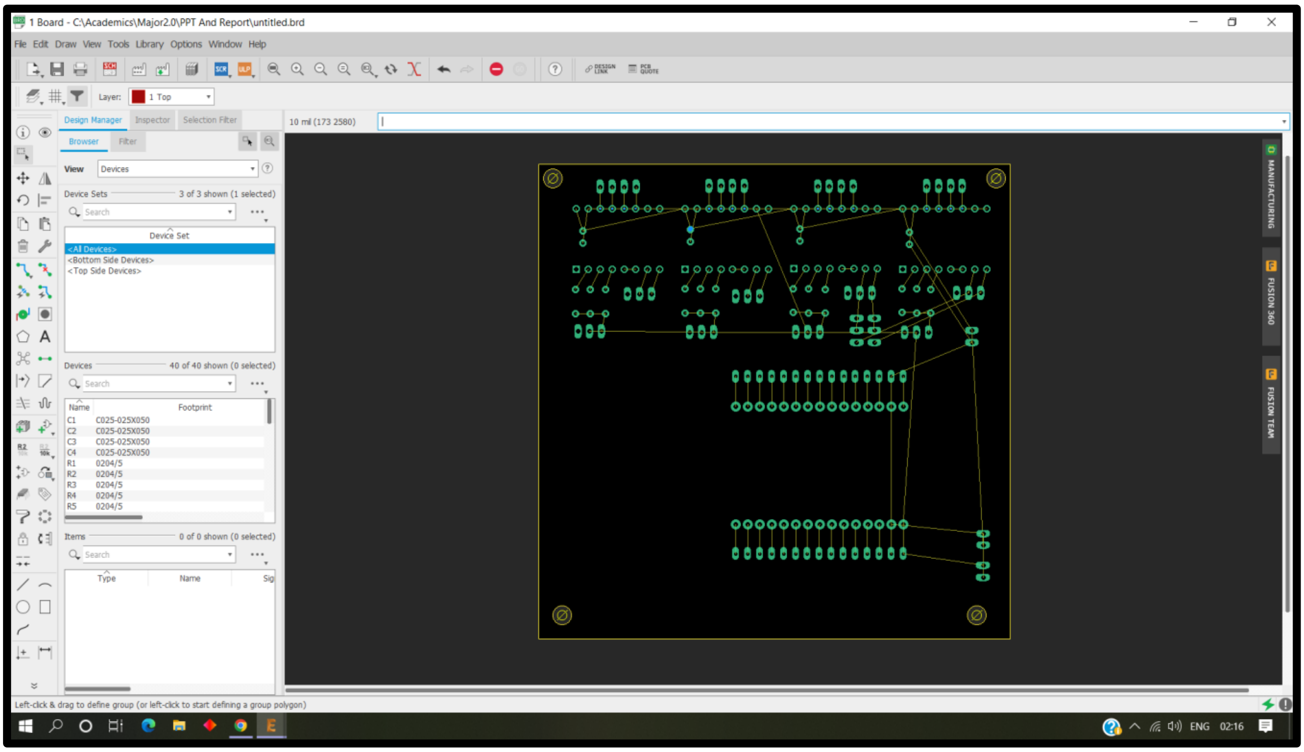


Figure 9.3: Placed, Unrouted Board

- *Adjusting the Dimension Layer*

The length and breadth are adjusted using the Move tool on board outline as per requirement. Extra area has been kept on the Printed Circuit Board to secure it on the Sunboard sheet using screws.

- *Routing the Board*

The gold airwires are turned into bottom copper traces without overlapping two different signals.

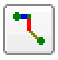
To draw copper traces, the ROUTE tool--  -- is used. After selecting the tool, there are a few options to consider on the toolbar:

Figure 9.4: Toolbar Options for Routing

- **Layer:** Routing is done on the Bottom (16) layer since the Printed Circuit Board is single layered and single sided and components had to be soldered on top side.

- **Bend Style:** 45° angles are used for routes (wire bend styles 1 and 3)
- **Width:** This defines how wide a copper trace will be. Wider traces can allow for more current to safely pass through. For example, the 12V Power trace has to accommodate currents around 5A, therefore it is kept slightly wide compared to other traces.
- **Via Options**: Not required because PCB is single layered.

A route is started by left-clicking on a pin where an airwire terminates. The airwire, and connected pins glow, and a red or blue line starts on the pin. The trace is finished by left-clicking again on top of the other pin the airwire connects to. Between the pins, left-clicks are done to glue a trace down. While routing it's important to avoid copper over copper overlap. The ALT key, which accesses the alternate grid, is pressed to achieve more precise control on the routes. This is set to be a much finer 0.005".

Ripping Up Traces**:** The **RIPUP** tool --  -- is used to go back, re-work a route and remove traces. This tool turns routed traces back into airwires. UNDO and REDO are also used to back/forward-track. The Trace-to-Trace Clearance and Trace Width considerations are discussed in Section 4.6.

Checking for Errors

Tools used to check the design for errors before packaging the design:

- Ratsnest

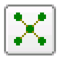
The first check makes sure all nets in the schematic have been routed. RATSNEST icon --  -- is pressed and then the bottom left status box is checked. Since everything is routed, it says "Ratsnest: Nothing to do!"

Figure 9.5: Ratsnest Message

- Design Rule Check

After completing routing, the design rule check (DRC) is done. For this step, the default EAGLE design rules are used. To load up the DRC, the DRC icon --  – is clicked which opens up this dialog:

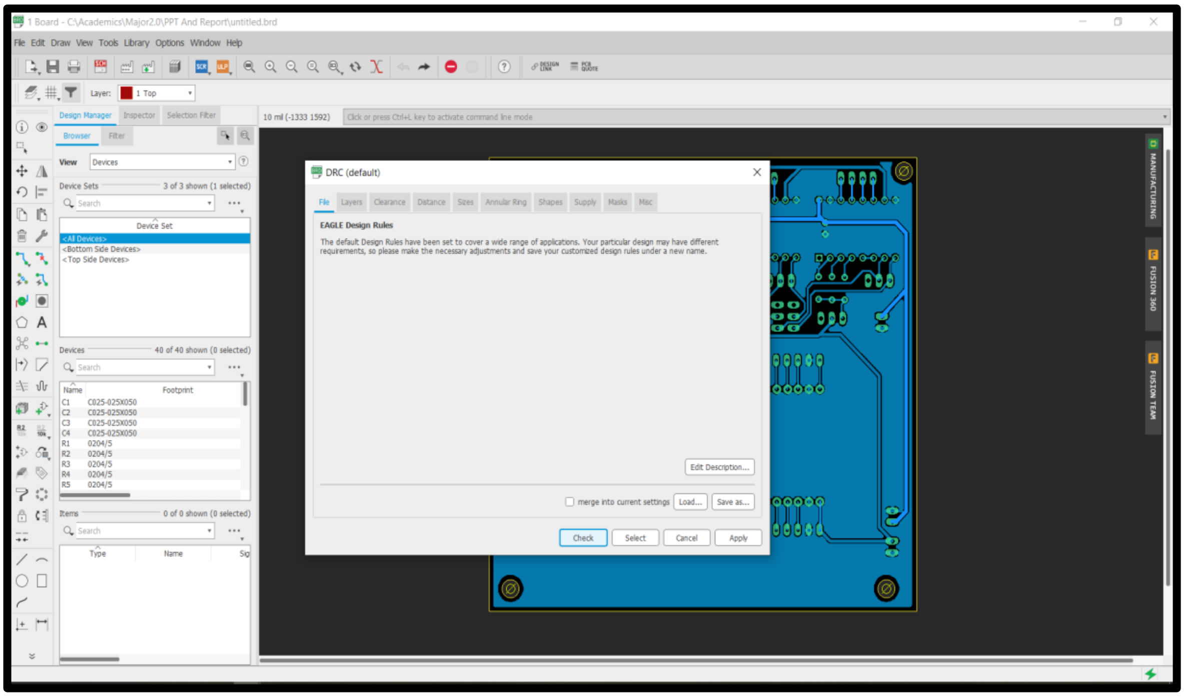


Figure 9.6: DRC Dialog

The tabs in this view (Layers, Clearance, Distance, etc.) help define a huge set of design rules which the layout needs to pass. These rules define things like minimum clearance distances, or trace widths, or drill hole sizes.

In case of Design Rule violations, ‘DRC Errors’ window opens up. The error window lists all of the open errors, and it also highlights where the error is.

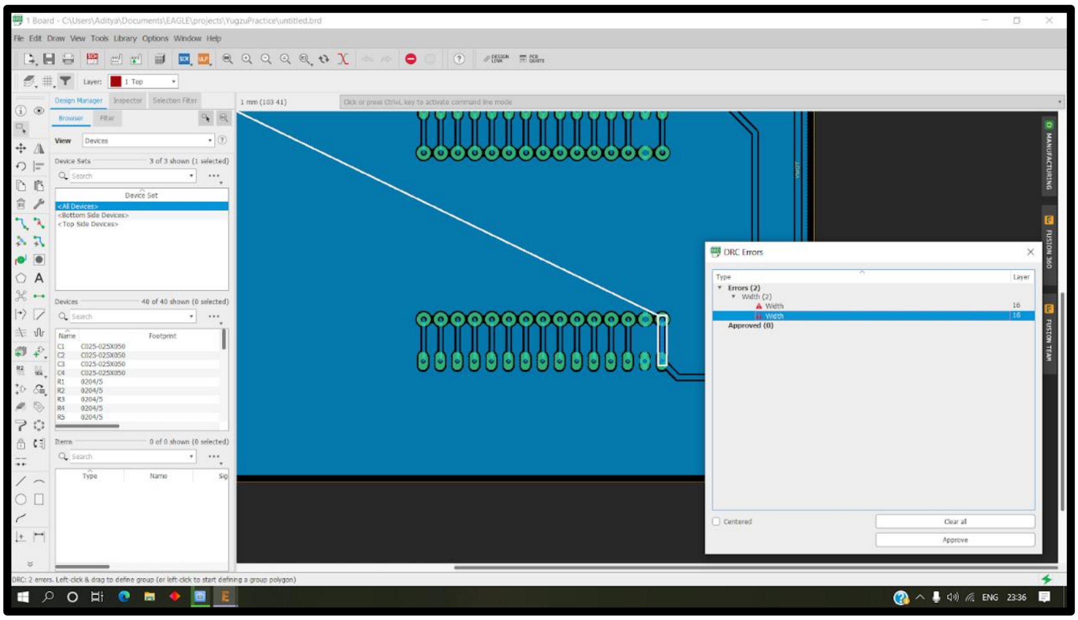


Figure 9.7: Error obtained during Routing

Once both ‘No airwires left!’ & ‘DRC: No errors’ messages are obtained; the next step is performed.

