Design and Construction of Mini 3-Axis CNC Machine

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Certification

This is to certify that **Ms. Saima**, **50607**, **Ms. Ariba Saleem**, **49553** and **Mr. Meraj Abbas**, **50507** have successfully completed the final project **Design and Construction of mini 3-Axis CNC Machine,** at the **Balochistan University of Information Technology Engineering & Management Sciences**, to fulfill the partial requirement of the degree **Electrical Engineering**

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Project Title (Design and Construction of Mini 3-Axis CNC Machine)

Sustainable Development Goals

(Please tick the relevant SDG(s) linked with FYDP)

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9	Industry, Innovation, and Infrastructure
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	SDG 11	Sustainable Cities and Communities
SDG 4	Quality Education	SDG 12	Responsible Consumption and Production
SDG 5	Gender Equality	SDG 13	Climate Change
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

Range of Complex Problem Solving			
	Attribute	**Complex Problem**	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	
3	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	
4	Familiarity of issues	Involve infrequently encountered issues	
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
7	Consequences	Have significant consequences in a range of contexts.	
8	Interdependence	Are high level problems including many component parts or sub-problems	
Range of Complex Problem Activities			
	Attribute	**Complex Activities**	
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

Abstract

Traditional mass production often suffers from limitations in accuracy and repeatability due to human error and process inconsistencies. While large CNC machines can offer high precision, their size and cost make them less accessible and limit their flexibility. This project addresses these challenges by developing a mini-CNC machine that combines automation, compact design, and affordability. Focusing on simulation and construction, this report details the creation of a mini-CNC machine capable of handling diverse workpieces such as wood, paper, tile, glass, acrylic, and PCB. The workflow of the proposed method for CNC machine starts with CAD software (Eisel), where the desired design is sketched and translated into graphical code (G-Code). This G-code is then converted into a microprocessor-readable format using a post-processor. The microprocessor instructs motors, guiding the machine to fabricate the desired workpiece. The machine features a compact size of 400x600x200mm and a working area of 250x400mm, delivering laser-sharp accuracy and consistent precision in processing diverse materials. Beyond hardware, the project delves into fundamental CNC concepts, 3D modeling, and the construction methodology of the machine, which offers a promising solution for small-scale production and prototyping, paving the way for automated, versatile manufacturing.

Keywords: Acrylic; CNC; PCB; Wood

Undertaking

I certify that the project **Design and Construction of mini 3-Axis CNC Machine** is our own work. The work has not, in whole or in part, been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/ referred.

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List of Acronyms

CNC	Computer Numerical Control
PCB	Printed Circuit Board
G-Code	Graphical-Code
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
APT	Automatically Program Tool
DIP	Dual in-line Package
ABS	Acrylonitrile Butadiene Styrene

Chapter 1

1.1 Introduction

CNC machine is a computer numerical controlled machine that is generally used in manufacturing processes and is becoming a widely successful technology in terms of manufacturing workpieces. Simultaneously, CNC machines can produce different kinds of products as they work on wood, plastic, or metals, depending on the structural strength of, manufacturing of the machine. For instance, a CNC machine utilizes any solid block such as aluminum, and further carves and cuts away the material to obtain a simple door handle at the end [1].

There are generally two types of CNC machines, two-axis, and three-axis CNC machines. The two-axis CNC machine moves on the horizontal X-axis and vertical Y-axis while the three-axis CNC machine works on three axes including the Z-axis which performs the task parallel with the spindle [2].

1.1.1 Brief History of CNC Machine

CNC machines, developed in the 18th century, had a metal frame using machining technics. It was the beginning effort to make the arrangements of the machine in the advanced form to operate more exactly and precisely instead of the carefully assembled technics. However, it was still not that preferable until the commencement of the concept of its automation was addressed. The U.S. Navy promoted the corporate Parson Works to produce a huge number of helicopter blades. The movement of various axis of the machine was then motorized by John T. Parsons to produce those blades and to perceive the control of these machines by computer. Hence, the CNC machine strategy started from this journey where later in 1952 the first CNC processing machine was built [3] [4].

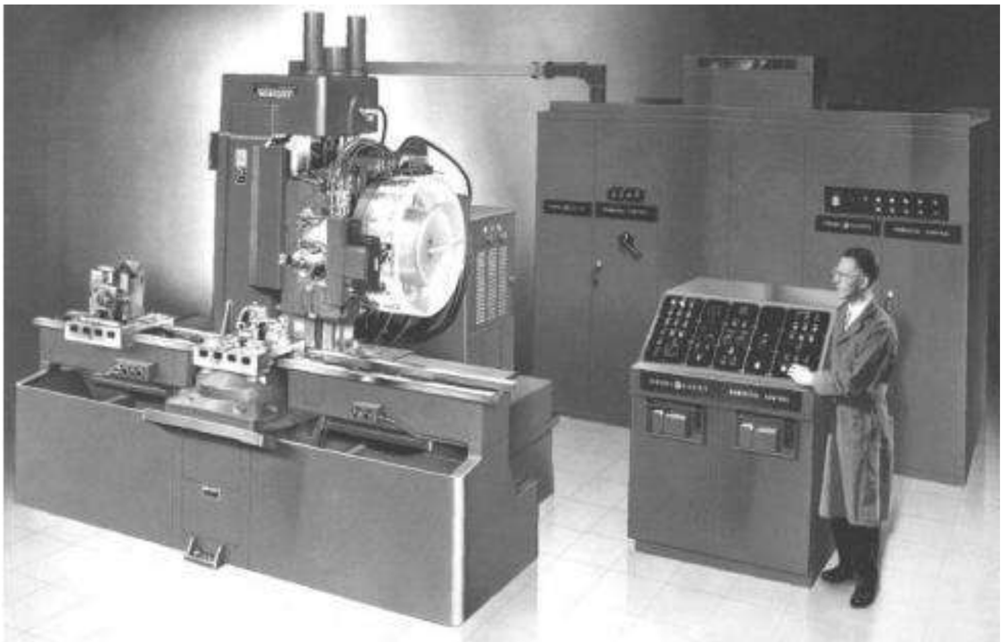

Figure 1: First CNC machine

1.1.2 Working Flow of CNC Machine

The main working process of a CNC machine begins with 2D or 3D modeling in the computer utilizing computer-aided design software (CAD). CAD software has certain accessibility with certain dimensions specifications for the various vector templates. Using this software, the CNC machine can be modeled. Moreover, this CAD design file is further given to another software known as Computer-Aided Manufacturing (CAM). This software is responsible for generating optimized tool paths for the CNC machine to be followed. Simultaneously, the Graphical-Code (G-Code) is the output of the CAM software which instructs the CNC machine [5].

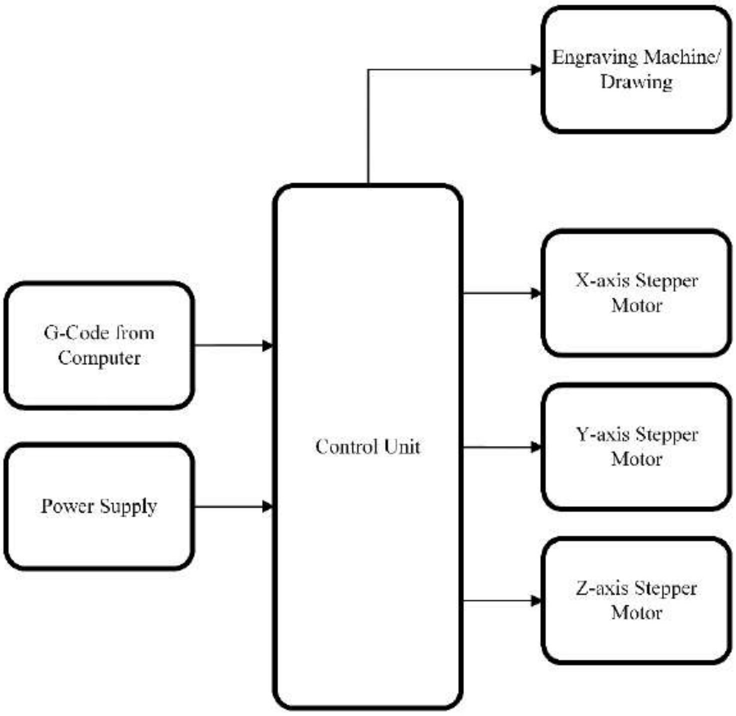

Figure 2: Working flow of the machine

The CNC machine basically consists of 4 basic components for the system of its operation. The four components are its mechanical design, drives module, system software, and Automatically Program Tool (APT) postprocessor [5].

The mechanical design is the hardware part of the CNC machine which is the body part. Moreover, the drive system which obtains the signals from the microprocessor for the operation of motors. The software system helps in generating the programs for the movement of various tools and workpieces of the machine. Simultaneously, the APT postprocessor was mainly developed for G-code and M-code which is further needed by the CNC machine for any design to be produced [5].

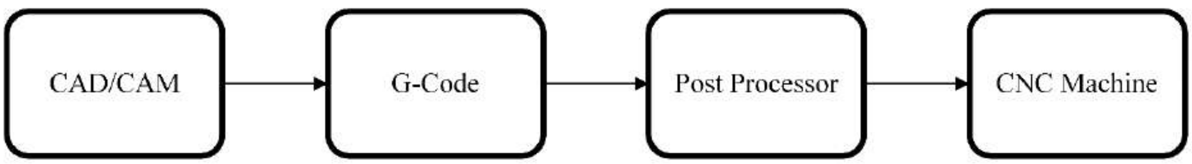

Figure 3: The design and control Flow of CNC machine

1.2 Statement of the problem

The machines used in traditional mass production were manually operated, and the accuracy of the complicated movements and dimensions depended entirely on the operator's skill. This inherent susceptibility to human error significantly limits the process's repeatability and consistency. While the advent of CNC machines revolutionized the landscape, their high cost and size restricted their accessibility and versatility.

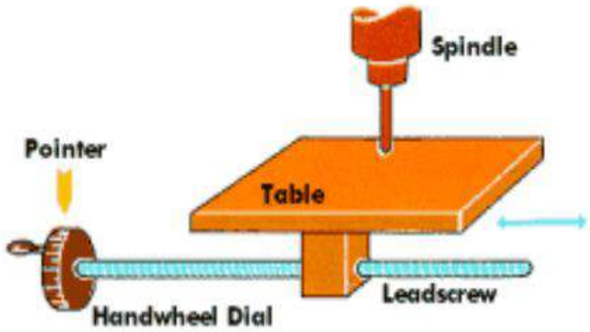

Figure 4: Working of Conventional machine

Certain other problems analyzed were:

- The cost and size of the CNC plotter were much higher.
- The conventional machine lacked accuracy due to inappropriate plotting that was done on the PCB frequently.
- The frame of the machine did not have the strength to control the vibrations of the motors; therefore, the frame was getting loose and sometimes even breaking down.
- Various faults and errors occurred during the cutting of the workpiece.

1.3 Proposed Solution

To overcome the problems which were discussed in the problem section, we present a mini 3-axis CNC milling and engraving machine. The main concept for designing and constructing this machine is to overcome the above-discussed problems with certain specifications:

- This mini-CNC milling machine will have high precision and accuracy because it is completely computer-based and controlled as well as high-end software will be used.
- The machine will be easy to operate and repeat.
- Another essential feature of our machine will be that it will be cost-efficient and with the smaller size of the machine, it will have the good strength to perform any task with a high level of reliability. The parts are easily replaceable.
- This mini-CNC machine will be user-friendly.

1.4 Goals/Aims & Objectives

As stated, the problems which are faced by industry and a certain level of concerned people, there are several goals which we seek to achieve in this project.

- Constructing a 3-axis mini-CNC machine.
- Programming of G-Code for the CNC machine.
- Demonstrating the working of CNC machine by cutting different materials into different designs

1.5 Motivation

The widespread availability of complex, customized designs in various sectors, such as the aerospace industry and the automotive industry, consumer electronics, defense industry, and health sector, highlights the increasing demand for affordable, precise carving solutions. Although effective for large-scale production, traditional mass production techniques are frequently hindered by inherent human error and process inconsistencies that lead to limitations in accuracy and repeatability. Large-scale CNC machines, while capable of delivering high precision, pose significant accessibility barriers due to their imposing size and prohibitive cost, which further limit their versatility for customized, smaller-scale projects.

Recognizing this critical gap in the technological landscape, this project undertakes the development of a mini 3-axis CNC machine. Inspired by the goal of providing makers with an affordable, adaptable alternative to expensive machinery, this project aims to close the gap between the limitations of conventional techniques and the unavailability of large-scale equipment. By achieving high accuracy and repeatability within a compact, affordable form factor, this mini CNC machine aims to promote a new era of accessible, precise, and flexible design creation, empowering a wider range of individuals and enterprises to realize their creative visions.

1.6 Report Overview

We can highlight the report organization as: Section #2 includes the literature review of the project, Section #3 is mainly the body of the project discussing the methodology where each component used in CNC machine as well as their specifications, ratings are being discussed, Section #4 is about the discussion of the results of the CNC machine and its certain workpieces produced. Section #5 includes the conclusion and future work.

