

Design and Fabrication of CNC Pyrography

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Abstract : The design and development of the CNC Pyrography is to automate the sketch of a two dimensional image on a rectangular wooden piece. CNC Pyrography setup sketches by moving a pyrographic pen across the surface of the wooden workpiece. This project is to operate drawing the figure or text by burning the wood. By using this CNC pyrography setup, we can draw the complex line art including text. The result is very accurate. This setup mainly uses Inkscape with GRBL extension. Based on G-code command, the desire outputs can be loaded rapidly. This research project controls the mechanical movements with the electronics pulse.

I. INTRODUCTION

A CNC pyrography is an automated machine which burn on the given work piece (wood), the design required by the user. The design can either be written as a program using G-codes and M-codes or it can be automatically generated by using soft wares like Inkscape or BenBox. A more artistic and realistic image can be achieved by using this machine. All the human errors that occur during manual designing can be reduced by this machine. The main focus is to push the limits of art and technology with the purpose of creating a low-cost solution that anyone could obtain. However, one should be passionate about building a system out of mostly open hardware solutions, allowing hobbyist and students to build on top of our initial design. We believe that not only does that improve the overall advancement in the field, but also motivates future generations to enter the field of embedded systems. This can potentially create a new market for natural art forms where everyone can be involved. It also raises opportunities for aspiring artists that lack the skills to create art with their hands.

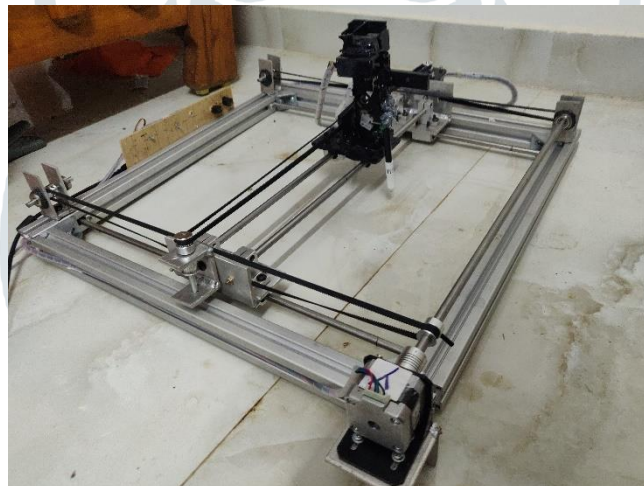


Figure 1: CNC Pyrography setup

Systems like CNC Pyrography allow us to emulate the skilled hands of an artist with hardware and software. The art form focuses on Pyrography. CNC Pyrography can create an art from analog to pyrography several times faster than if done by hand. Our system does this by combining a Burner Pen with open hardware CNC solutions. The art is created by first sending a grayscale image from a host application (Inkscape or BenBox) to Arduino. The image sent can then be burned on a piece of wood without the need of a host being present. This machine differentiates itself from its competition mainly because of its cost, which is about 5 times less than a normal CNC machine, and its ability to burn images in different shades of grey, instead of just monochrome. Through CNC Pyrography, users can achieve results as beautiful and artful as with a human hand.

II. LITERATURE REVIEW

Haripriya Joshi et al. (2018) - In this work, using Arduino as microcontroller they have designed and fabricated mini CNC plotter. In which it recognizes the G codes and executes accordingly. The CNC plotter which they had designed was capable to draw difficult design on paper. Their machine worked on input as a G codes of design and converting it via use of software further transferring to Arduino CNC Shield, Stepper motors, Servo Motor. The Setup of machine is flexible so that it can be transported easily and Maintenance time is short. [1]

R. Dayana et al. (2014) - in this work, they have designed the plotter in an economical way where in the tool can be replaced based on the application such as engraving, laser cutting, printing etc they have used ultra-low power microcontroller MSP430. they have used MATLAB to analyse data and develop algorithm depending on the system. Their system consisted of belt drive with pulley with stepper motors. [2]

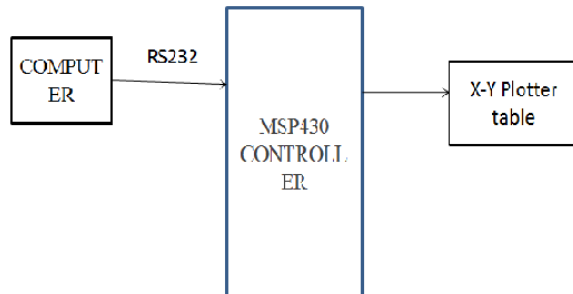


Figure 2: Block Diagram of complete setup

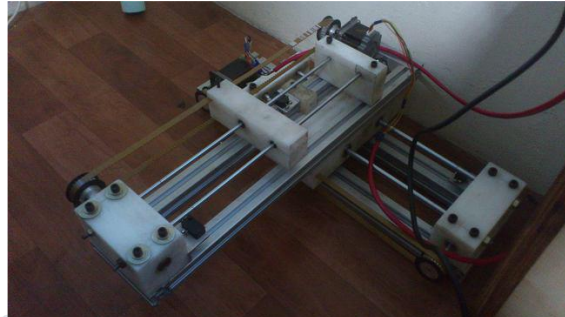


Figure 3: Complete hardware setup

Aneeta pinheiro et al. (2016) - In this project they have designed a low cost three axis mini CNC plotter using stepper motor, Arduino, and a motor control software. The numerical data required for working of the plotter is provided by a program called part program which in turns converts the numerical data to electrical signal. driving system includes stepper motor, which converts electrical pulses into discrete mechanical rotation of motor shaft. [3]