- *Adding Copper Pours*

Copper pours are for the ground signal. The POLYGON tool -- -- is selected and settings are adjusted in the options bar. The bottom copper (16) layer is selected.

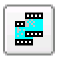
Next, a set of lines is drawn along the dimension box. A dotted red box appears around the dimension of the board. After drawing the polygon, it is connected to a net using the NAME tool -- . This tool is used on the dotted red box and "GND" name is given in the dialog that pops up.

The last step is to **hit ratsnest**, to watch the red pour fill the entire area of the board.

- *Generating Gerbers*

After design finalization, Gerber files are generated. These files describe the copper of every layer in the PCB in a way that a computer-aided manufacturing system (CAM) can understand. Autodesk EAGLE includes a handy computer-aided manufacturing (CAM) processor which is used to load a CAM file and generate specific files required for the design. Each Gerber file describes a single layer of the PCB. In all, 4 Gerber files are generated for this design which are: Top Copper layer, Board Outline layer, Drills layer and Holes layer.

Steps followed:

- Open PCB layout (.brd) file in the Autodesk EAGLE Control Panel.
- Select the CAM Processor --  -- tool at the top of interface or select File » CAM Processor to open the CAM Processor dialog.
- Loading a CAM job: Select File » Open » Job. Then navigate to default EAGLE cam folder, choose the gerb274x.cam file, select Open.
- Some new tabs are added to each CAM file that will be generated with this job. Select the Process Job button to create all Gerber files.

All of these new Gerber files are listed alongside existing project files in Autodesk EAGLE Control Panel.

- *Generating Drill Files*

While the Gerber files generated contain all of the details a manufacturer needs to know about individual layers, what they don't include is information about drill holes. A file is now needed that will specify the location and size of each drill hole.

The process for making this file in Autodesk EAGLE is:

1. Select the CAM Processor -- -- tool at the top of interface or select File » CAM Processor to open the CAM processor dialog.
2. Load a drill CAM job to get things started. Select File » Open » Job and in the default EAGLE cam folder select the excellon.cam file, then select Open.
3. A single Generate drill data tab will be available, which will grab the data from layers 44 Drills and 45 Holes. Select the Process Job button to generate this file.

Loading the Excellon CAM job will create an NC Drill File based on Drill and Hole layer data. Just like Gerber files, NC Drill File will be stored in the project folder that can be accessed through the Autodesk EAGLE Control Panel or folder directory. It will be a .drd file.

9.2 Fabrication

Software Used: LPKF CircuitPro PM

Machine Used: LPKF ProtoMat S103

The CircuitPro PM user interface is divided into several information and display panes that can be displayed or hidden as necessary. The user interface is structured as follows:

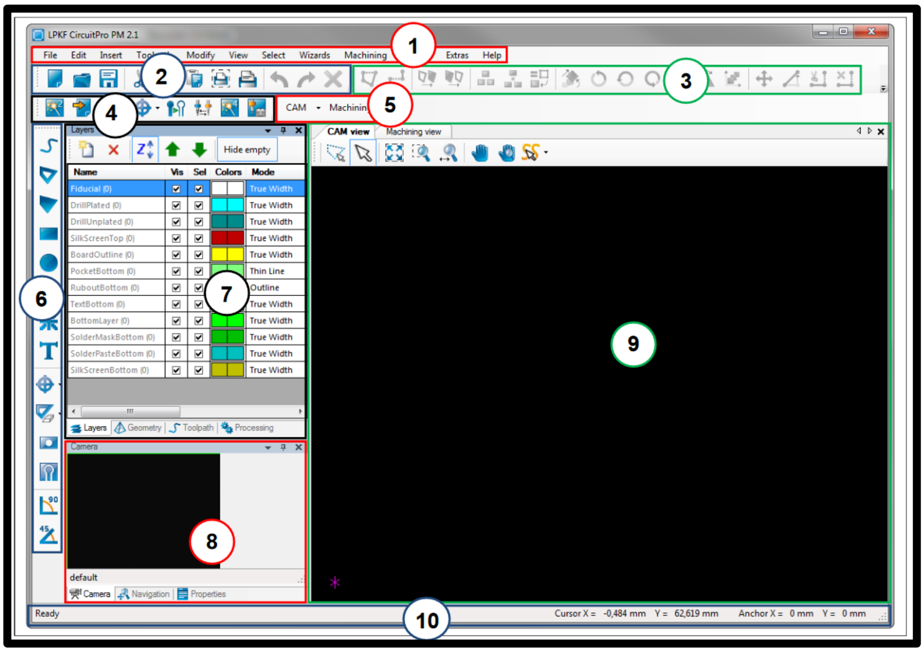


Figure 9.8: User Interface of CircuitPro

No.	Pane	Name
1.		Menu bar
2.		“Standard” toolbar
3.		“Modify” toolbar
4.		“Prototyping” toolbar
5.		“Layouts” toolbar
6.		“Insert” toolbar
7.	Layers	The “Layers” pane contains a table listing the individual layers of the circuit board to be processed.
8.	Navigation	The “Navigation” pane displays an overview of the project with a zoom rectangle.
9.	CAM view	Editing pane displaying a 2D representation of the project.
10.	Status bar	The status bar displays the coordinates of the current cursor position and of the anchor point. Measurement results are displayed in the “Length” field.

Table 9.2: Panes in User Interface

Steps:

1. Open the software LPKF CircuitPro PM. Click on File > New.
2. Select the tab “Templates”. The dialog of the templates available in CircuitPro PM is displayed.

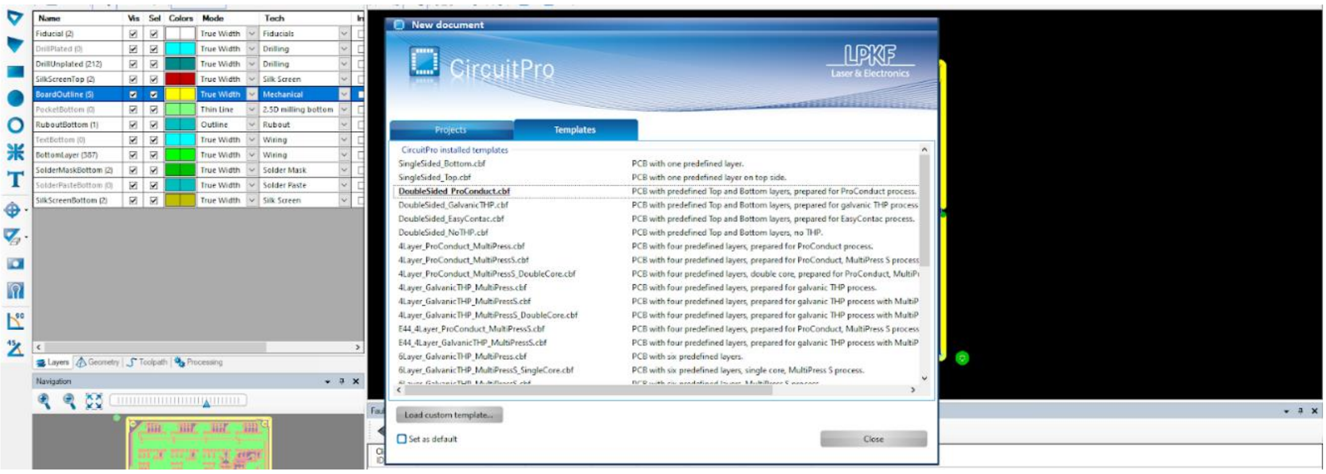


Figure 9.9: The dialog of available templates

3. Select the template ‘SingleSided_Bottom.cbf’. It is a PCB with one predefined layer on the bottom side. A new document is created based on the selected template.
4. Click on Wizards (on the Menu Bar) > Process planning wizard…