Chapter 2

2.1 Literature Review/Related Work

In a related study, the focus was on the development and implementation of a mini CNC milling machine. The researchers aimed to create a compact and versatile milling machine [6], suitable for various small-scale machining tasks. The study provided the comprehensive design and fabrication process of the mini CNC milling machine, including the selection of components and materials. The compact size and flexibility of the machine made it a potential solution for industries or workshops with limited space. The authors employed computer-aided design (CAD) software for designing the machine and utilized precision machining tools for fabricating its parts. The machine was operated and controlled using computer numerical control (CNC) software. This combination of CAD software, precision machining tools, and CNC software [6] allowed for accurate and precise milling operations. However, the paper lacked critical performance evaluation and practical testing of the machine's capabilities, which could limit its applicability in real-world scenarios. Additionally, the study does not deliver the cost-effectiveness or affordability of the mini CNC milling machine, which is an important aspect for potential users and industries with limited budgets.

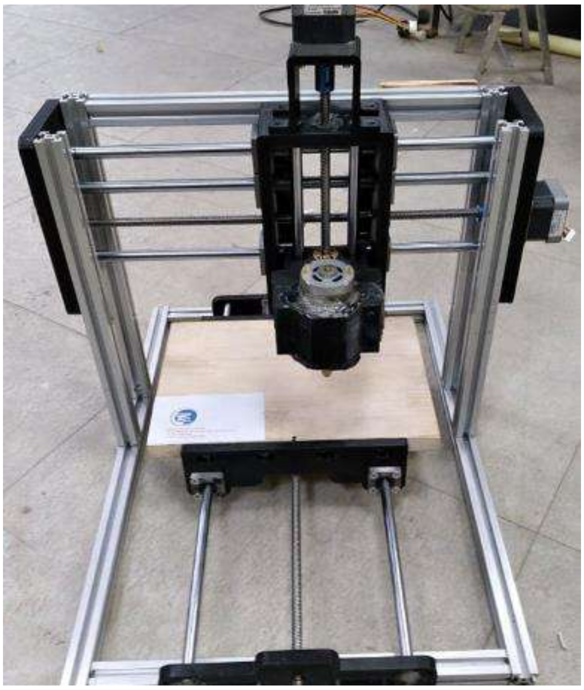

Figure 5: Final fabricated prototype milling machine assembly

Similarly, by reviewing further literature, a PC-based design of the 3-axis CNC milling machine was proposed. The study aims to develop a versatile machine capable of precise milling operations [7]. The authors discuss the design process and components used in the machine's construction, supporting the implementation of the machine. The paper serves as a useful resource for individuals interested in PC-based CNC milling machines. The workflow of the machine involves designing the machine using CAD software, procuring components and materials, assembling and calibrating the machine, controlling it through PC-based software ArtSoft Mach4 [7], which serves as an interface for controlling and managing various aspects of the machine's functions. It is used to generate precise tool paths, define cutting parameters, and monitor the machine's movements. This machine covers the working area of X: 240 mm, Y: 300 mm, Z: 600 mm. However, there are several potential drawbacks to consider. Firstly, the focus on a desktop-sized CNC router may result in a limited workspace, restricting the size of workpieces that can be accommodated. Secondly, the machine's smaller size may lead to reduced rigidity, which can affect the accuracy and precision of machining operations. Additionally, due to size and portability requirements, the machine may have lower power and cutting capabilities compared to larger industrial-grade CNC routers. These limitations should be taken into account when assessing the practicality and suitability of the PC-based 3-axis CNC milling machine for specific applications.

Figure 6: PC based CNC Machine Structure

In another recent work focusing on the development of CNC milling machines, researchers undertook the task of designing and fabricating a 3-axes mini CNC [8] milling machine. Their study aimed to provide a compact and versatile solution for various machining tasks. The researchers utilized the Mach3mill G-Code CAD/CAM [8] software package as the machine controller, running on a PC. The 3Axis CNC driver board type Kit TB6560 [8] was used for smooth motor control. The machine was designed, fabricated, and assembled with an easy-to-use interface capable of interpreting standard G-M codes. The maximum work piece size that can be fabricated is: X = 350 mm, Y = 400 mm and Z = 220 mm. By detailing the design and fabrication process of the machine, the authors provided the implementation process of the machine. However, the paper lacked the performance evaluation and testing of the mini CNC milling machine, limiting our understanding of its accuracy, precision, and efficiency in milling tasks. Furthermore, the limitations of the machine in handling larger workpieces or complex milling operations were not thoroughly addressed.

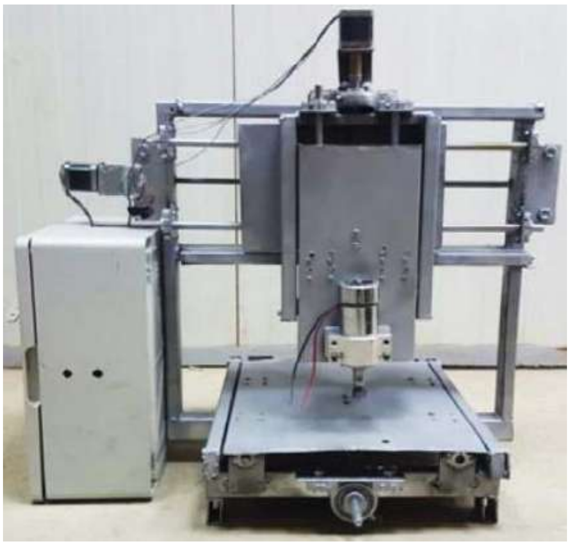

Figure 7: Fabricated Prototype of the mini CNC machine

In another related study, some researchers focused on designing and fabricating a CNC router machine specifically constructed for wood engraving. Their study aimed to address the growing demand for precision and efficiency in woodworking tasks [9]. The router machine utilizes stepper motors driven by a 3-axis motion system. CAM processing involves the use of G-code programming through MACH 3 software. The machine's workspace measures 800 mm x 500 x 150 mm and employs TB 6600 drivers for the stepper motors, to ensure precise motion. By exploring the machine's design process, components, and materials, the authors provided the specifications of the CNC router machine for wood engraving. However, the study lacked comprehensive performance evaluation and cost-effectiveness analysis, which are crucial factors in assessing the practicality and applicability of such machines. Furthermore, this machine is specifically designed for wood engraving, thus it lacks versatility.

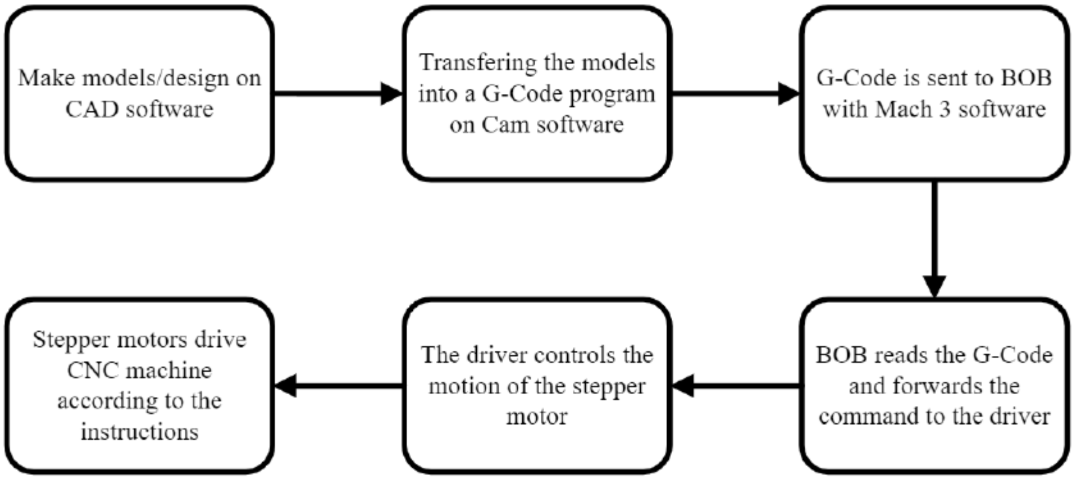

Figure 8: Block diagram of the working of case study model [9]

Moving forward to another related study, an affordable solution for printed circuit board (PCB) milling through CNC machine is proposed. The study focused on creating a machine that offers precise and efficient PCB milling capabilities [10] while keeping costs low. The PCB fabrication procedure involves designing the circuit using Autodesk Eagle CAD [10] software, followed by transferring it to the board layout file. The CAM software, Flat CAM [10], converts the layout into a machine-readable G-Code file that guides the CNC machine. The G-Code files are loaded into the CNC controller using Universal G-Code [10] converter, enabling the machine to cut out tracks and pads and perform drilling. The working area of the machine is 0.2 mm x 0.2 mm x 3.175 mm. The results proposed the effectiveness of the machine in the field of PCB prototyping and small-scale production. However, the paper lacked detailed performance evaluation, scalability analysis, and exploration of the machine's versatility beyond PCB milling. Further research is needed to assess accuracy, speed, repeatability, scalability, and the machine's potential to handle different materials and machining tasks, thus enhancing its practicality and usefulness.

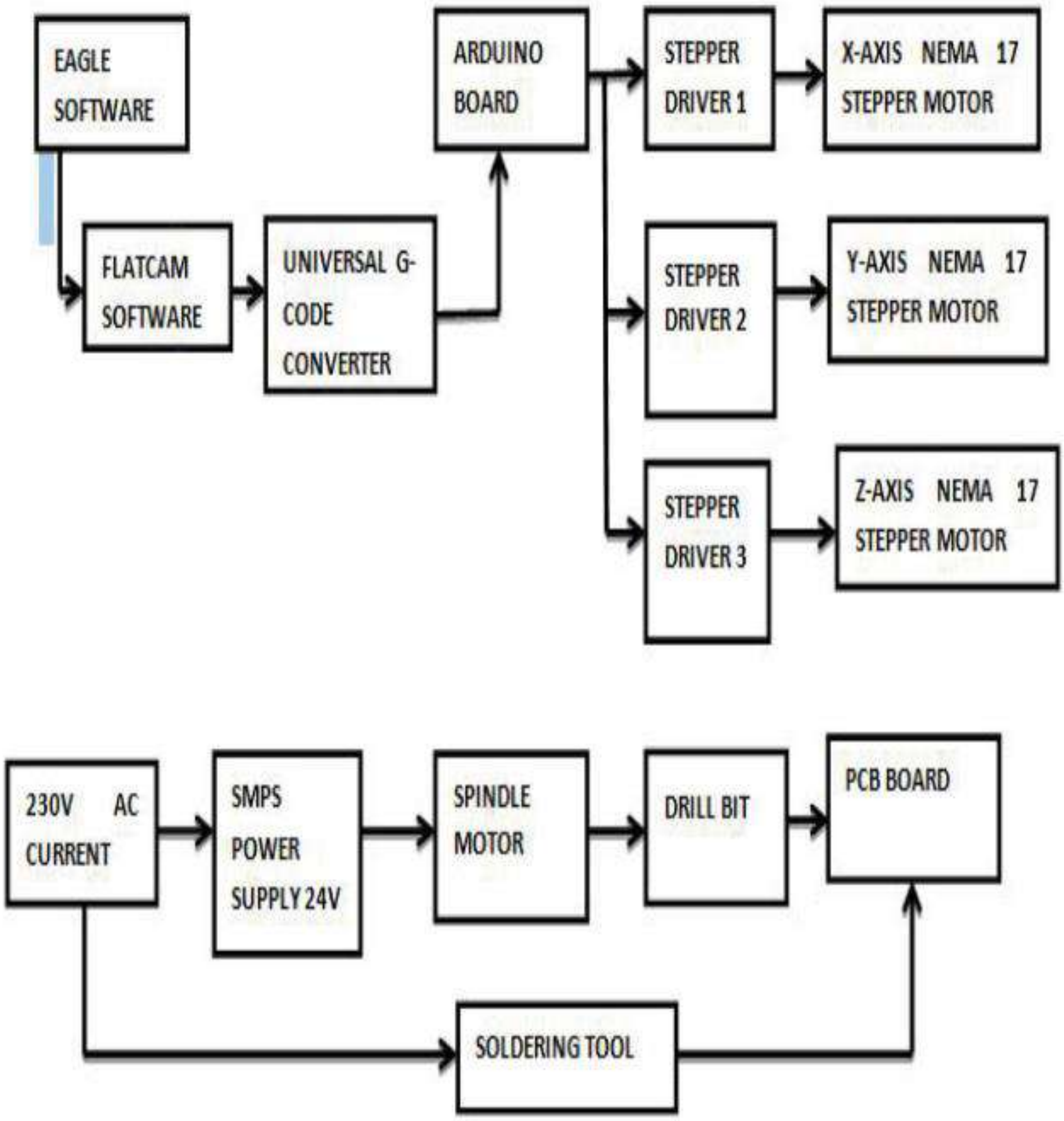

Figure 9: Workflow of the machine in related work

In another related work, design and implementation of a CNC milling bot for milled circuit board (PCB) fabrication was another new achievements of CNC [11]. The research focused on creating a CNC milling bot capable of precise and efficient PCB fabrication. The study provided information related to design considerations, components used, and implementation process of the CNC milling bot. It offered a valuable contribution to the field of PCB fabrication. The working area of the machine is 10 cm x 10 cm x 10 cm. The authors utilized DipTrace [11], an EDA/CAD software, for creating schematic diagrams, while CopperCam [11] converts the design into G-code files. These files are then uploaded to the CNC machine using Universal G-code Sender software, enabling the microcontroller to control motor rotation and coordinate the end effector's movements for engraving the board design onto a copper clad. However, one limitation of the paper is the lack of thorough performance evaluation of the CNC milling bot. Additional information on its accuracy, speed, and repeatability would have enhanced the study's outcomes. Moreover, the paper did not explore the scalability of the machine or its potential limitations when dealing with larger or more complex PCB designs and carving on other materials such as wood.