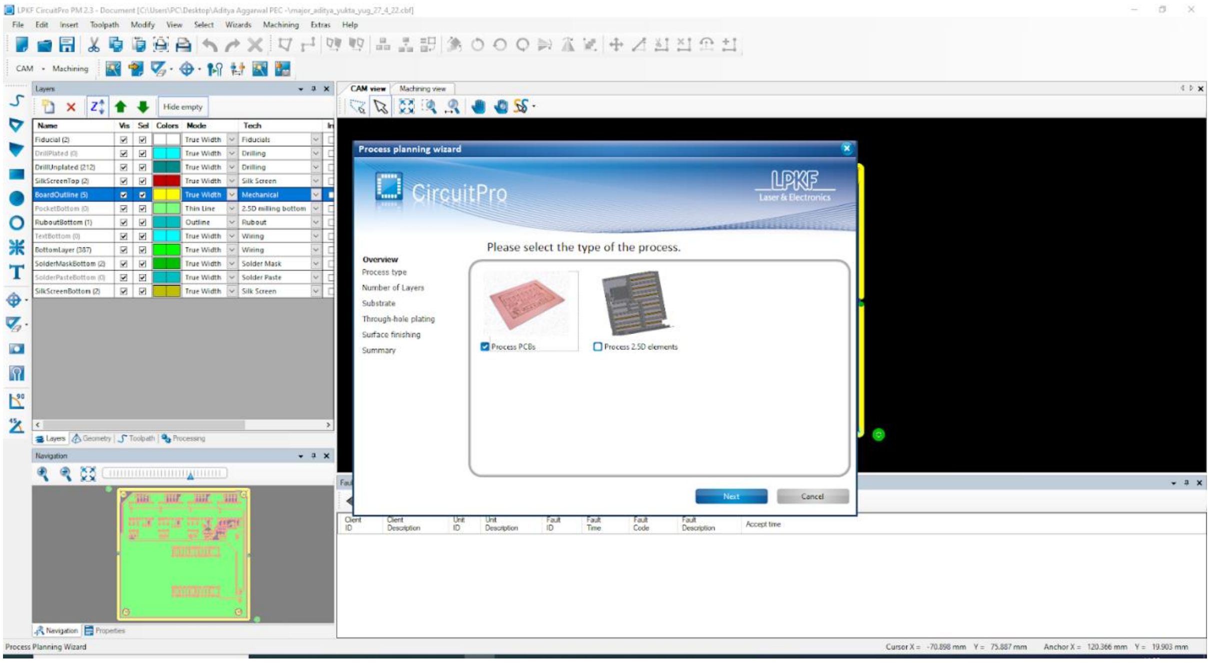


Figure 9.10: Process Planning Wizard

5. Select ‘Process PCBs’ and click the Next button.
6. Select ‘Single sided bottom’ from the ‘Number of layers’ tab.

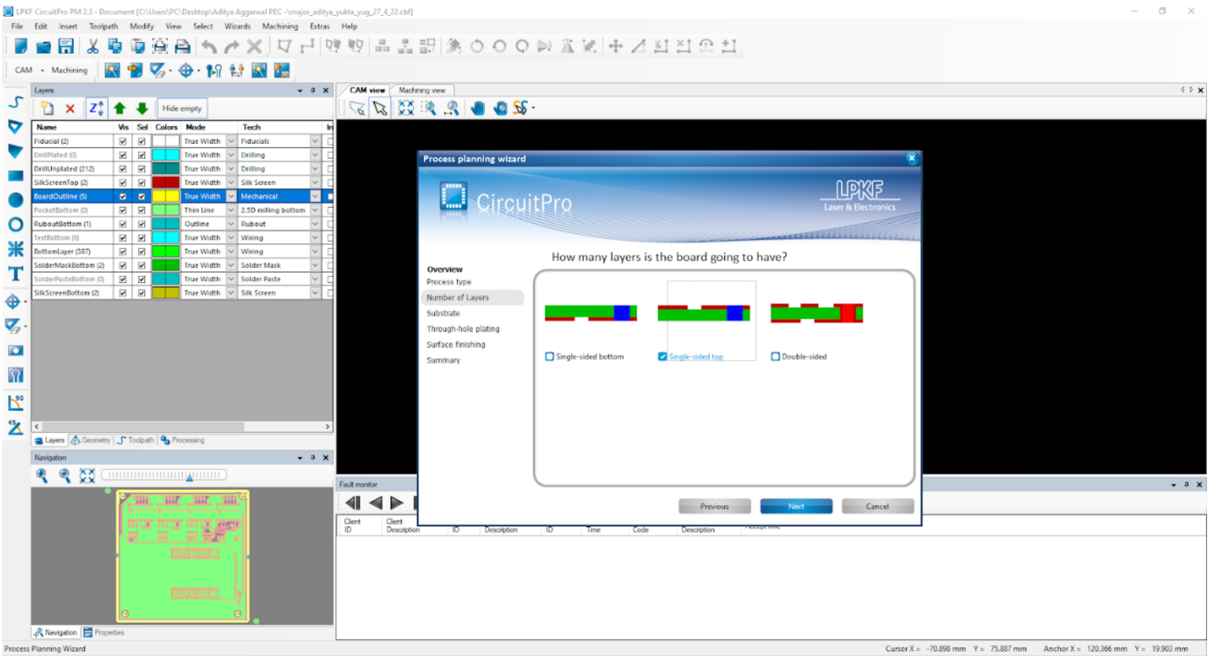


Figure 9.11: Selecting Number of Layers in Process Planning Wizard

7. Select ‘FR4/FR5’ from the ‘Substrate’ tab.

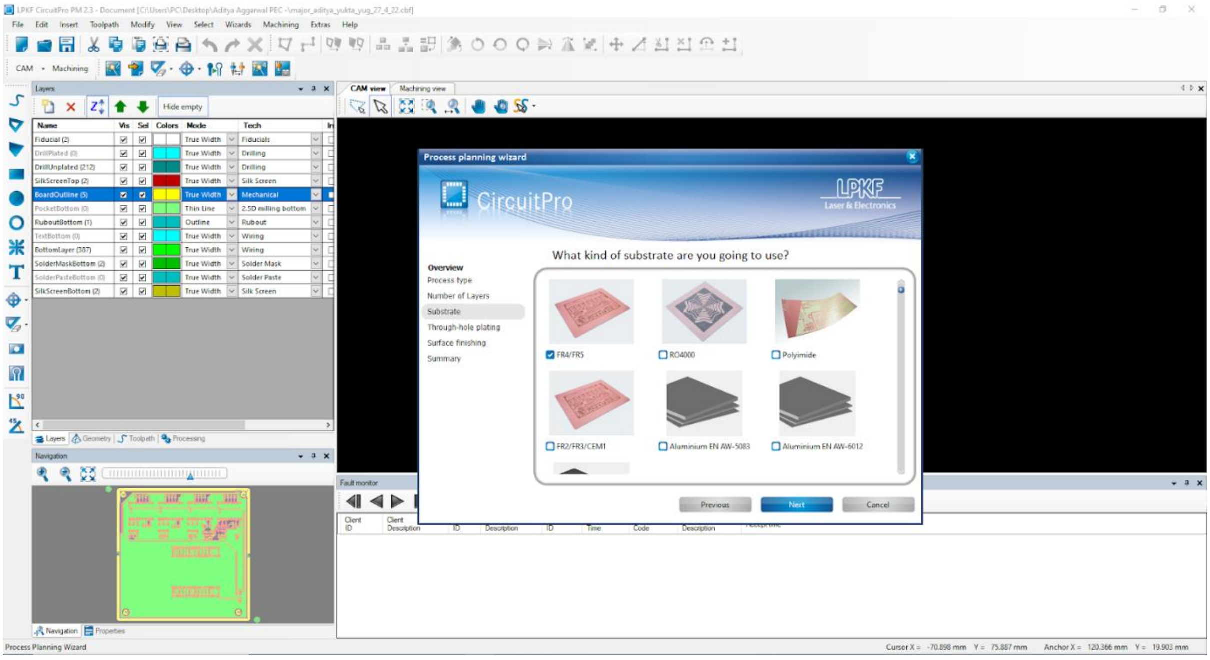


Figure 9.12: Substrate Selection

8. Summary of process is displayed. Click on the ‘Done’ button.
9. Click on ‘Import’ which is the 2nd icon on the Prototyping Toolbar.

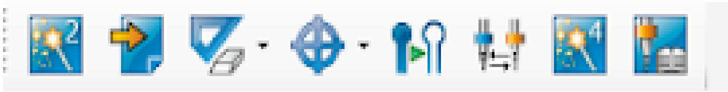


Figure 9.13: Prototyping Toolbar

10. Select required Gerber Files and click Open.

Figure 9.14: Matched Copper Bottom Layer

Match the Layers with the correct Gerber Files. Remove any unnecessary files. In this case, silkscreen and soldermask files were removed.

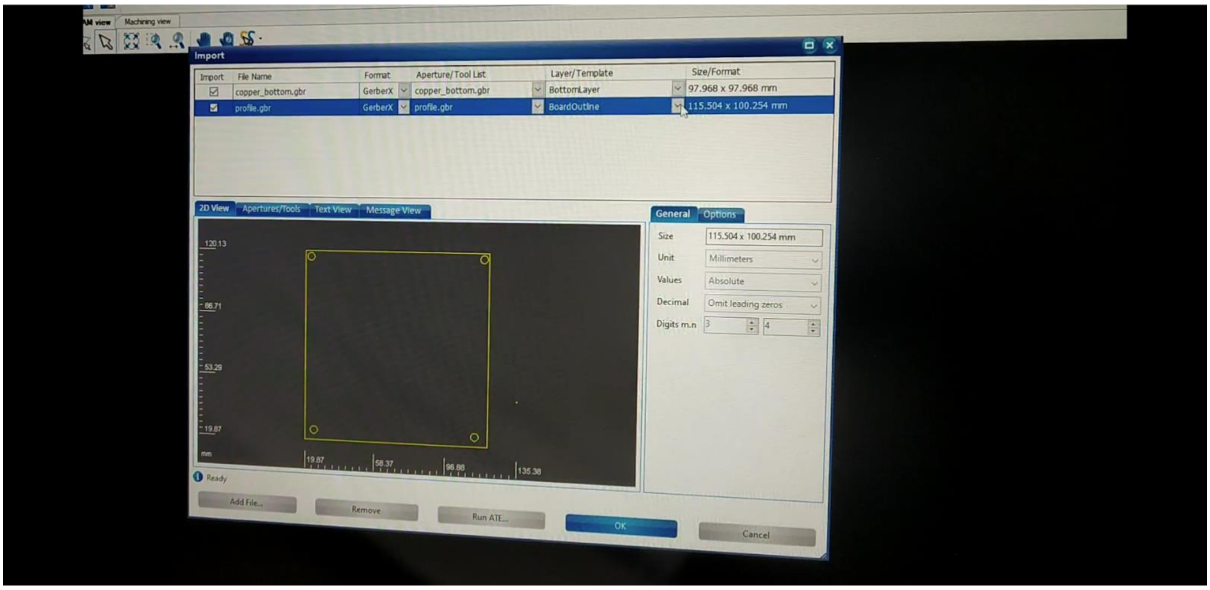


Figure 9.15: Matched Board Outline Layer

11. Using the 'Measure' menu item from the 'Edit' menu, diameter of drill hole is measured to be 4mm. In the CAM view, click on the starting point from which to measure. Move the mouse to the second point in order to measure the distance. The mouse cursor draws a line. Read the length of the line from the status bar of CircuitPro PM.
12. Dimensions of board are found to be 100mm * 100mm by using Create Rectangle tool from Insert menu in the same way as Measure tool.