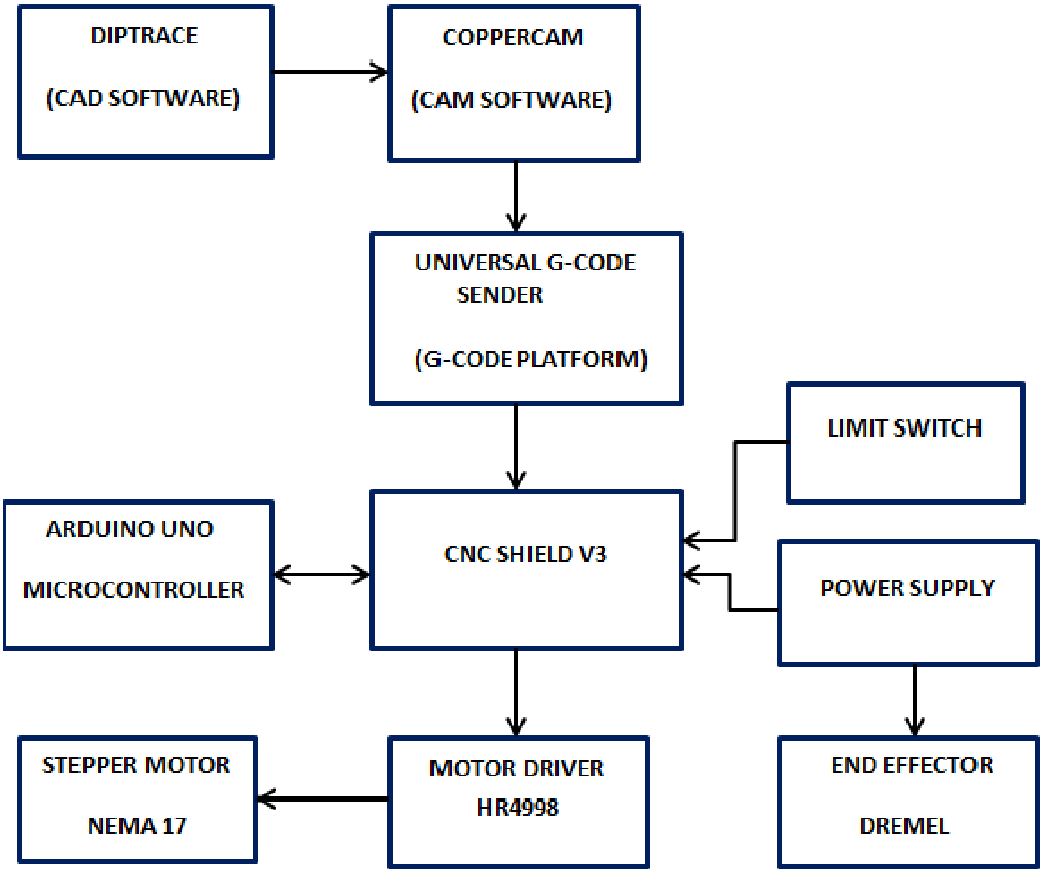

Figure 10: System Architecture of the PCB milling bot

Chapter 3

3.1 METHODOLOGY

This chapter will cover the machine's construction and working methodology, starting with initial design, and modeling, as well as the collection of data for each component of the machine's specs. Additionally, the building of the machine and the testing of electrical components (such as motors and spindles) are displayed.

3.1.1 Design and Modeling

There are a few factors that need to be carefully taken into account while designing a small 3-axis CNC machine. Establish the machine's dimensions that is 400x600x200mm taking into account the size of the workpiece which is 250x400. The depth of the cut, and the level of precision needed. Then, when designing the machine's base, take into account the machine's proper size and weight as well as the necessary stiffness and stability.

The X and Y axis rails, which will support the machine and move the workpiece, are first modeled. Make the Z axis, which will retain the spindle and move up and down to change the cutting depth, according to your design. Plotting the spindle mount to support the spindle and motor is another step. The mounts have to be built to give the spindle and motor a sturdy, steady foundation that vibrates as little as possible.

In this study, a miniature CNC machine is designed using the Fusion 360 and SketchUp program. Certain investigation and identification of the design specifications for the CNC machine, including the intended cutting area, the material type and thickness, the spindle speed and power, etc.

3.1.2 SketchUp Software

A 3D modeling program called SketchUp is utilized for a variety of design applications, such as architecture, interior design, and engineering goods. The program used to create 3D models, called SketchUp, offers an intuitive user interface and easy-to-use capabilities. Software like CAD and CAM may be connected with SketchUp to develop precise designs and become ready for production. In our project, we built 3D printed parts for the CNC machine using SketchUp software, including an x-axis supporter, an x-axis and z-axis connection, a holder for the Y axis bearing, a holder for the Y axis stepper motor, a holder for the Z axis bearing, and a holder for the spindle.

The stepper motor, bearings, shaft, and spindle, among other CNC machine elements, were intended to be held and supported by these pieces. All of the 3D printed components were crucial to the CNC machine's overall precision and operation. The spindle holder retained and rotated the cutting tool while the stepper motor holders and bearing holders provided secure support for the numerous axes of movement. The x supporter, x axis, and z axis connection all contributed to the cutting tool's precise and accurate movement. The y-axis movement is guided by the y-axis bearing holder. Download the 3D models as an STL file when they have been created. Use an STL file to print these 3D pieces.

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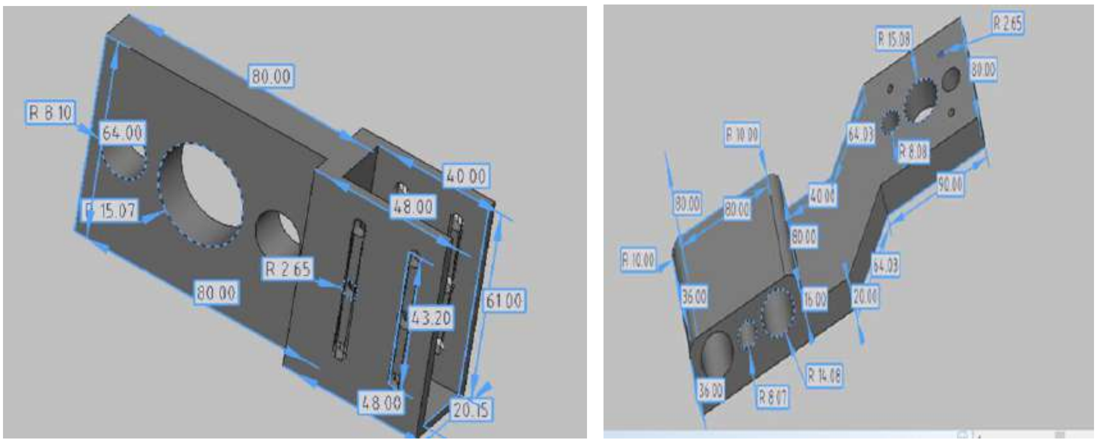
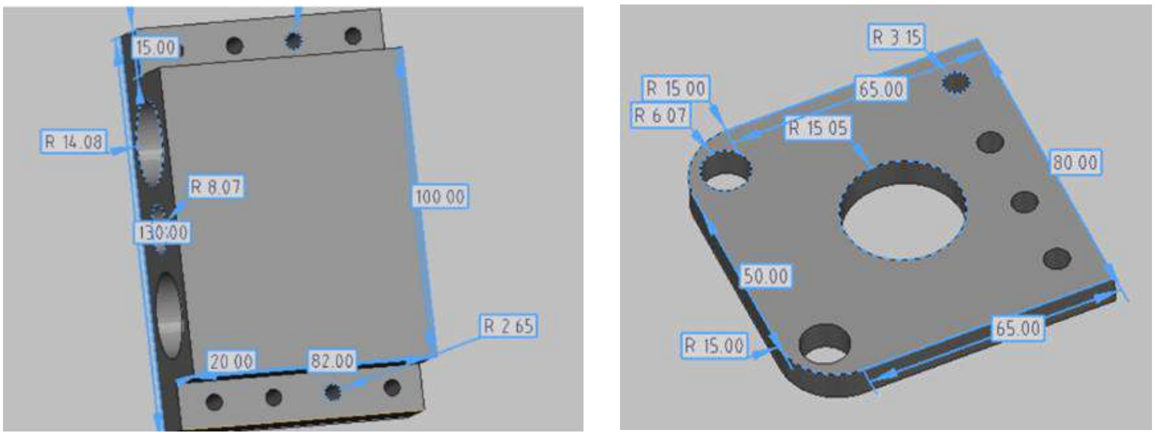


(a) (b)

Figure 11: (a) Y- axis stepper motor/bearings **(b)** X axis side supporter



(a) (b)

Figure 12: (a) Z and X axis Connector **(b)** Z- Axis stepper motor/ bearing holder

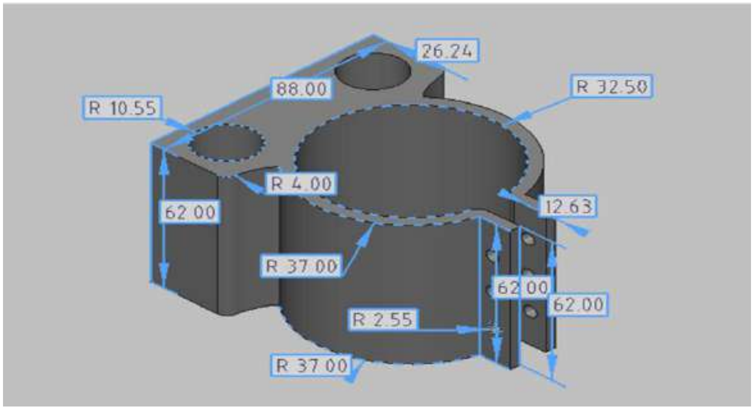


Figure 13: Spindle Holder

3.1.3 Fusion 360

Autodesk created the cloud-based 3D CAD/CAM program Fusion 360. Mechanical engineering, product design, and industrial design are just a few of the many applications it is used for. It is also utilized for product design, engineering, and manufacturing.

Create a T-Track spoil board that will serve as the machine's foundation. To create this Create a rectangle with a size that corresponds to the spoil board. Set the board's precise size using the "Dimension" tool. The rectangle's center should be cut out with a central line.

Draw a line parallel to the rectangle's center line at its top using the "Line" tool. This will be the initial T-track. At the bottom of the rectangle, draw a second line that is parallel to the center line. The width of the T-track you wish to make must match the distance between the two lines. To make many copies of the T-track, choose the two lines that make up the T-track and use the "Pattern" tool. You may decide how many tracks you wish to make and how far apart they should be from one another.

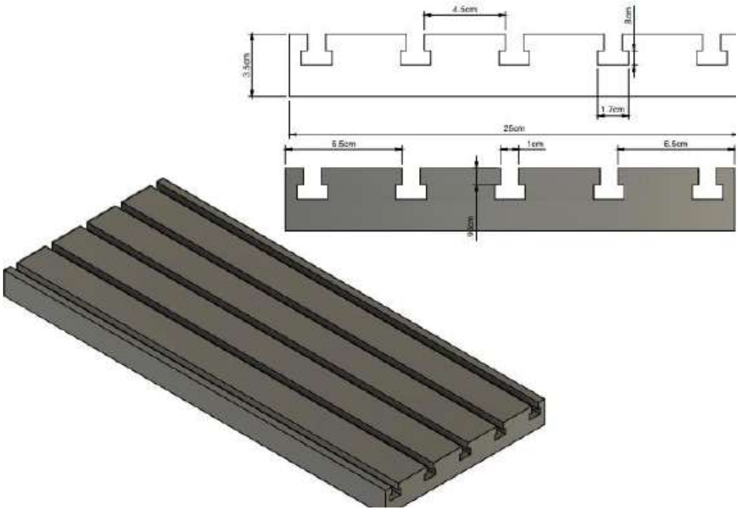
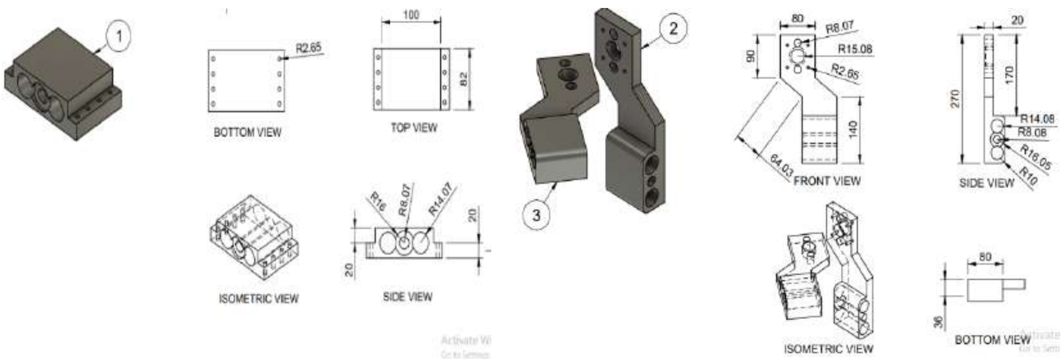


Figure 14: T- track Spoil Board

Import the 3D printed components into the Fusion 360 program, then put together all the components to create a CNC machine. Take the measurements of 3d parts in mm in fusion 360.



(a) (b)

Figure 15: (a) Dimension of z-x axis connector **(b)** Dimensions of x- axis supporter

(a) (b)

Figure 16: (a) Dimension of Y- axis bearing/ stepper motor holder **(b)** Dimensions of Z- axis Bearing/ stepper motor holder.

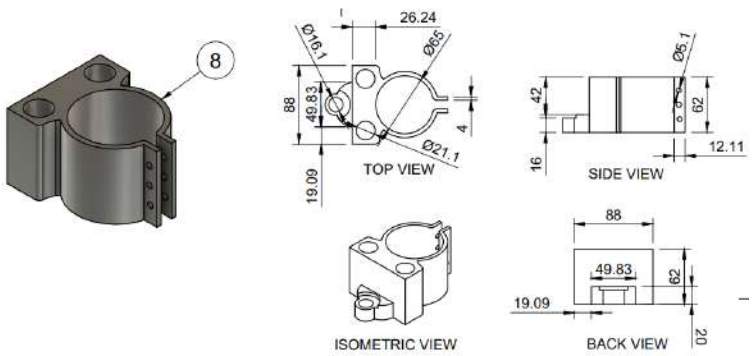


Figure 17: Dimensions of spindle holder

Another parts like spindle, lead screw, shaft, motors and nuts assembled to make a CNC machine in fusion 360.Design should be saved as an STL file. To create the toolpaths needed to cut the pieces, export the STL file to CAM software.

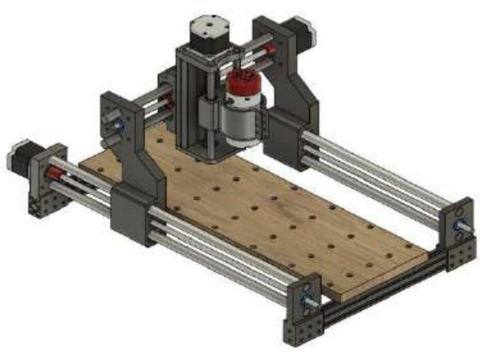


Figure 18: CNC model in fusion 360

There are two types of components used for the construction of a CNC machine.

1. Electrical components
2. Mechanical components

3.2 Electrical Components

The electrical components used for the fabrication of the CNC machine, are discussed as:

3.2.1 Arduino

Arduino UNO is one of the project's key elements. A microcontroller board called Arduino Uno is totally dependent on the ATmega328P. It contains fourteen pins for computer input and output. Six analog pins are present. It runs on 5 V and contains 32Kb of flash memory in addition to 2Kb of RAM. There is a DC power Jack for attaching an external power source and a USB port for connecting to the host computer.

Figure 19: Arduino UNO

Following are the specifications of Arduino UNO.

Parameters	Specifications
Microcontroller	ATmega328
Operating voltage	5V
Input voltage limit	8V – 20V
Dc current per I/O pin	40mA
SRAM	2Kb
EPROM	1Kb
Clock speed	16MHz

Table 1: Specification of Arduino UNO

3.2.2 CNC Shield

The axis of our machine is controlled by the CNC shield. Although the final axis, for instance, A-axis, is for the choice of providing the rotating motion to the cutting instrument, it should be noted that the X-Y axis is a linear axis for movement while the Z-axis operates the cutting motion. Three jumpers on each axis may be configured to determine how the axis steps. It is directly connected, and spindle enabled. To make the connection possible, it contains a coolant. As a control program, it makes use of GRBL.

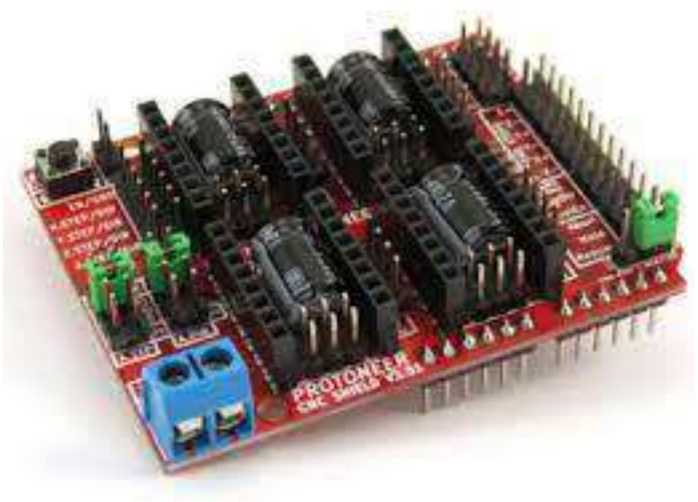


Figure 20: CNC shield.

Following are the specifications of the CNC shield.

Parameters	Specifications
Motor voltage	9V – 36V
Logic circuit voltage	3V – 5.5V
Current	4A (max)

Table 2: Specification of CNC shield

3.2.3 Stepper Motor

With computer control, the stepper motor is employed to attain the precise position. Stepper engines are the best choice for applications that call for a quicker environment and shorter distances since they have the ability to deliver strong torque at low speed while minimizing vibration.

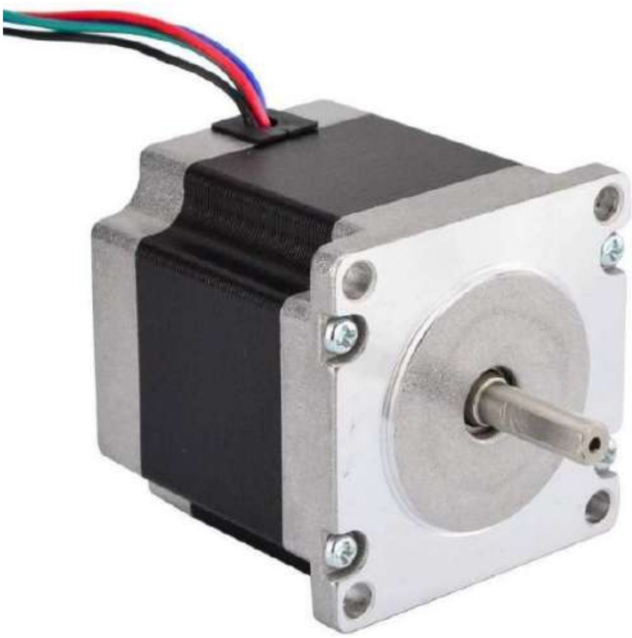


Figure 21: Stepper motor

Following are the specifications of the Nema 23 stepper motor.

Parameters	Specifications
Wire	4
Current	2.8 A
Holding torque	126N.cm
Step angle	1.8
Voltage	2.5V

Table 3: Specification of Nema 23 stepper motor

3.2.4 Stepper Motor Driver

It is suitable for driving bipolar stepper motors. It is cost effective. Its supply voltage is up to 40VDC. Its rated output current ranges from 0.5 to 4A. Set the current via 8 DIP switches. The micro steps are set according to the step angle of motors. The micro steps range is 200 to 6400 micro steps set via DIP switch.

Figure 22: Stepper driver TB6880

3.2.5 Spindle:

The spindle is the component on which shaped milling cutters are attached for cutting features in rotating-cutter woodworking machines. The

CNC machine's spindle is its brain. When using a tool to grind, crush, or create a pattern on a workpiece, a spindle is a revolving shaft with a fixture to retain it. The spindle functions as a CNC machine in this project to cut a piece of wood.

Figure 23: Spindle

Following are the specifications of the spindle.

Parameters	Specifications
Model Number	300W Spindle Motor
Operating speed	3000-12000r/pm
Voltage	12V-48 V
Maximum Torque	400mN.m
Diameter	52mm

Table 4: Specification of the spindle motor

3.3 Mechanical Components

The specifications of all the mechanical parts are as follows:

Name	Size	Components	About Component
Aluminum profile (2040)	400x600		Aluminum alloys are the raw materials for aluminum profiles, which are then extruded into shaped products.
Shaft (16mm) (12mm)	400mm 600mm 200mm		A shaft is a spinning machine component that transmits power from one part to another or from a machine that generates power to a machine that absorbs power. Shafts are typically circular in cross-section.
Linear bearing (16mm) (12mm)	37mm 28mm		As a form of bearing with minimal friction, linear bearings "bear" or sustain the load of the carriage throughout its single-axis linear movement.

Name	Size	Components	About Component
Lead screw	400mm 200mm 600mm		A leadscrew is a screw that is used as a linkage in a machine to convert turning motion into linear motion. It is also referred to as a power screw or translation screw.
Shaft coupler	8mm to 10mm		A mechanical part known as a shaft coupling joins a motor's driving and drive shafts so that power may be transferred.

Table 5: Mechanical components of the CNC machine and their specifications

3.4 Construction

The first step is to create a list of all the parts and supplies needed to build the CNC machine and to analyze their costs. Examples include stepper motors, bearings, spindles, controllers, frame materials, screws, nuts, and bolts. After making a list, you may purchase the materials and supplies from a reliable supplier.

3.4.1 3D Printed Parts

ABS (Acrylonitrile Butadiene Styrene) material is used to print three-dimensional components for CNC machines. A thermoplastic substance for 3D printing is ABS. It is sturdy, heat-resistant, and easily moldable with a 3D printer into a variety of forms. For the frame of the CNC machine, which costs around $25,000, we print 10 parts. The crucial part of the CNC machine is the X side supporter. It offers the liner rail, which is in charge of the horizontal movement during cutting, structural support. The linear x axis rail movement requires the use of two parts.

Figure 24: X- axis side supporter

Both the Y and Z axis stepper motor holders are made with mounting holes that line up with the stepper motor's bolt holes. It was quickly fastened to the holder and secured. This 3D item holds the stepper motor in the appropriate place, ensures smooth movement, and guards against any damage when vibration begins during the cutting process. The Y-axis stepper motor holder enables motion along the linear shaft of the Y-axis. Stepper motor holder for the Z axis allows for vertical movement. To hold the two stepper motors along the y axis, two parts must be printed, while a single piece of z axis stepper motor holder is needed for movement along the z axis.

Figure 25: Y- axis stepper motor holder

Figure 26: Z- axis Stepper motor holder

To guarantee accurate and fluid movement along the y-axis and z-axis, bearing holders are used on both axes. The 3D components' ball bearing inserts enable the shaft to be moved with the least amount of resistance and friction. It assists in reducing friction and raises the machine's overall effectiveness. For movement along the y axis, two parts of the y axis bearing holder are needed, while only one piece is needed for the z axis.

Figure 27: Y- axis bearing Holder

Figure 28: Z- axis bearing holder

The Z axis spindle holder aids in shielding the spindle from harm. This helps to guarantee that the spindle stays steady and centered during the cutting operation. This makes sure that the cutting material is taken from the workpiece at the proper depth and in the proper place.

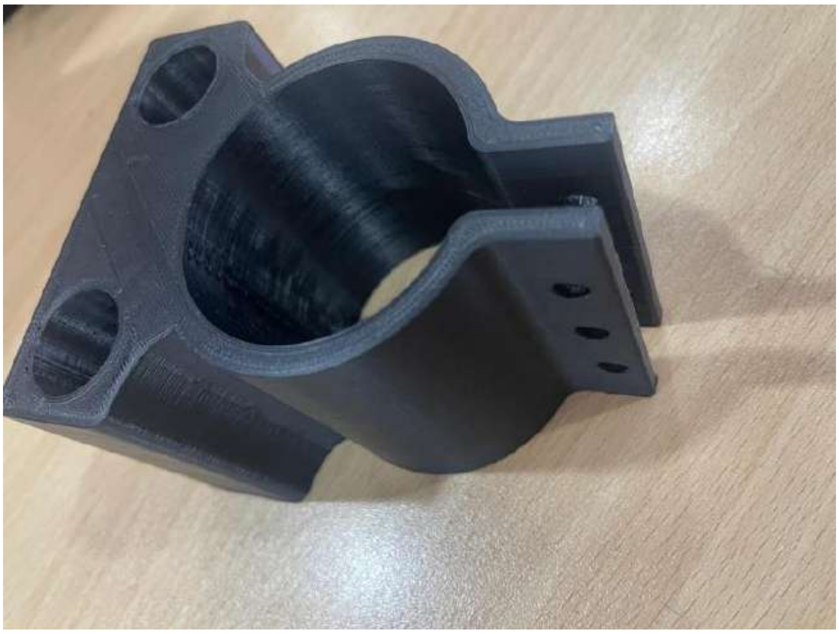


Figure 29: Spindle holder

The X and Z axis connectors aid in keeping the linear motion system stable and aligned during the cutting operation. Incorporate the linear bearing to provide a precise, friction-free movement. Inserting the shaft into linear bearings permits movement along the z and x axes.