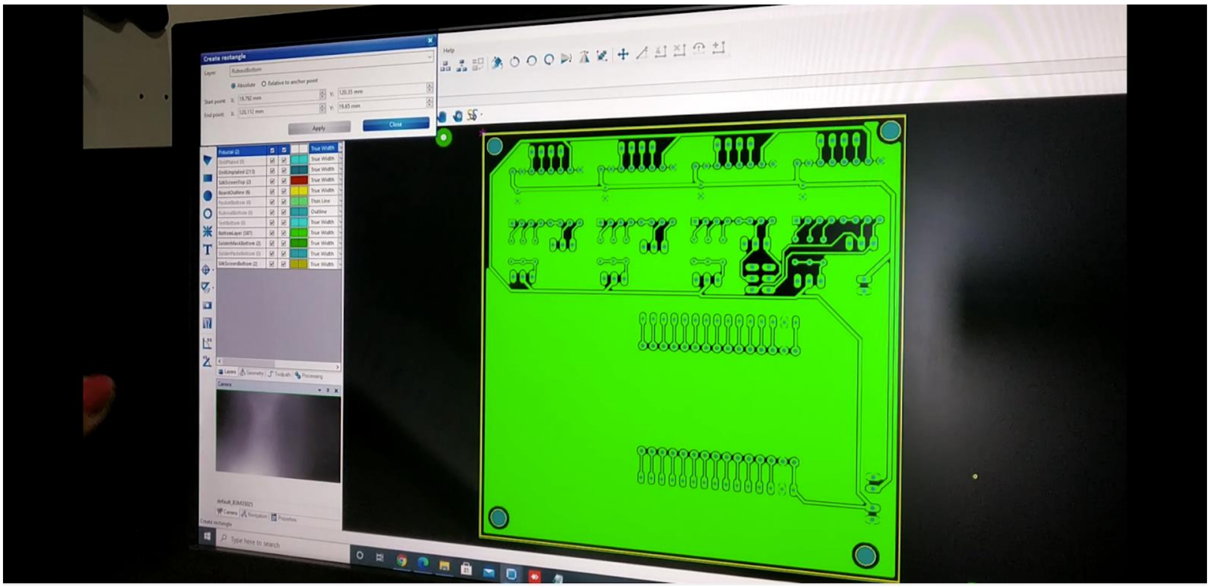


Figure 9.16: Measuring using Rectangle Tool

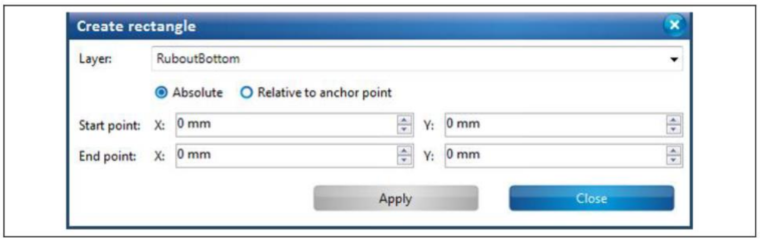


Figure 9.17: Create Rectangle Dialog Box

13. Next step is to create toolpaths that can be used in processing for the following steps:

    • Isolate

    • Contour routing

    • Drilling holes

    • Drilling fiducials

    • Milling pockets

For that, Click on Toolpath > Technology Dialog.

<u>Material Type: FR4.</u>

<u>Insulation Method: Partial Rubout</u>

<u>Contour Routing Method: Vertical Gaps</u>

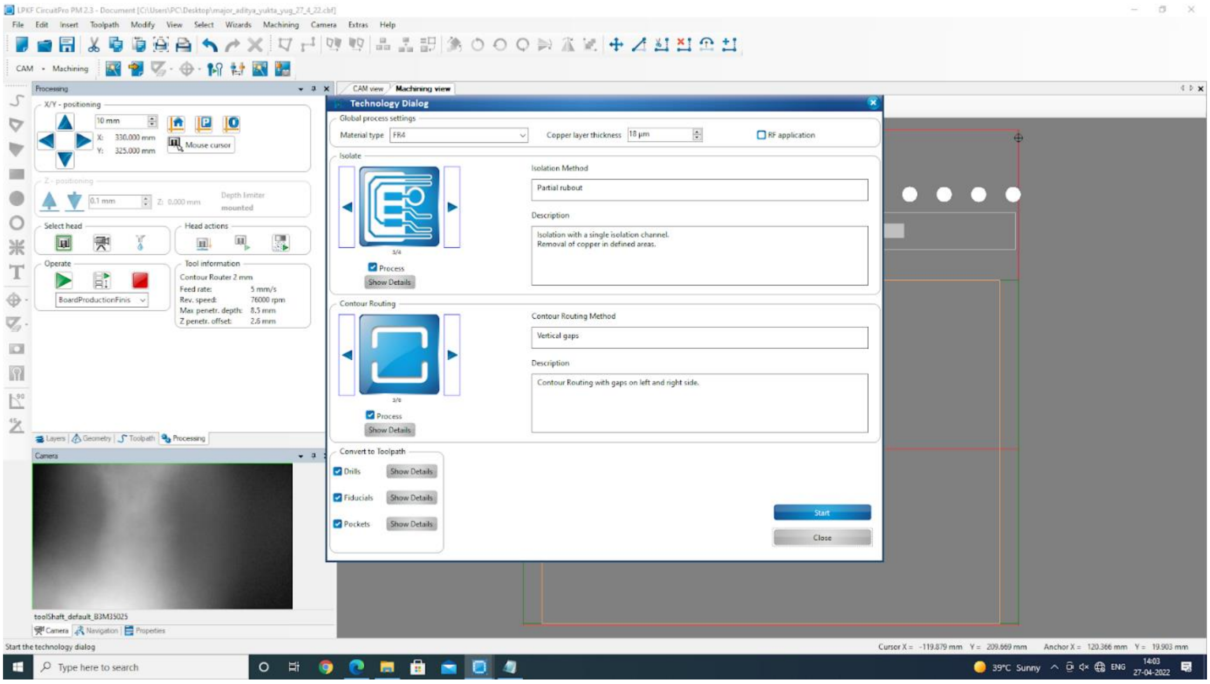


Figure 9.18: Technology Dialog

- Isolate milling is the process of removing not needed copper from coated base material by surface milling.

  Partial rubout: Isolation with a single insulation channel and removal of copper in defined areas.

- Contour routing of a PCB is a process to cut out the final PCB from the surrounding material. This is done by milling along the outline of the PCB.

  Vertical gaps: Contour routing with breakout tabs on left and right side.

14. Click on start and view the computation results.

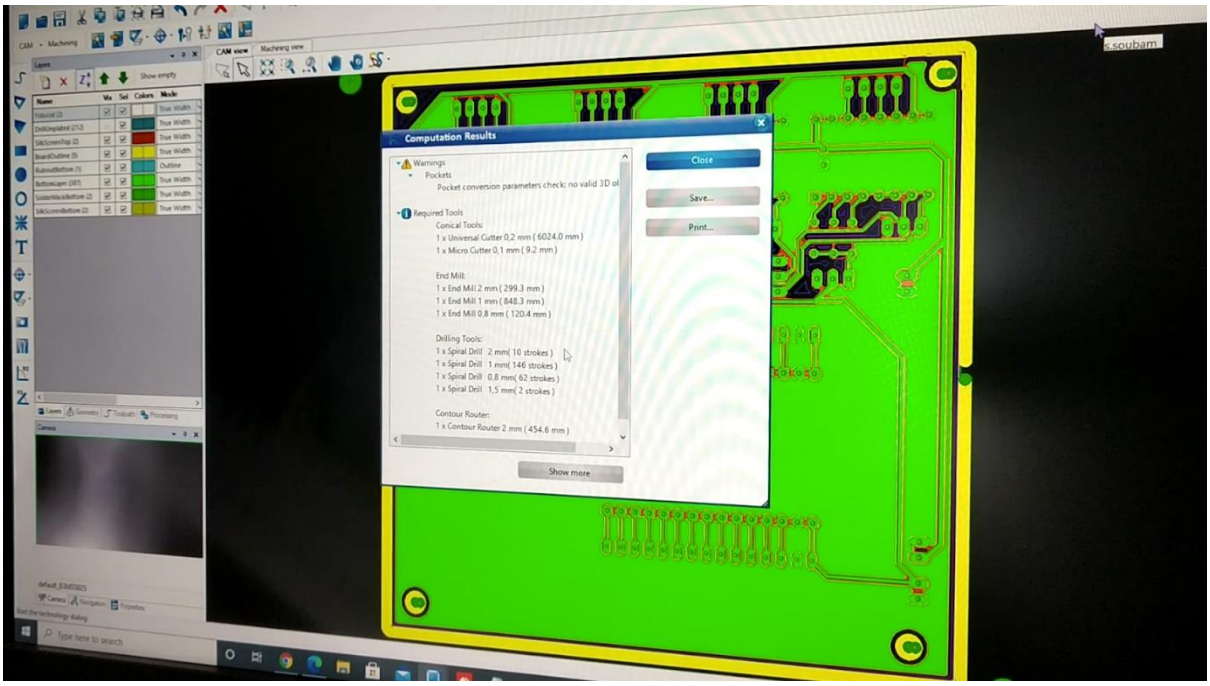


Figure 9.19: Computation Results

The work steps and results of creating the toolpaths are listed in this dialog.