Figure 30: Z- X Axis connector

3.5 Cost Analysis

S. no	Name	Size	Number	Picture	Price
1	2040 V-Slot Aluminum Profile Extrusion for 3D Printer & CNC Machine	400mm	2 pcs		2400
2	10mm Screw Rod T10 Threaded Rod For CNC & 3D Printer	200mm	1 pc		500
3	10mm Screw Rod T10 Threaded Rod For CNC & 3D Printer	400mm	1 pc		1000
4	10mm Screw Rod T10 Threaded Rod For CNC & 3D Printer	600mm	2 pcs		3000
5	8mm,Linear Rail Shaft Smooth Rod For CNC Machine And 3D Printer	200mm	2 pcs		???
6	8mm,Linear Rail Shaft Smooth Rod For CNC Machine And 3D Printer	400mm	3 pcs		1420
7	8mm,Linear Rail Shaft Smooth Rod For CNC Machine And 3D Printer	600mm	8 pcs		
8	Arduino UNO R3 Development Board	///	1 pc		1900
9	CNC Shield Board for A4988 Stepper Motor Driver For Arduino V3 Engraver 3D Printer	///	1 pc		300
10	DRV8825 Stepper Motor Driver Soldered Pins with Heat Sink	///	4 pcs		2200
11	T10 lead screw nut	8mm	4 pcs		3200
12	Circular bearings	8mm	4 pcs		700
13	Linear bearings	8mm	28 pcs		10400
14	M5 nuts and bolts				200 + 1130

S. no	Name	Size	Number	Picture	Price
15	Nema 23 stepper motor + driver		4 , 4		22000
17	SMPS power supply		1		4000
18	Spindle 300W		1		12000
19	Shaft coupler 8mm to 10mm		4		3000
20	3d parts		10		25000
Product cost					96350
Shipping cost					900
Sub total					97250

Table 6: List of the mechanical parts used to build the CNC machine and their costs

3.6 Workflow of the Machine

The main working of CNC machine is based on software, microcontroller and motors which is demonstrated in the flow chart form below as:

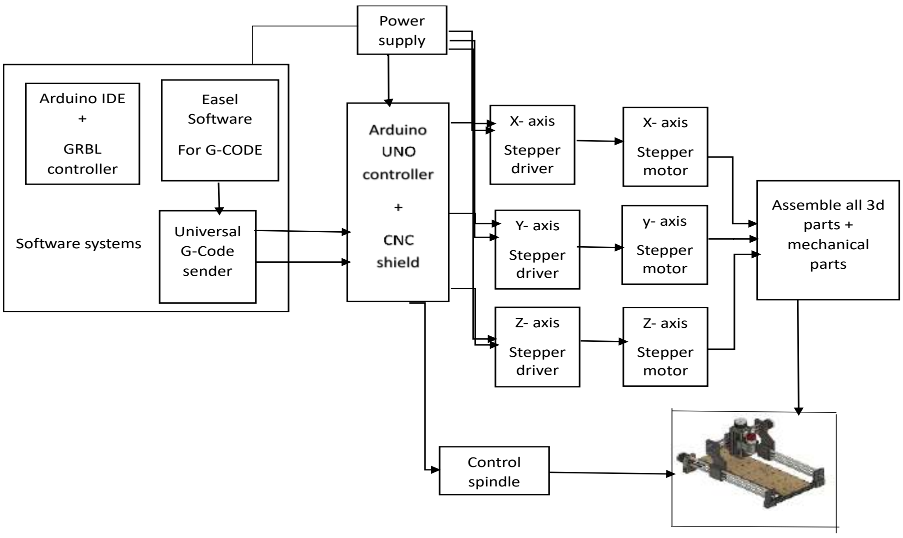


Figure 31: Block Diagram of overall process

Using CNC shield and Arduino, check the stepper motor's rotation and direction. Using the included headers, attach the CNC shield to the Arduino board.

Figure 32: CNC shield with Arduino

Then, to prevent the stepper motors from overcurrent, install the drivers on the CNC shield. Since stepper motors demand more current and voltage than an Arduino board can supply, they need a driver TB6880 to function. The four pins of the stepper motors and the four pins of the drivers must be connected to link the stepper motor with the drivers. The drivers must then be connected to the CNC shield so that the motors may receive power and signals.

The proteus software is used for the connection of the drivers with Arduino and stepper motors. For the simulation of the circuit in proteus use the Arduino IDE in which code is pasted. After importing the hex file insert this file in circuit which is drawn in proteus for proper working of the circuit.

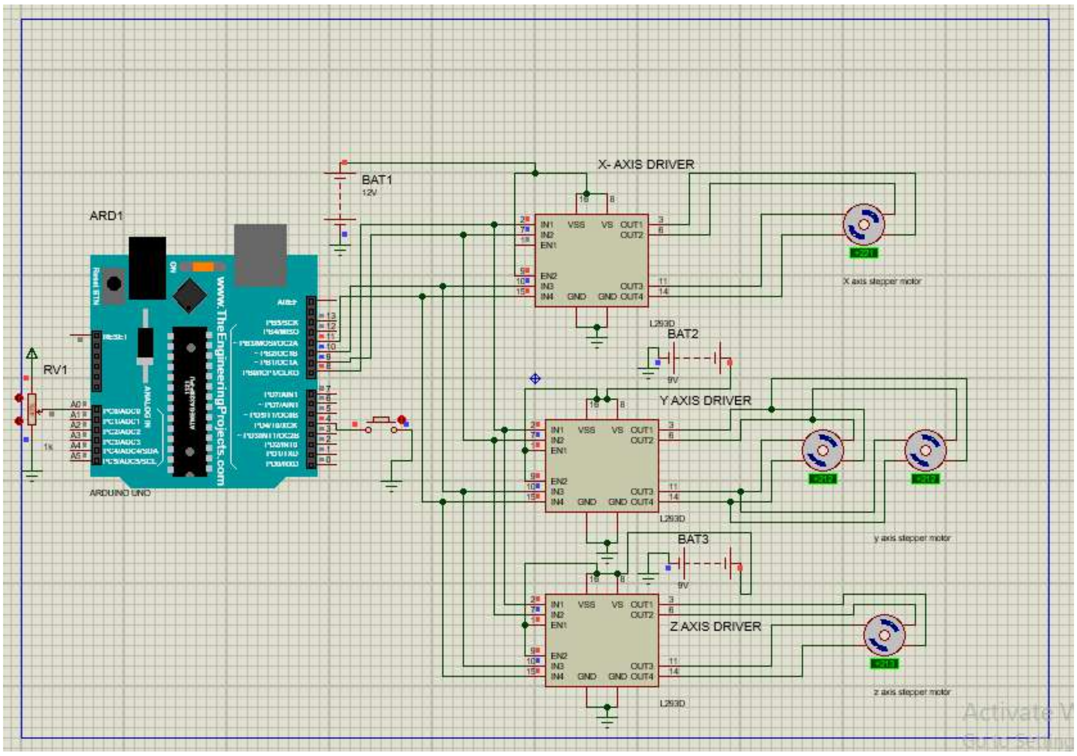


Figure 33: Circuit Simulation in proteus

```
#include <Stepper.h>

// change this to the number of steps on your motor
#define STEPS 20

// create an instance of the stepper class, specifying
// the number of steps of the motor and the pins it's
// attached to
Stepper stepper(STEPS, 8, 9, 10, 11);

const int button =  4; // direction control button is connected to Arduino pin 4
const int pot    = A0; // speed control potentiometer is connected to analog pin 0

void setup()
{
  // configure button pin as input with internal pull up enabled
```

Figure 34: Arduino code for simulation of circuit in proteus

After the simulation implement the circuit connection in hardware for the working of the stepper motors.

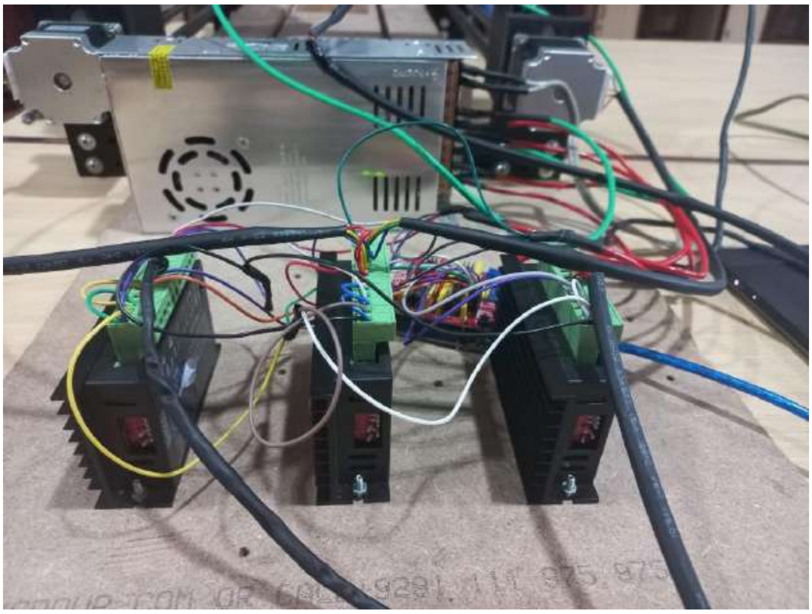


Figure 35: Connection of stepper motors with CNC shield

Connect the Arduino to the PC using a USB cable after making these connections. Install the GRBL library after that in the Arduino IDE. Then launch the Arduino IDE and run the code to test the motors. Insert the code into the Arduino. Observe the motors when the power source is on. GRBL software may be used to manually inspect the motors as well. This application is free and open source. It is simple to install, and you can then use the GRBL controller to control the motors manually or automatically.

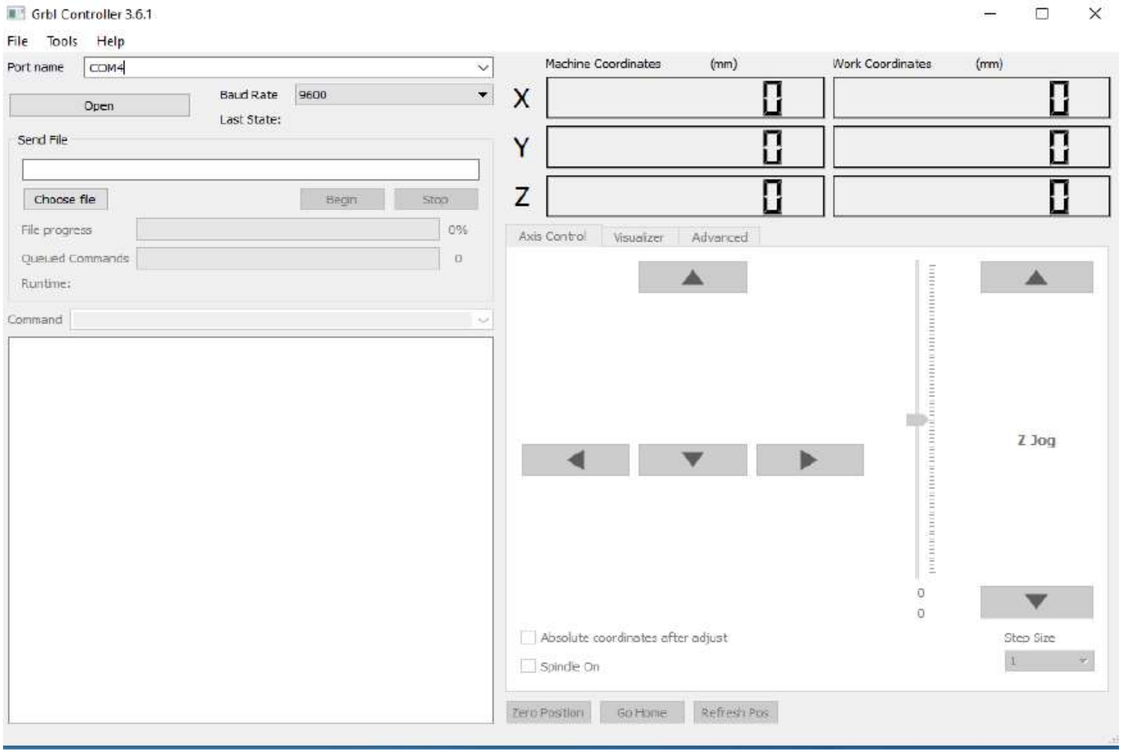


Figure 36: GRBL controller workspace

By pressing the jog buttons that appear on the screen after choosing the appropriate port and clicking open, you may manually control the x, y, and z axis motors.

3.7 Generating G – Code

Software called Easel is used to produce G-Code. Although the Easel program is a premium product, you can use it for 30 days without paying anything. Create an account before using the easel program. This program has many wonderful features, including the ability to choose the machine type, drill bit, and material kind. Once the home page has loaded, select the machine configuration that best suits your machine.

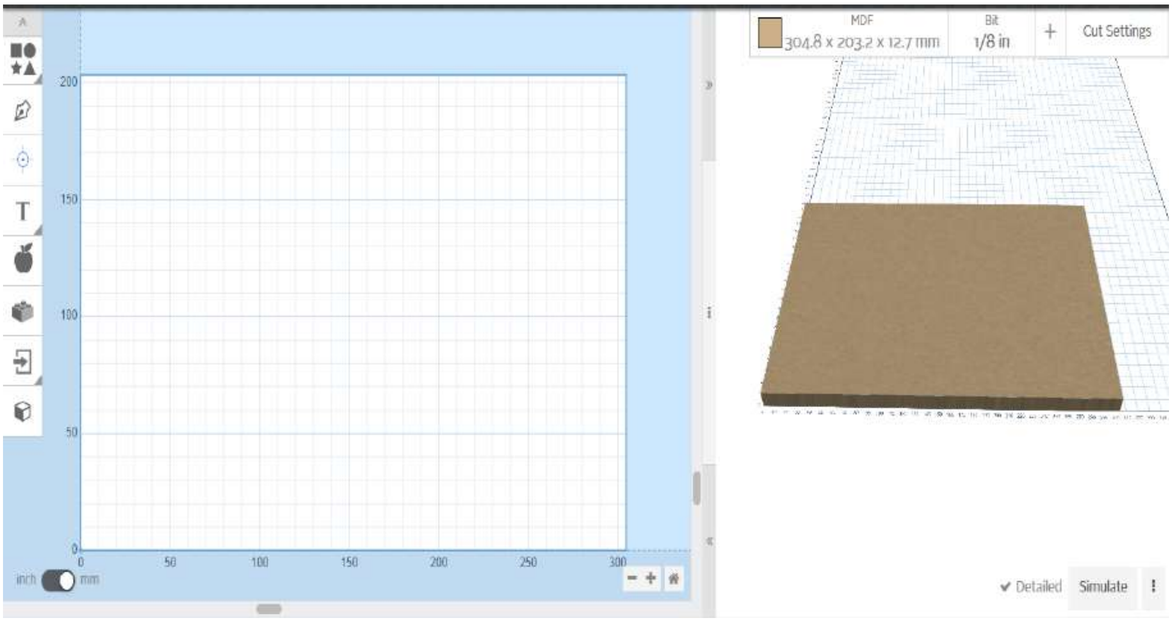
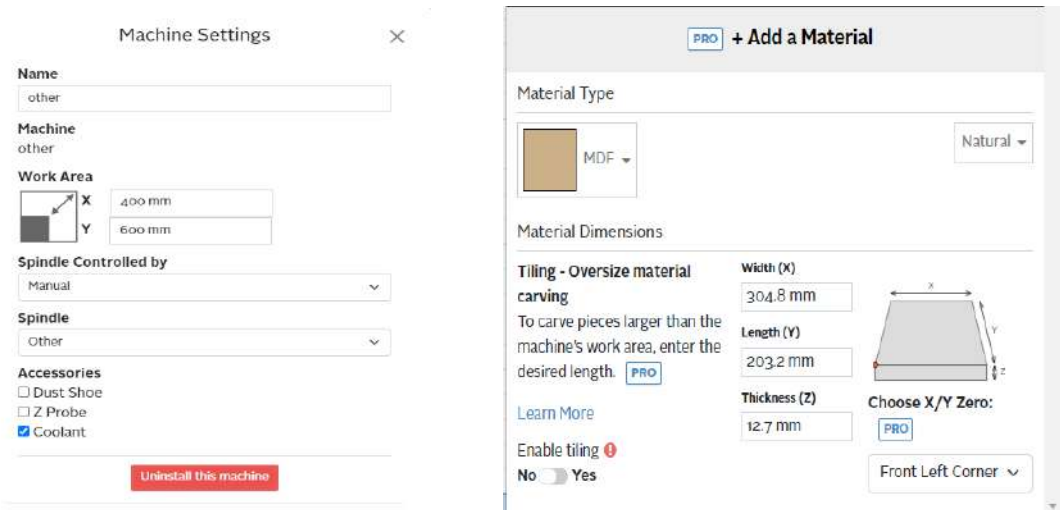


Figure 37: Easel interface

After that, configure the machine settings and choose the bit and material types.



(a) (b)

Figure 38: (a) Machine Setting **(b)** Material setting.

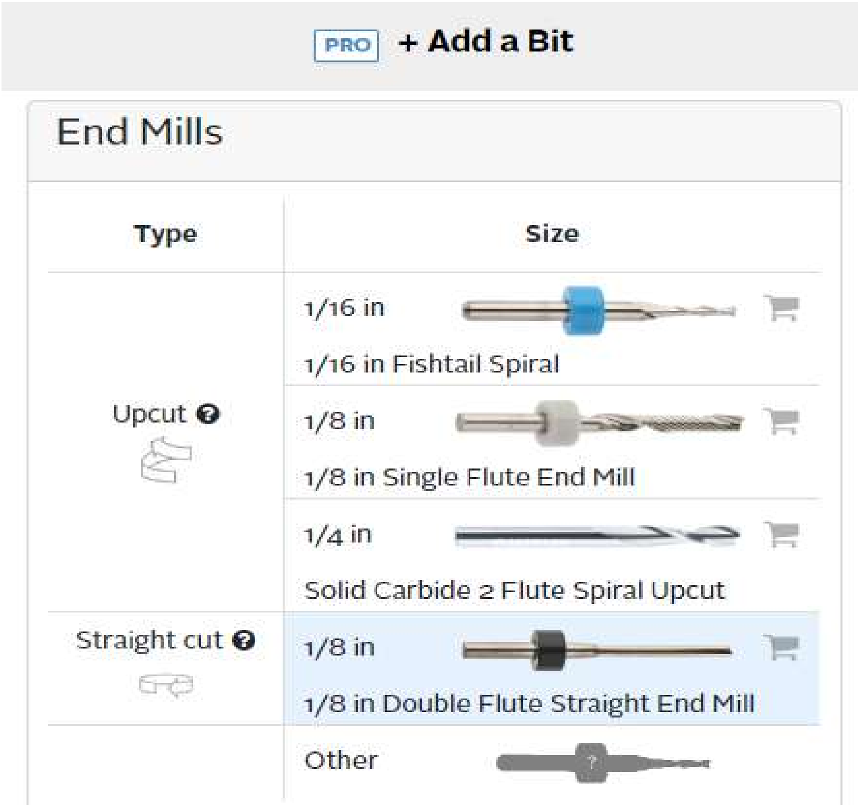


Figure 39: Bit setting

Once you have completed all of these steps, you can type or doodle. The depth and many other parameters may then be chosen based on your needs.

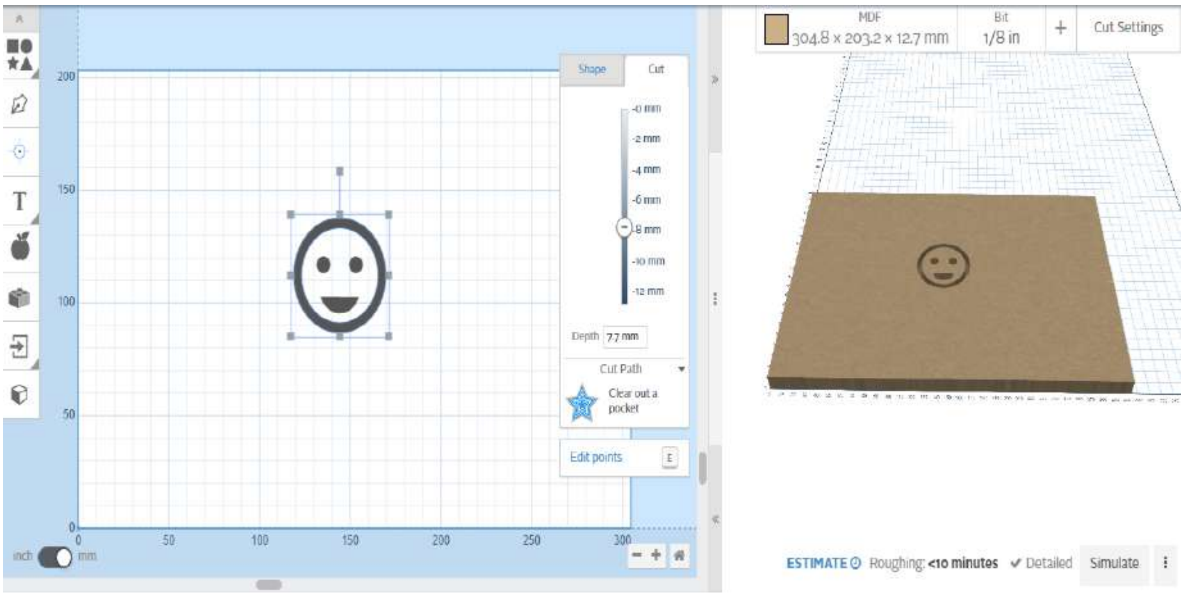


Figure 40: Drawing an object On Easel

Verify these parameters and run the simulation after connecting the USB cord to the device.

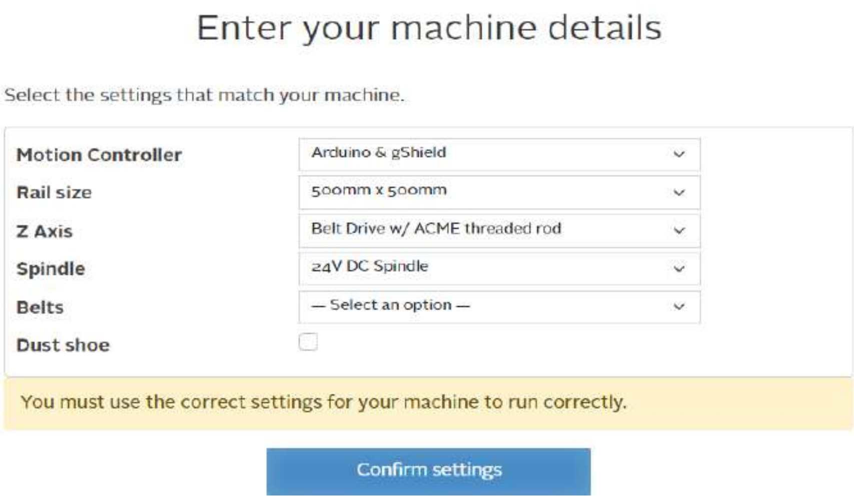


Figure 41: Setting of confirmation window

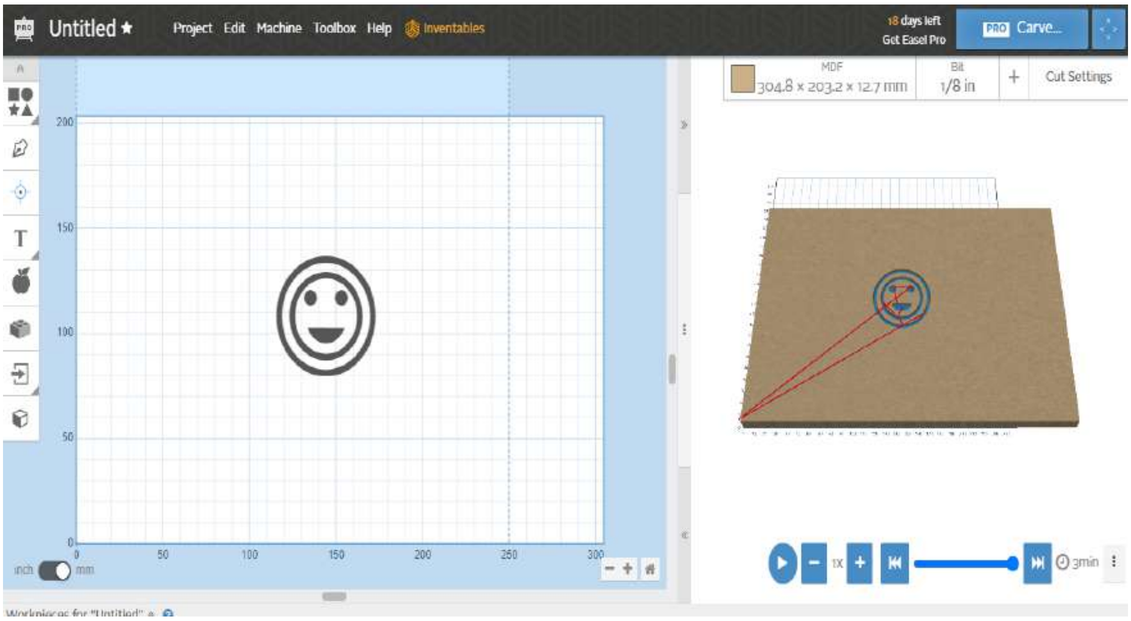


Figure 42: Simulation In easel software

You may also obtain G-code via the Easel program. This code opens in the default G code sender. After choosing a port and waiting for an Arduino connection, click the run button to begin the simulation. Additionally, you may see it on the right side of your computer's display.