Click on [Close] in the dialog. The toolpaths are created.

15. Change to the Machining View. Click on Edit > Tool magazine...

The tool magazine dialog is used to:

- view a list of the tools required for the current project,
- view the tools currently present in the machine,
- load the tool magazine,
- view/put back the tool currently present in the clamp,
- pick up a tool with the clamp,
- check the milling width of a tool (only for Universal Cutter and Micro Cutter),
- view the current state of the tool life spent,
- replace an old tool with a new one.

The required tools are inserted into the tool magazine manually. Tools have been assigned to the tool holders in the “Tool magazine” dialog and are inserted into the tool Holders according to the list.

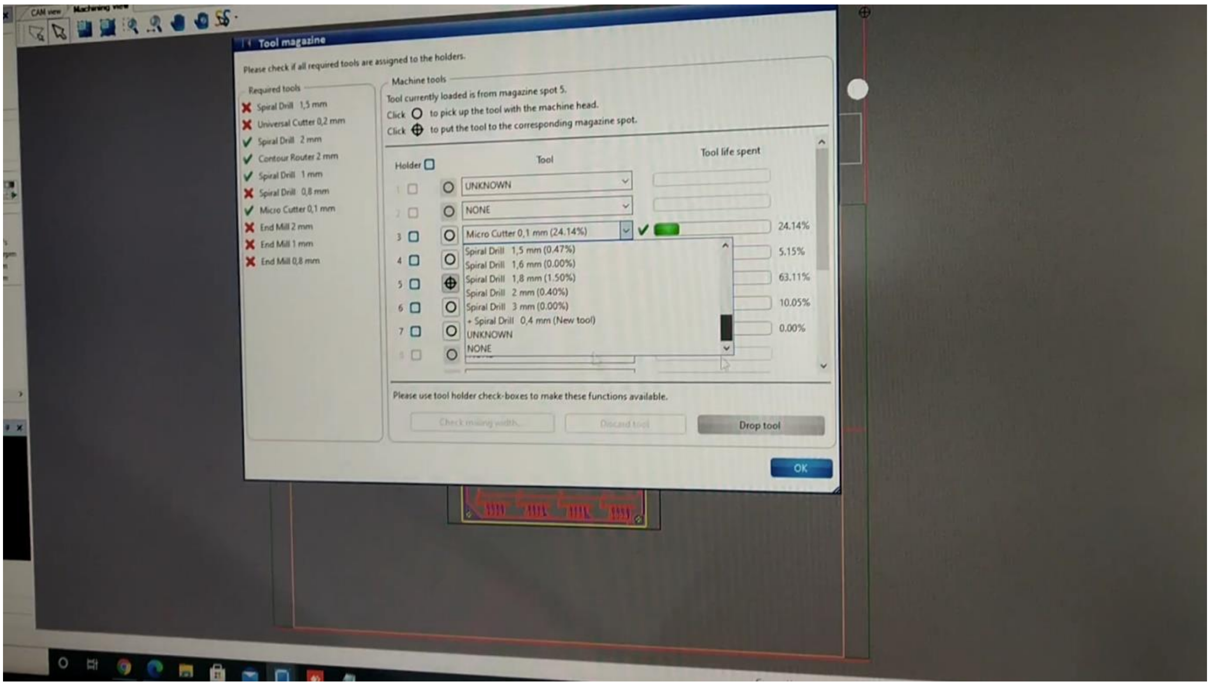


Figure 9.20: Tool drop-down menu for selecting tool

Steps for loading the tool magazine:

– Click on the drop-down list of the first tool holder:

– A list of all tools that can be used with the machine is displayed.

– Select the required tool (in this case: Spiral Drill 1.5 mm, as in Figure 9.20).

– From the tool box, locate the required tool using labels on top of the box, then pick the corresponding tool carefully and insert it into the tool magazine manually.

– For improved accuracy:

  - Match the colour coding of the tool with the colour shown in Machining View in Software.
  - Read tool diameter mentioned on tool bit as well.

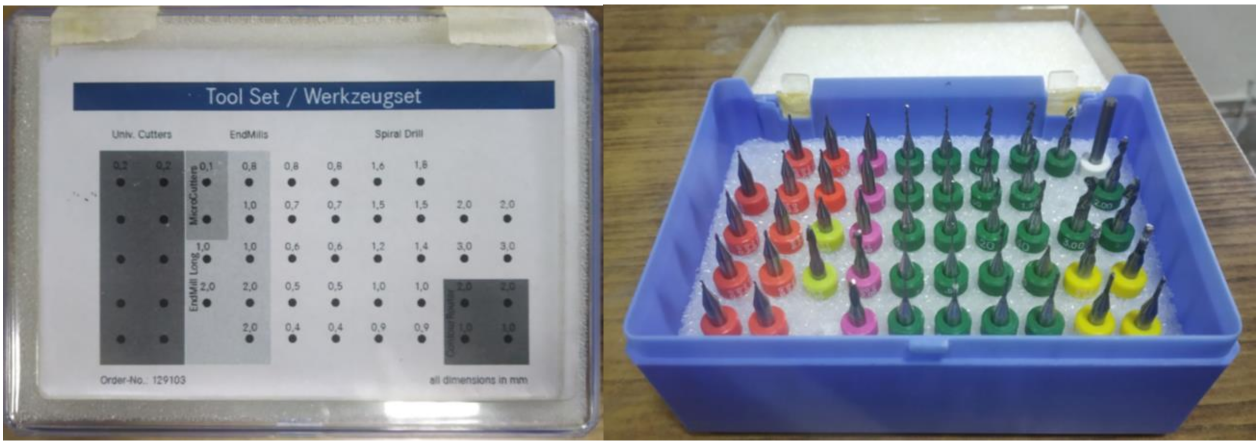


Figure 9.21: Tool Box Top View and Inside View

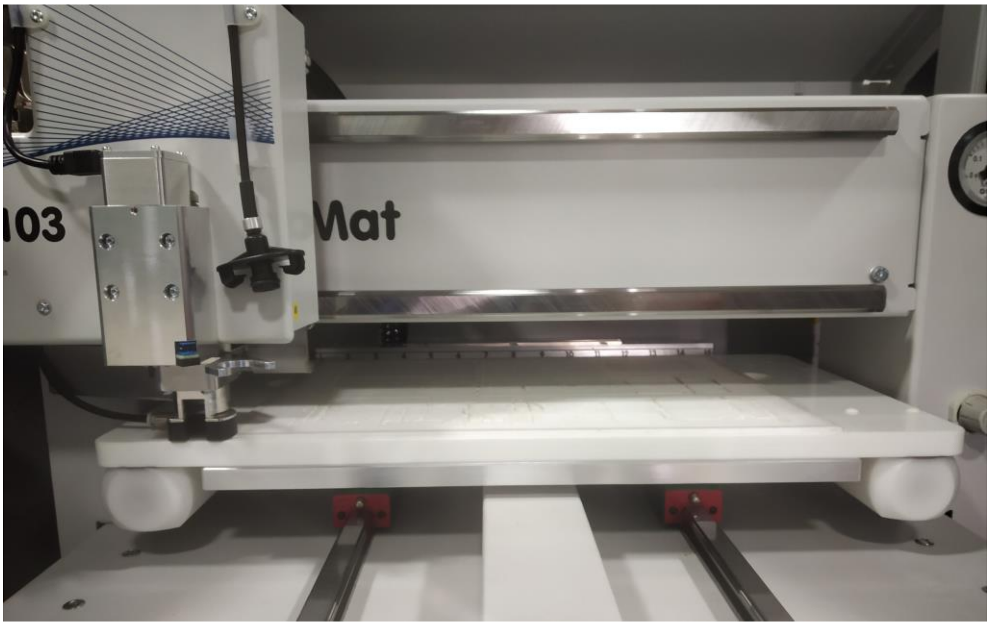


Figure 9.22: Tool Magazine (labelled 1-15) and Work Job Bed

The tool is marked with a green check mark in the list of the required tools. Also, a green check mark is displayed next to the corresponding drop-down list and the tool life spent is displayed on the right. Repeat above steps for all tools that are required for the project with the other tool holders.

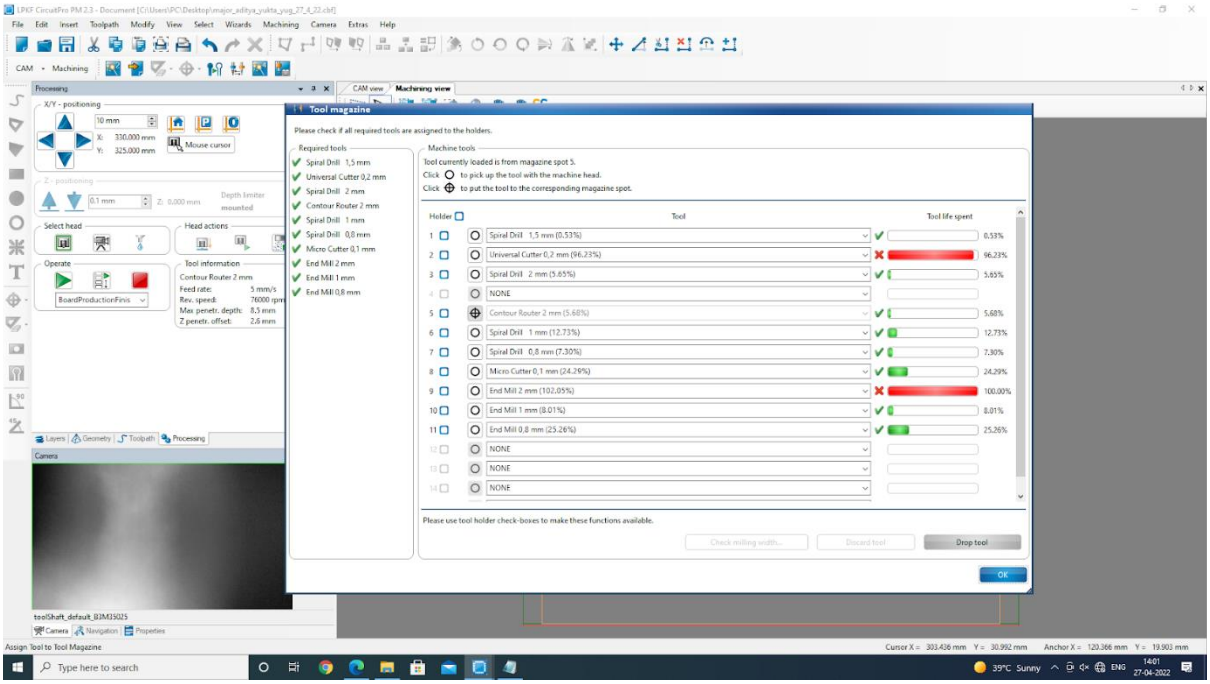
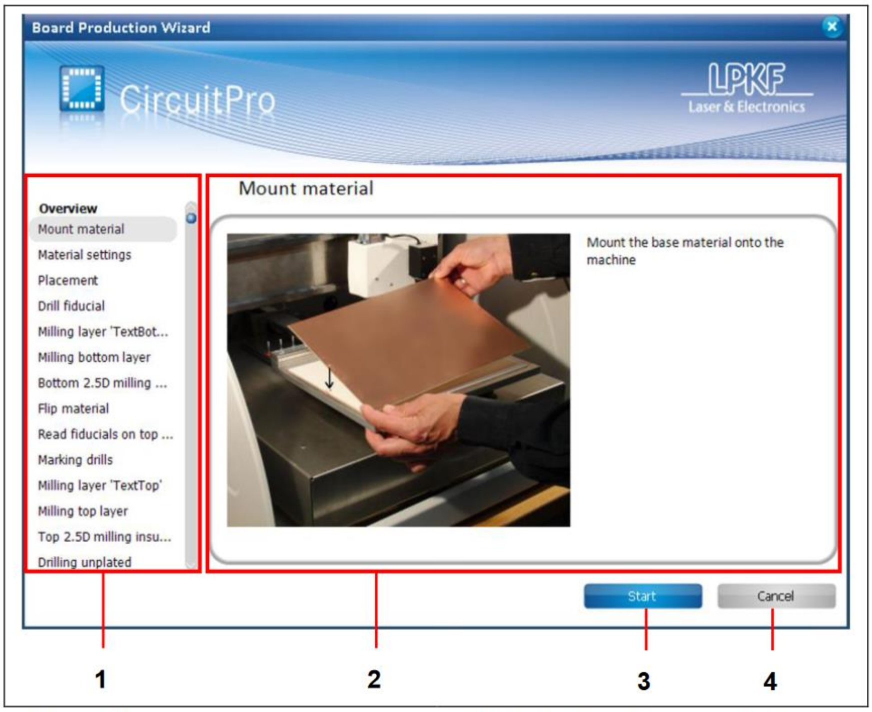


Figure 9.23: Tool Magazine Dialog after Tool Insertion

16. Click on Wizards > Board Production Wizard...

This wizard guides the user through the board production process.



/1/ List of the production phases

/2/ Section for prompts and display of progress

/3/ [Start] – Starts board production

/4/ [Cancel] – Closes the board production wizard and aborts the production process.

Figure 9.24: Board Production Wizard

17. Mount the material in the machine and close the cover. Click on *Start*.

    Click on *Edit* > *Material Settings…*, then click on *OK* after adjusting the material settings.

Material Settings Used:

- Material Type: FR4
- Copper Thickness: 18 µm
- Material Thickness: 1.55 mm
- Material Thickness: 1.55 mm

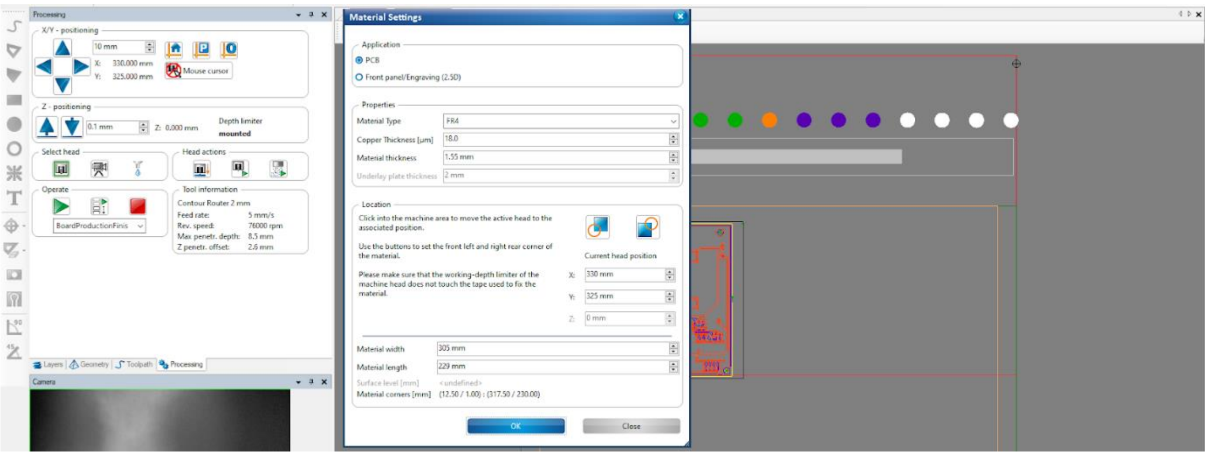


Figure 9.25: Material Settings Dialog Box

18. On the Menu Bar, click on Machining > Placement. Move the processing data in the Machining view using the mouse. To do this, click on the processing data and while pressing the left mouse button drag the circuit frame to the desired position.

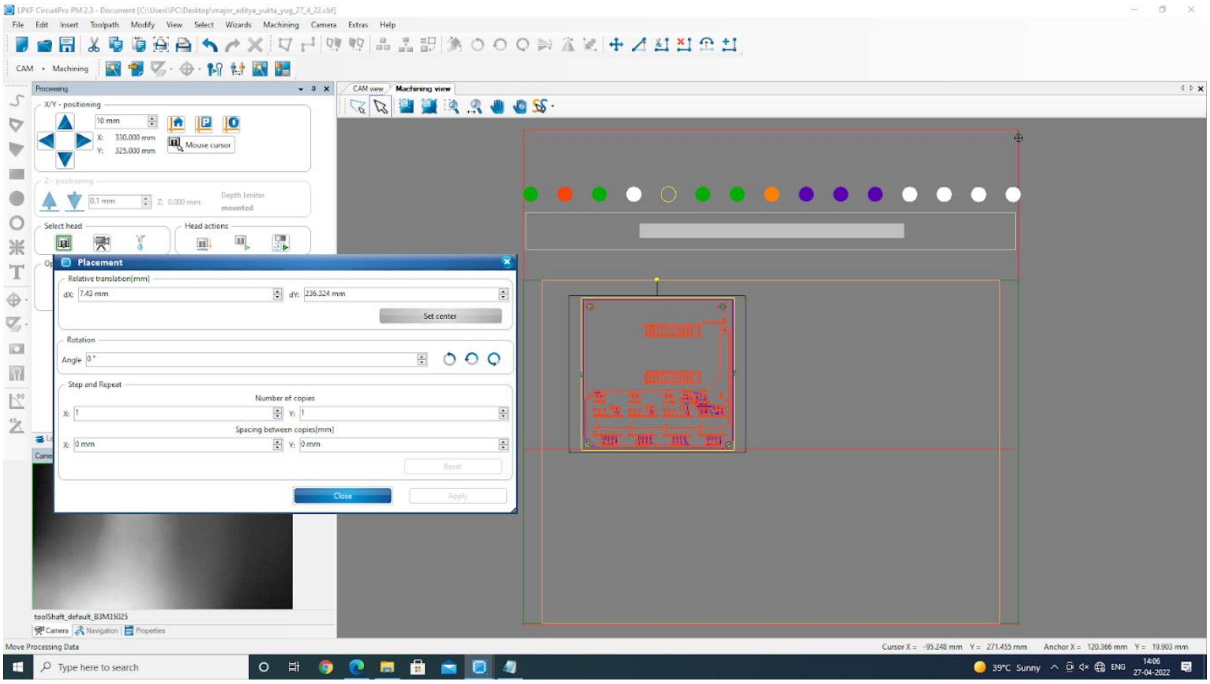


Figure 9.26: Placement Dialog

Other options in Placement Dialog Box:

- *Relative translation* lets the user move the whole circuit board design within the machining view.
- The *Step and Repeat* section is for producing multiple circuits on one panel.