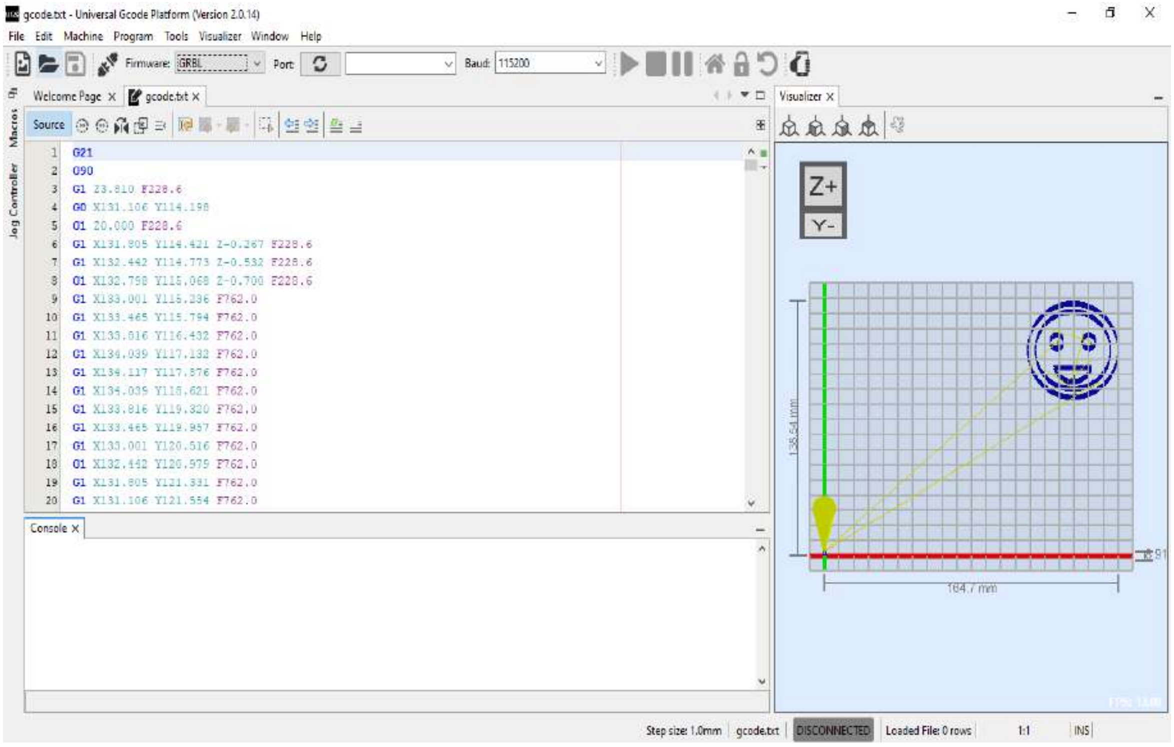


Figure 43: Universal g-code sender interface

Next, use a USB cable to connect to the device and launch the simulation to test the device. The machine's frame, which provides the other parts with structural support, is usually put together first. The machine's frame, which serves as its supporting structure, should be sturdy and strong. Aluminum extrusion, shaft, lead screw, and 3D printed components make up the frame material. You can weld, use screws, nuts, or bolts to assemble the frame. The linear rod is placed to create a frame. Lead screw and bearings are attached to the printed x- and y-axis supports. These parts enable the machine's x and y axis motion to be precise and fluid. To move the shaft smoothly, insert the bearings into the 3D-printed components. After that, connect the shaft to the bearings.

Figure 44: Bearings in 3d printed parts

Figure 45: Shaft in Bearings

After that, put all the 3D-printed components and other pieces together to create the CNC machine's frame.

Figure 46: Frame of CNC machine

Connect the stepper motors to the linear component after mounting them to the machine frame. Connect the electrical wires with the control board, stepper motor drivers, and other electronic components. These parts will regulate the machine's motion and enable you to operate and program it.

Figure 47: Complete Construction of CNC machine

Chapter 4

4.1 Proposed Solution

This project proposes an innovative solution to bridge the gap between limited manual techniques and inaccessible large-scale CNC machines with a mini 3-axis CNC machine designed for affordability and adaptability. Inspired by the maker community's need for accessible tools, this machine overcomes the inherent inaccuracies of conventional techniques and unlocks the versatility of large-scale CNCs for an affordable price. By achieving high accuracy and repeatability, this project empowers a wider range of individuals and businesses to realize their creative visions, from complicated prototypes to customized products, resulting in a new era of accessible, precise, and flexible design creation.

4.2 Results and Discussion

In this section, we conducted tests on our CNC machine to evaluate its engraving capabilities on two different materials: wood and acrylic and PCB. We began by creating 3D models of the prototypes that we intended to engrave. These models served as a reference for the desired designs. Next, we proceeded with the hardware setup of our CNC machine and initiated the engraving process. The results obtained from these tests, including the quality and precision of the engravings on both wood and acrylic, and PCB are presented in detail in this section. By examining these results, we can gain insights into the performance and effectiveness of our CNC machine for engraving purposes.

4.2.1 Engraving on Wood

We employed the user-friendly Easel software to engrave our project name and group members' names onto wood using our CNC machine. Following the selection of a working area measuring 85mm x 130mm and a material thickness of 15mm, we positioned the starting point at the center of the workspace. By utilizing a 90-degree ¼ inch SHK bit and MDF as the wood material, we fine-tuned the step size for the XY and Z axes to achieve precise engraving with a depth of 2mm. Furthermore, we carefully adjusted the feed rate to 500mm/min, the plunge rate to 230.6 min/mm, and the depth per pass to

0.4mm. Using the Easel software, we entered the desired text and configured all the engraving settings as depicted in Figure 4.1. The engraving process took approximately 15 to 20 minutes to complete, resulting in a visually appealing output displayed in Figure 4.2, featuring our project name and group members' names beautifully engraved onto the wood surface.

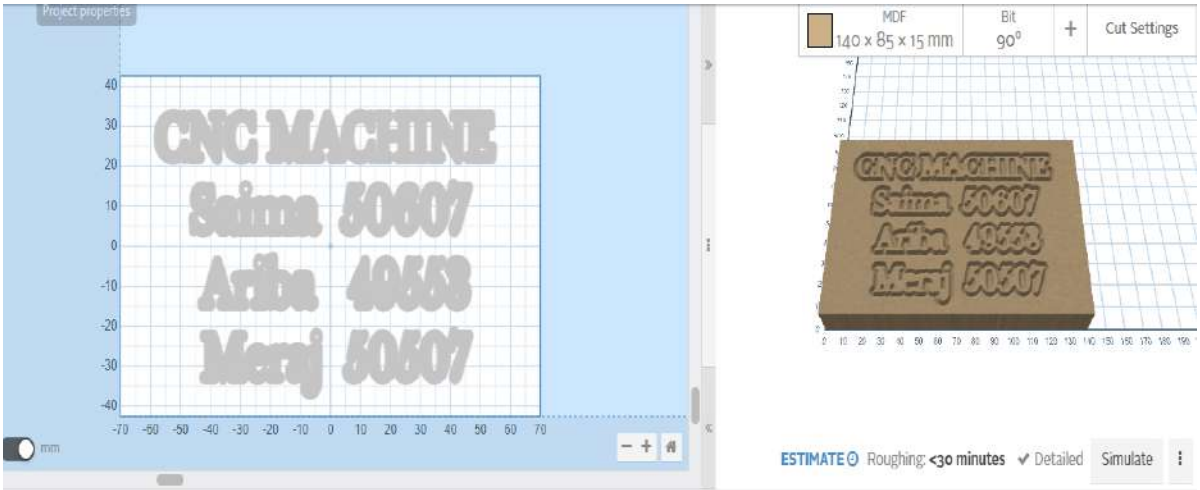


Figure 48: 3D model of the protype to be printed on wood with CNC machine built on Easel software

Figure 49: Engraved output on Wood

The outcome of engraving our project name and group members' names onto the wood surface using the CNC machine and Easel software was impressive. The machine executed the engraving process with great precision, accurately reproducing our desired model on wood. The engraved text and design exhibited clear and well-defined lines, showcasing the capabilities of the CNC machine to accurately replicate intricate details. The final result was visually appealing, with our project name and group members' names beautifully etched onto the wood, adding a personalized touch to our project. This successful outcome demonstrates the effectiveness of the CNC machine and Easel software in achieving precise and aesthetically pleasing engravings.

We also created another design for engraving on wood using the Easel software. In this design, we wanted a deeper engraving effect, so we set the depth to 4mm. All the other parameters remained the same as before. By adjusting the depth, we were able to make the engraving more noticeable and give it a unique look. This experiment allowed us to explore different engraving options and see how the CNC machine and Easel software can adapt to different design preferences.

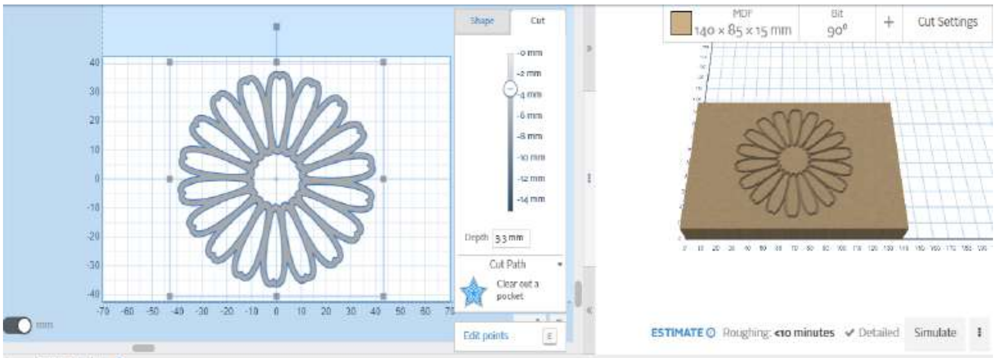


Figure 50: 3D model of a flower to be printed on wood with CNC machine built on easel software

Figure 51: Engraved output on Wood

The second engraving design on wood using the CNC machine and Easel software resulted in a deeper and more noticeable engraving effect. By adjusting the depth to 4mm while keeping other parameters the same, we achieved a visually striking outcome. The CNC machine demonstrated its precision and capability to capture intricate designs, allowing us to create unique and visually appealing engravings on wood surfaces.

4.2.2 Cutting on Wood

We create design for the cutting on wood using Easel software. Set the depth for the cutting on wood according to the thickness of the wood. The thickness of the wood is 3mm, so we set the depth in software is 3mm for cutting purpose. The feed rate is 800mm/min and plunge rate are 300mm/min. The safety height should be set to 4.5mm for giving better result.

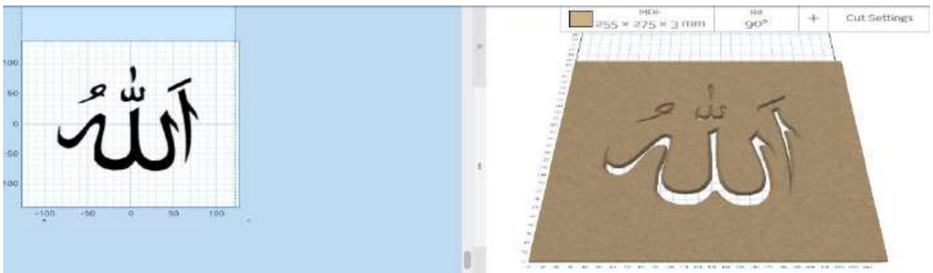


Figure 52: Design built on ease software for cutting on wood with CNC machine

Figure 53: Cutting output On Wood

The cutting design on wood using CNC machine and easel software give more clear and accurate results. The CNC machine demonstrated its precision and capability to capture intricate designs, allowing us to create unique and visually appealing cuttings on wood.

4.2.3 Carving on Acrylic

For Acrylic engraving, we utilized the Easel software, which provided us with the necessary tools for designing number plate. The acrylic material was selected, and we used a 1/8 double flute straight upcut bit for the engraving process. The dimensions of the acrylic were set at 170x100mm, with a thickness of 1mm. To create the design, we followed the software's instructions and selected the desired components and connections. The depth of the engraving was set to 0.2mm to ensure precision. With a feed rate of 700mm/min, a plunge rate of 338min/mm, and a depth per pass of 0.4mm, we optimized the parameters for efficient engraving. Once all the settings were adjusted, we manually lowered the bit to touch the surface of the material and initiated the engraving process. Following is the design o to be printed on acrylic.