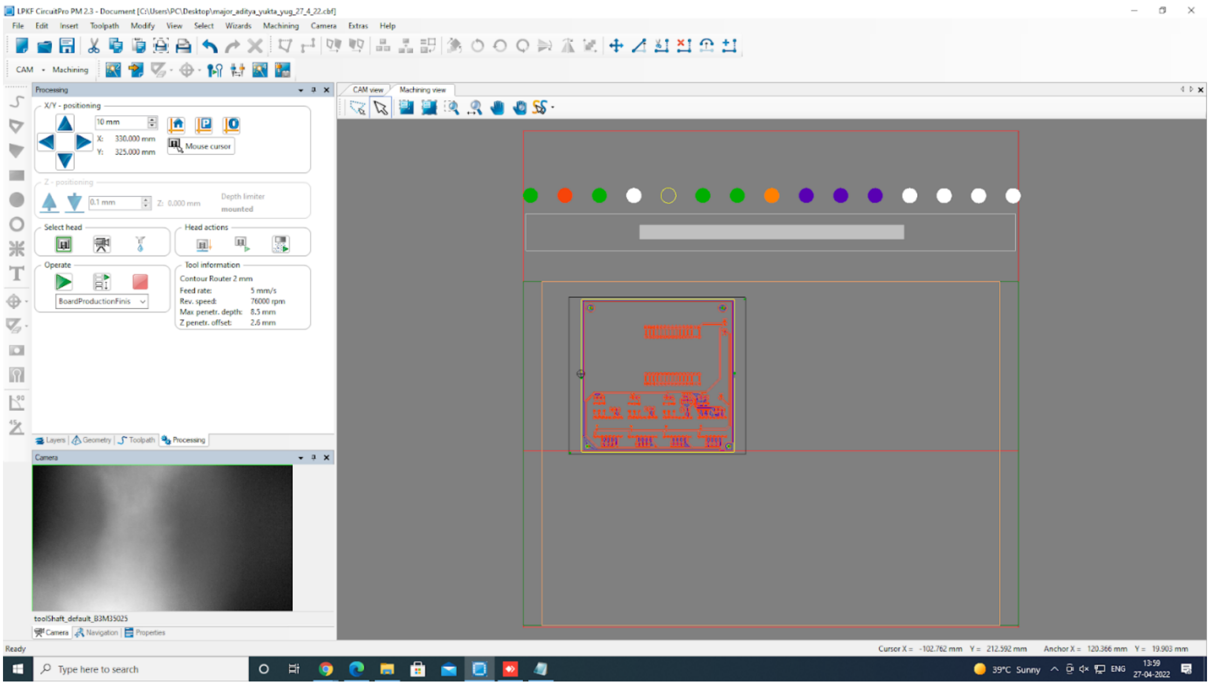


Figure 9.27: Final Placement of the Circuit Board in Machining View

19. Click on *Start processing the shown phase and all following phases* button.
20. Unmount the PCB carefully and turn off the machine and computer after taking relevant screenshots for the technical report.

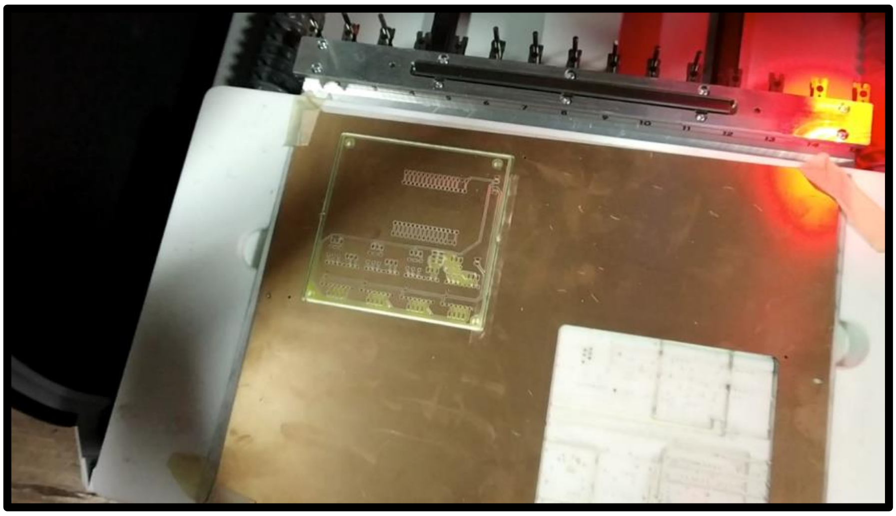


Figure 9.28: Fabricated PCB

Testing the PCB Traces

Required Tests:

- Test each trace for short circuit to Ground
- Test continuity of each trace: like V_{cc} test, V_{mot} test, etc.

Testing procedure followed:

i. Preparation and Safety: This step ensures that neither the electrical circuit nor the multimeter get damaged while finding a short circuit. For the same, make sure the electrical circuit is completely turned off before checking anything. This includes removing any batteries as well as power adapters.
ii. Turn the multimeter settings knob to "continuity." The continuity setting is indicated by a small microphone symbol.
iii. To test each trace for a short circuit to Ground, place the black probe on the Ground plane, and red probe on the trace/pins to be tested. Beep should not be heard, except for Ground pins.
iv. To test continuity of each trace, place the negative multimeter probe, the black one, on one end of the trace to be tested for continuity. Place the red probe, the positive one, on the other end of the trace. A sustained beep indicates continuity of the trace.

10 Results

10.1 Status and Completion

The intended design was successfully implemented.

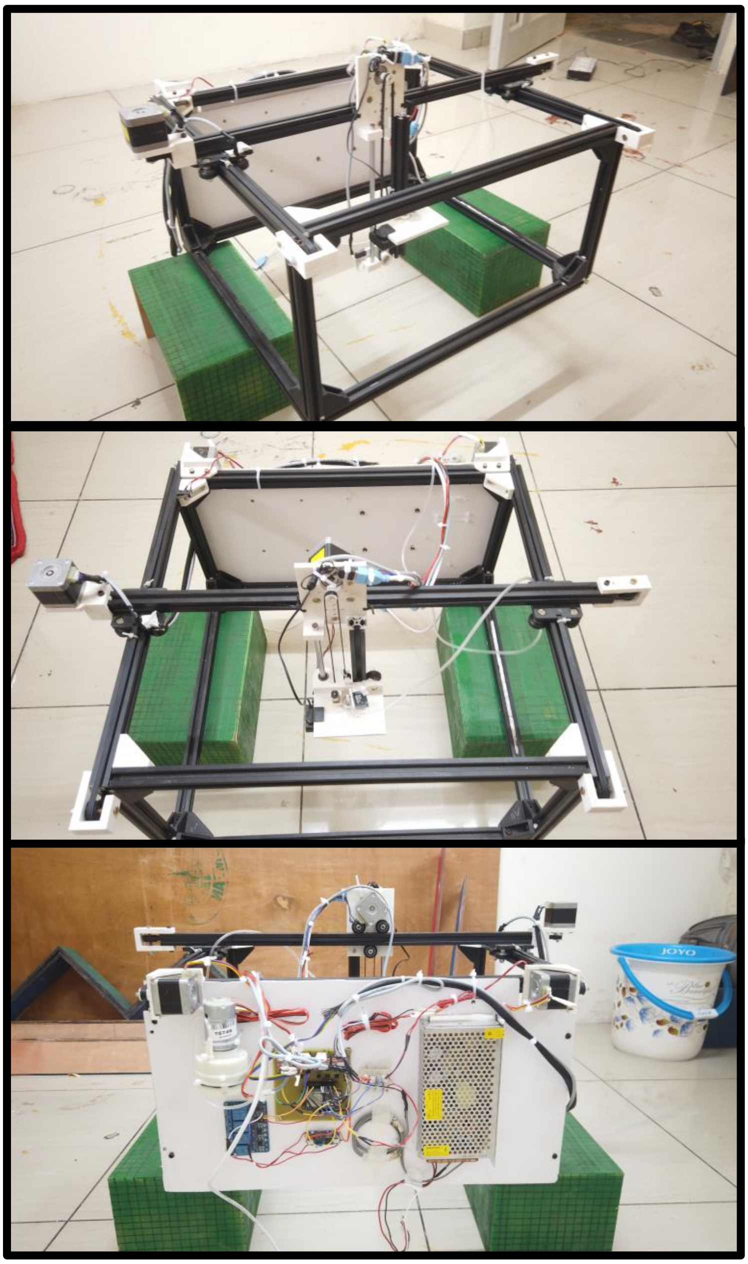


Figure 10.1: Designed Machine (from different angles)

10.2 Machine Features

- Movement in 3 Linear Axes X, Y, Z.
- Additional Rotational Movement of Nozzle Head (4^{th} axis).
- Bottom-facing Camera for precise control over software.
- Bottom-facing LED Fixtures for clear image processing.
- Modular Design with provision to add features.
- Designed and Fabricated in PEC.
- Backward compatible Motor Driver sockets.

10.3 Machine Specifications

- Max Acceleration: 3000 mm/s^2
- Max Travel Speed: 50mm/s
- Minimum Translational Distance for X, Y, Z axes: 0.5mm
- Minimum Angle of Rotation for component: 15^o
- Minimum SMD Component Compatible: 1209 Package
- Usable Bed Size: 30×30 cm

11 Applications and Limitations

11.1 Applications

Direct application of the machine:

11.1.1 SMD Pick and Place:

Pick-and-place machines are used for circuit board assembly in printed circuit board manufacturing. A placement head 'picks' electronic SMT components (surface mounted technology) off of feeders and 'places' them on a printed circuit board (PCB).

Figure 11.1: SMD Pick and Place

Extended Applications:

11.1.2 Light Material Routing:

A computer numerical control router is a computer-controlled cutting machine which typically mounts a hand-held router as a spindle which is used for cutting various materials, such as wood, composites, metals, plastics, glass, and foams. The machine can be modified to perform this function for light materials.

Figure 11.2: Routing of Light Materials

11.1.3 2D Plotting:

A CNC plotter machine is a 3D controlled 2D plotting machine which uses a pen to draw text or image on any given solid surface. The coding for the CNC system is GCODE programming.

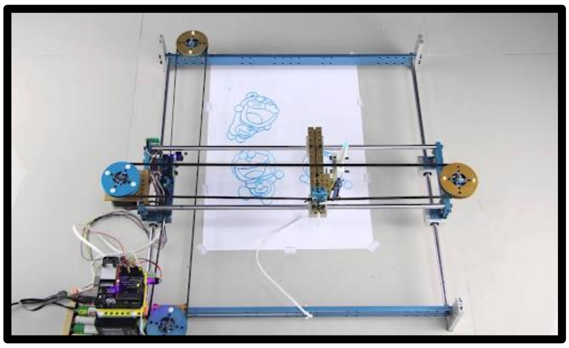


Figure 11.3: 2D Plotting

11.1.4 Precise Camera Movements:

Since the machine can move with constant acceleration and velocities as per user needs, mounting a small camera on the head can provide it with the ability to act as a camera motion control system that could be used for cinematography purposes.

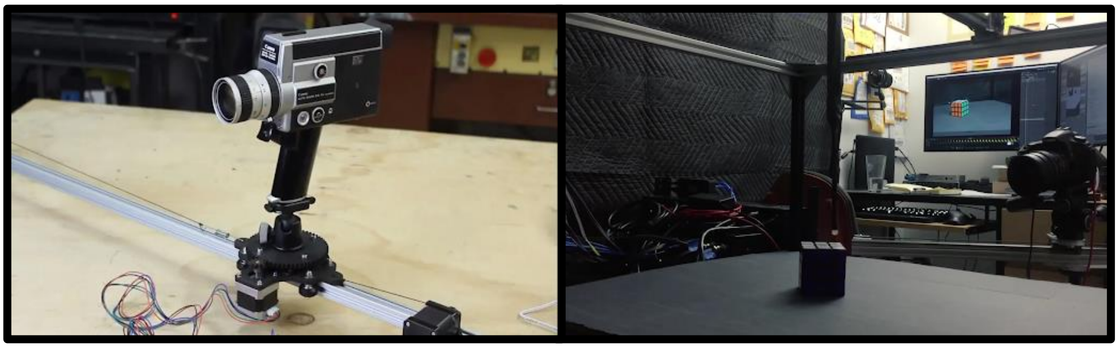


Figure 11.4: Automatic Camera Movements

11.1.5 Fabric and Sheet Cutting:

Stencils can be cut using laser or a sharp head automatically on fabric or any given soft material by modifying the head of this machine.

Figure 11.5: Stencil Cutting

11.2 Limitations

1. Bed size:

   The base of the machine is 50×50 cm, but due to various moving components the remaining usable area for bed size 30×30 cm which implies only 36% of the total area is usable which can be considered a major drawback of the selected design.

2. Cable management:

   For the purposes of a modular design and keeping the system easy to debug, a lot of cables are left loose. Proper Cable management of the system is required for smoother functioning. and better user experience.

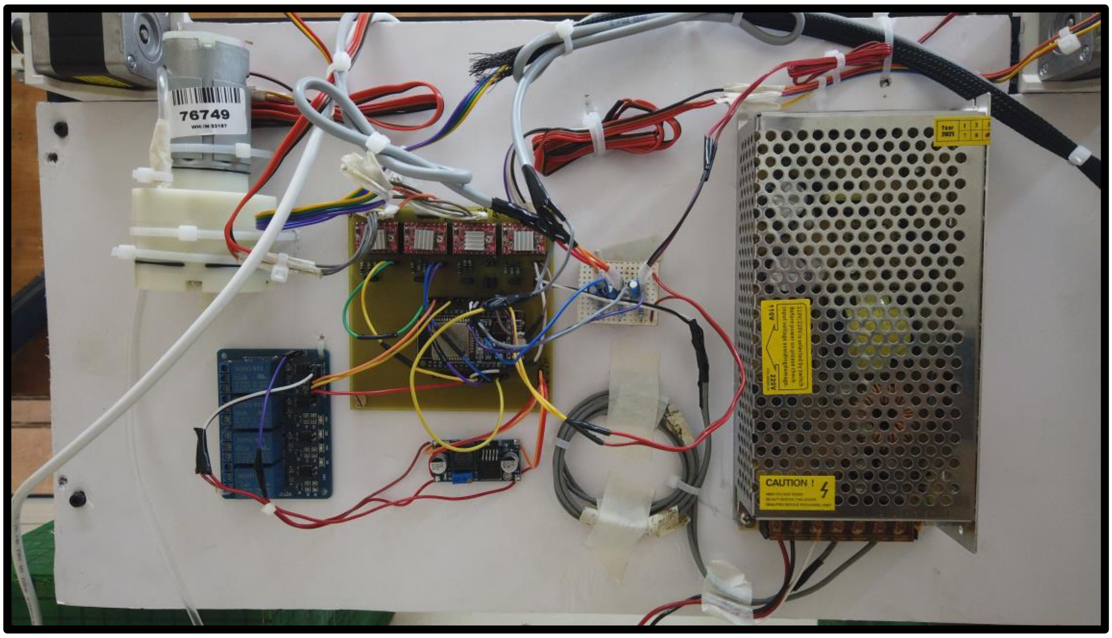


Figure 11.6: Loose Cables

3. Only SMD Components-Friendly:

   The system uses pneumatics and no gripper mechanism to pick and place components, hence it is not compatible with Through Hole Components and work only with SMD Components.

4. Limited Repeatability:

   Since the system is only a Minimum Viable Product and the first iteration of the concept design, it has various backlash errors, deviation in angles and other non-quantified errors, these effect the repeatability of the machine and will require work to make the machine completely autonomous and capable of working without any supervision.

12 Difficulties Faced

12.1 EMI Shielding

Due to high current values flowing in the circuit, a huge amount of electromagnetic noise is generated that leads to various critical errors on the micro-controller which halts the firmware. This causes the machine to require a soft reset.

Solution: The EMI Shielding has been reduced to some extent by using shielding cables.

A Proper Earthing connection needs to be installed to the machine to ensure minimal EMI.

12.2 Un-Familiarity with Mechanical Subsections

Since the hardware and mechanical design of a CNC lies outside the scope of study, researching and working on the design aspect of the mechanical portion was a challenging task for team due to limited expertise in the field.

12.3 Torque Issue with N20 Motor

The N20 Motor, which is used for rotating a component (4^{th} axis), lacked enough torque and had to be manually instigated to execute the input GCODE.

Solution: Analog Voltage value sent to the motor was increased, but within limits as motor can get heated. De-coupling capacitor was also added at motor terminals. Oiling in gears was increased.

13 Future Scope

13.1 Easy to Manufacture Design

The current design of the machine can be further modified to increase the modularity of the machine as well as make it easier to manufacture on a large-scale.

13.2 Solder-Paste Dispensing Mechanism

Since Solder Paste is an essential part of the SMD PCB Assembly process, adding a mechanism for automatic disposal of solder paste at designated spots will be a feature with great utility.

13.3 Open-PnP

Using OpenPnP will fully automate the machine, giving it the capability of identification of component and placing it in the exact location by using Gerber files and feedback from cameras.

13.4 Image Processing

The bottom facing camera provides a view of the board. This image can be further fed to a computer installed on the machine, like, RaspBerry Pi, to perform Image Processing Algorithms which will improve accuracy of component being placed.

14 References

i. For Market Research

- https://kns-engineering.ru/products/ustanovschik-smd-komponentov-borey-t15-f30-l4
- https://imall.com/product/2-Heads-SMT280-SMD-Components-PCB-Assembly-Machine-SMT-Chip-Mounter-0402-0603-BGA-With-28-Feeders/Tools-Welding-Soldering-Supplies/aliexpress.com/32786062409/144-13758115/en
- https://www.lpkfusa.com/products/pcb_prototyping/smt_assembling/protoplace_e4/
- https://www.bid-on-equipment.com/industrial/used-manufacturing-equipment/338194~lpkf-protoplace-s-pick-and-place-system.htm
- https://opulo.io/products/lumenpnp-kit

ii. Other References

- https://learn.sparkfun.com/tutorials/using-eagle-board-layout/all#checking-for-errors
- https://winder.github.io/ugs_website/guide/platform/
- https://ultimaker.com/software/ultimaker-cura
- https://www.lpkfusa.com/datasheets/prototyping/LPKF_TechGuide_2016.pdf
- https://formlabs.com/asia/blog/fdm-vs-sla-compare-types-of-3d-printers/#:~:text=While%20FDM%20printers%20produce%20a,that%20are%20water%20and%20airtight.
- https://markforged.com/resources/blog/pla-abs-nylon#:~:text=PLA%20and%20ABS%20are%20both,better%20plastic%20for%20prototyping%20applications.
- https://www.creality.com/products/ender-3-3d-printer
- https://code.visualstudio.com/download
- https://github.com/bdring/Grbl_Esp32
- https://github.com/grbl/grbl
- https://marlinfw.org/
- https://gcodetutor.com/cnc-machine-training/cnc-g-codes.html
- https://www.gadgetronicx.com/pcb-trace-design-guidelines/
- https://components101.com/motors/nema17-stepper-motor
- https://components101.com/modules/a4988-stepper-motor-driver-module
- https://www.ti.com/lit/gpn/lm2596
- http://www.ee.ic.ac.uk/pcheung/teaching/DE1_EE/stores/sg90_datasheet.pdf
- https://www.electrocraft.com/files/downloads/Datasheets/bldc/RPX32-DataSheet-UK.pdf
- https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf
- https://www.researchgate.net/publication/326537516_Open_Source_Automated_SMD_Pick_and_Place_Machine