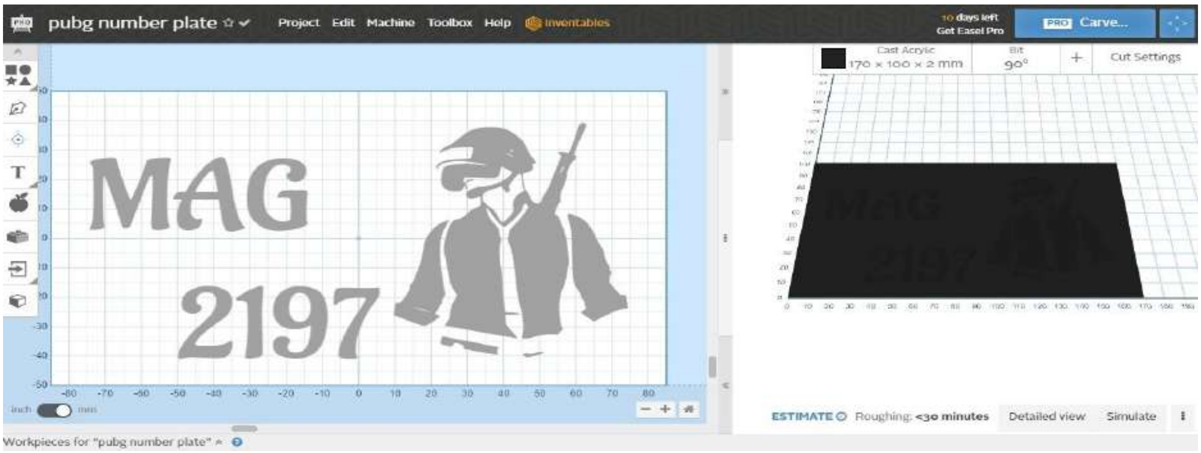


Figure 54: Design a number plate on Acrylic material with CNC machine built on Easel Software

Figure 55: Carved output on Acrylic

We created another design for the carving on acrylic using Easel software. This design contain our group members' name, CMS ID, project title and our supervisor name. The depth for this design is 0.3mm. Remaining parameters like feed rate, plunge rate and depth per pass is same for this design. The design approximately completed in 1 hour.

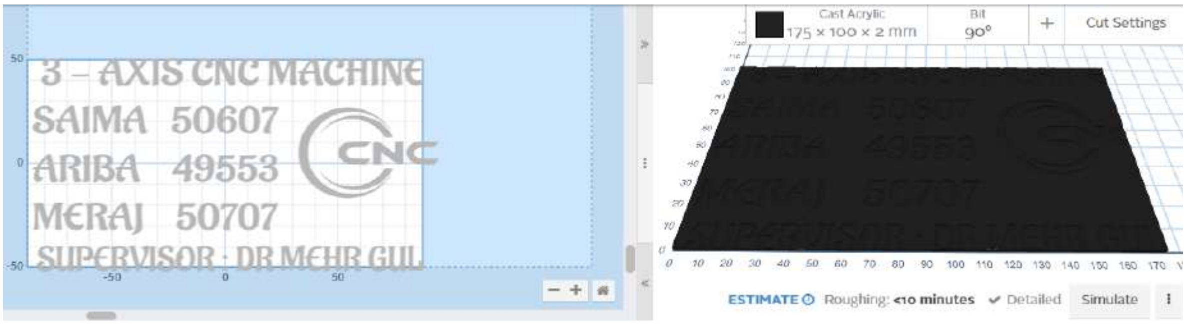


Figure 56: Text written on acrylic using Easel software

Figure 57: Output carved on acrylic

This output we put on our machine which shows our group members' name, CMS.ID, project title and our supervisor's name. The CNC machine demonstrated its precision and capability to capture intricate designs, allowing us to create unique and visually appealing carvings on acrylic surfaces. Acrylic gives more accurate, precise and noticeable result than others material. Both the design gave very beautiful result with the CNC machine.

4.2.4 Carving and Milling on PCB

Easel software is used for making the circuit on PCB. Select the PCB material and 1/8 90-degree bit is used for craving. The dimension of the PCB is 130x70 and its thickness is 1mm. Make a circuit of rectifier then select the depth is 0.1mm. The feed rate is 700mm/min and plunge rate are 338min/mm and its depth per pass is 0.4mm. For making holes in a circuit 1/8 fishtail down cut bit is used after setting all the setting lower the bit down manually to touch the surface of the material and start the carving.

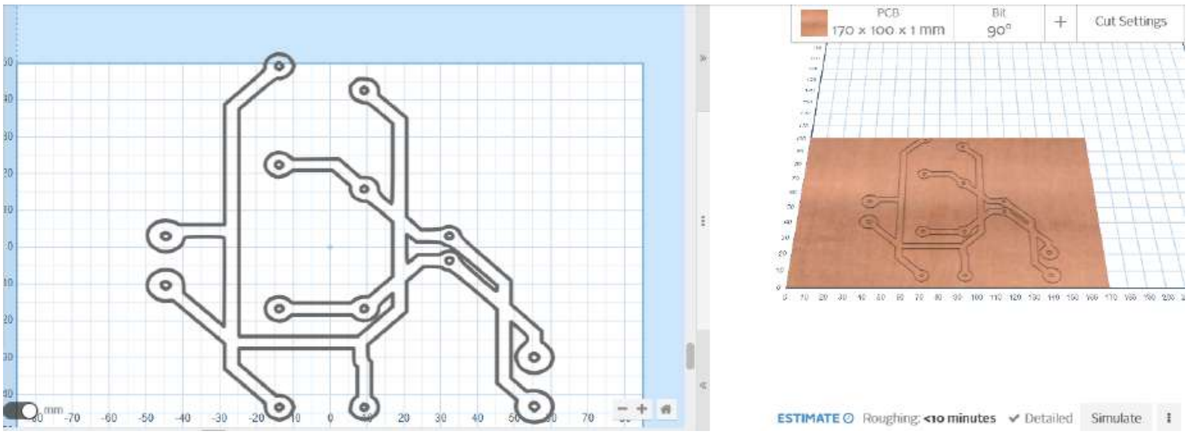


Figure 58: Design a rectifier circuit On PCB using Easel Software

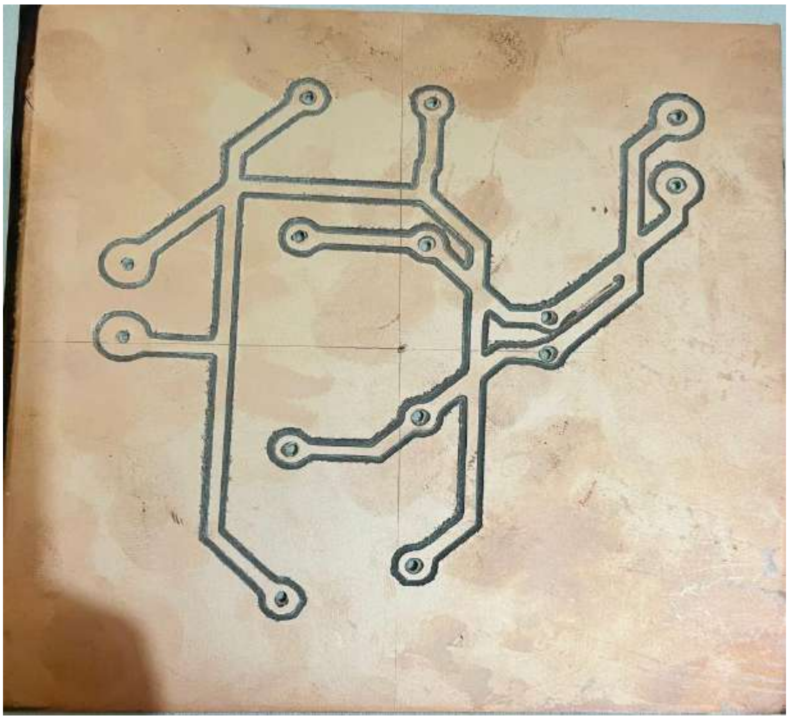


Figure 59: Carving Output on PCB

4.2.5 Analysis of Results

Table 6 highlights the contrasting performance of the mini-CNC machine across various materials using the same design and drill bit. Notably, all workpieces maintained identical dimensions (170mm x 100mm x 12mm). While wood and acrylic emerged as the most efficient substrates, requiring only 9 minutes each, PCB lagged at 19 minutes. Interestingly, precision followed this pattern, with wood achieving 92%, acrylic 96%, and PCB slightly lower at 90%. This suggests a potential trade-off between speed and accuracy for harder materials like PCB.

Type of Material	Bit used	Carving depth mm	Time estimated	Carving Accuracy
Wood	V-bit 90 degree	4mm	9 minutes	92%
Acrylic	V-bit 90 degree	4 mm	9 minutes	96%
PCB	V-bit 90 degree	4 mm	19 minutes	90%

Table 7: Comparative Analysis of the carvings done on different materials

Despite the extended carving time for PCB, it's crucial to note that even its lower accuracy falls within acceptable tolerances for complex designs, showcasing the machine's outstanding capabilities. The ability to effectively handle diverse materials, from softwoods to hardened PCBs, within a relatively short timeframe underscores the success of this research. This mini-CNC machine proves adept at performing complex carving tasks, opening doors for a wider range of applications in prototyping, small-scale production, and personalized fabrication across various material domains.

Chapter 5

5.1 Summary and Future work

This thesis is mainly about design and construction of mini 3-axis CNC machine where the machine is used in manufacturing processes and is becoming a widely successful technology in terms of manufacturing workpieces. Simultaneously, CNC machines can produce different kinds of products as it works on wood, plastic, or metals, depending on the structural strength of, manufacturing of the machine. The main working process of a CNC machine begins with 2D or 3D modeling in the computer utilizing computer-aided design software (CAD) where we used Fusion 360. Using this software, the CNC machine is modeled. Moreover, this CAD design file is further given to another software known as Computer-Aided Manufacturing (CAM). This software is responsible for generating optimized tool paths for the CNC machine to be followed. Similarly, an other CAD software is used for the modeling of 3D parts of the CNC machine. As the software modeling of the machine is achieved we moved towards the hardware part where we established the machine's dimensions that is 400x600x200mm taking into account the size of the workpiece which is 250x400. Before installing the stepper motors in the hardware form the simulation of the circuit in proteus is used in the Arduino IDE in which code is pasted. After importing the hex file we inserted this file in circuit which is drawn in proteus for proper working of the circuit. Furthermore, there is used a GRBL software which is simple to install, and can then be used the GRBL controller to manually or automatically control the motors. In contrast, an other software called Easel is used to produce G-Code as well as any design feed to it will be obtained on the work pieces. In this project three type of work pieces are designed on using the CNC machine naming them as: wood, acrylic and PCB. CNC machine has always been the top recommendation for the industries where automotive industries should utilise this machine as much as possible to make their work easy and less time consuming.

Here are some ideas for the future which can be implemented on our CNC machine for advanced results, safety, accuracy etc…

1. **Enhanced Spindle Control:** A variable frequency drive (VFD) can be incorporated to enable more precise control over the spindle speed. This would

allow to optimize the cutting parameters for different materials and achieve even best possible results.

2. **Automatic Tool Changer:** By implementing an automatic tool changer mechanism one can enable quick and effortless swapping of different tools during the machining process. This would enhance the machine's flexibility and reduce the time for manual intervention.
3. **Enclosure and Dust Collection System:** Building an enclosure around the machine to contain dust and debris generated during the engraving and milling processes. Additionally, one can integrate a dust collection system e.g vacuum, to maintain a clean working environment and improve overall efficiency.
4. **CNC Machining Probes:** Integrate touch probes or tool length sensors to automate tool height and work piece surface measurements. This would streamline the setup process, increase accuracy, and reduce the chances of errors.
5. **Additional Axis:** Adding a fourth or even fifth axis to enable more complex machining operations, such as rotary or multi-sided milling. This would expand the capabilities of our CNC machine and open up possibilities for more intricate designs.

Chapter 6

6.1 Conclusion and Recommendation

This project addressed the limitations inherent in traditional mass production and the inaccessibility of large CNC machines by designing and constructing a miniaturized 3-axis CNC machine. This compact tool, measuring 400x600x200mm with a dedicated 250x400mm working area, employs automated control systems and G-code commands to overcome human error and deliver laser-sharp accuracy while keeping the cost within budget. Its dedicated microprocessor guarantees precise and consistent carving in various materials like wood, paper, tile, glass, and even certain soft metals.

The outcomes of this research are fascinating. Wood and acrylic demonstrate exceptional performance, requiring only 9 minutes for sophisticated carving with accuracy exceeding 90%. Even PCB, although requiring slightly longer carving times, exhibits impressive adaptability with an accuracy of 90%. This versatility demonstrates the machine's potential for a wide range of applications and highlights the accomplishments of this study. From this, we conclude that miniaturization, wielding advanced control, carves not just materials but possibilities. This project combines precision with affordability, unlocking diverse creative opportunities through its compact frame.

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