Shani Ranjan et al. (2018) – In this work, the use of Inkscape to process the image to get a vector file which can be used to generate the G-codes for the complicated images. The machine developed by them had 3 degrees of freedom, in which pen could move up and down in z axis and could move freely on X and Y direction. The base of the robot was made of stainless steel, and the power was transmitted through lead screw. The X axis was attached with two plastic parts which was cut to fit the construction to ensure the straightness of the Y axis. [4]

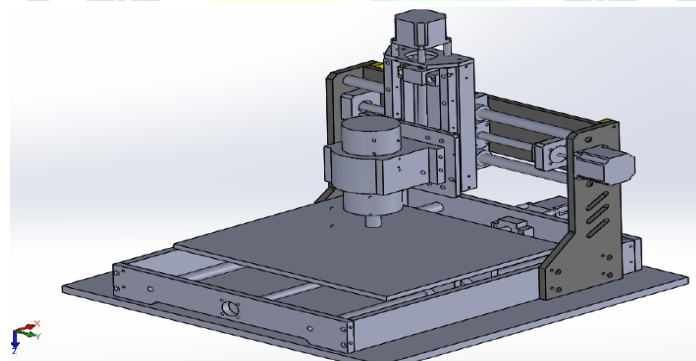


Figure 4: Design of CNC Plotter by Shani Ranjan [4]

Samah mohtar et al. (2013) - The mechanical subsystem of a CNC provides the means needed to cut and machine various materials for a given job. The choice of materials has a direct impact on performance, precision, repeatability, longevity, and mechanical noise transfer into the parts. The mechanical subsystem is comprised of the guide system, the drive system, and the frame housing structure. Each of these systems has a direct impact on the aforementioned qualities of a CNC. The remainder of this section will focus on the types of these systems and look at the advantages and disadvantages of each. [5]

Mihai Rata et al. (2015) - In many specific laboratories the students use only a PLC simulator software, because the hardware equipment is Expensive. This paper presents a solution that allows students to Study both the hardware and software parts, in the laboratory Works. The hardware part of solution consists in an old plotter, An adapter board, a PLC and an HMI. The software part of this Solution is represented by the projects of the students, in which They developed applications for programming the PLC and the HMI. This equipment can be made very easy and can be used in University labs by students, so that they design and test their Applications, from low to high complexity [7], [8].

The proposed application is used in laboratory by the students. The idea presented in this paper is to control an old XY Plotter with a PLC-HMI system. It makes the lab works more practical, getting the students closer to real world applications. Our system permits that the laboratory be more practical, in order to provide students an experience closer to real world applications. [6]

Summary

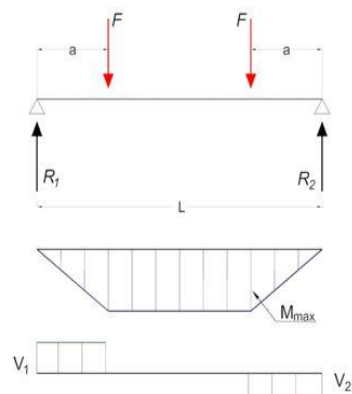
In conclusion, this chapter mainly summarizes some key concepts of computer numerical control and design considerations of CNC machine tools mentioned in literature. These concepts will be implemented in the whole design process of this project. Several components are chosen based on the reasons discussed in section 2.1. The literature provides clear background knowledge and guidance for the development of a small-scale CNC machine tool.

III. CALCULATIONS

BASE FRAME CALCULATION

It is the supported beam at two ends with eccentric loads

Beam Supported at Both Ends - Two Eccentric Loads



F = 50 N.
a = 45 mm.
L = 500 mm

Considering the FOS, a weight of 5 kg acts on the beam.

Assuming g = 10 and F = 5 x 10 = 50 N.

For the cross section of the beam, the standard value of moment of inertia is known to be I = 4.072 cm⁴ and for aluminium material E = 71000 N/mm².

Maximum moment: -
 $M_{max} = F \times a$
 $= 50 \times 45 = 2250 \text{ N-mm.}$

Maximum stress: -
 $\sigma_{max} = (y_{max} \times Fa) / I$
 $y_{max} = 15 \text{ mm (dist from neutral axis to extreme end).}$
 $\sigma_{max} = (15 \times 2250) / (4.072 \times 10^4)$
 $\sigma_{max} = 0.828 \text{ N/mm}^2$

Maximum deflection: -
 $\delta_F = Fa(3L^2 - 4a^2) / (24EI)$
 $\delta_F = 2250(3 \times 500^2 - 4 \times 45^2) / (24 \times 71000 \times 4.072 \times 10^4)$
 $\delta_F = 0.024 \text{ mm}$

Reaction forces: -
 R1 = R2 = F = 50 N. (symmetrical eccentric loads)

Yield stress of aluminium is about 70 MPa(σ_y)
 To find the force acting for this particular stress,

$F^1 = \sigma_y \times A$
 $F^1 = 70 \times 30 \times 30$
 $F^1 = 63000 \text{ N}$

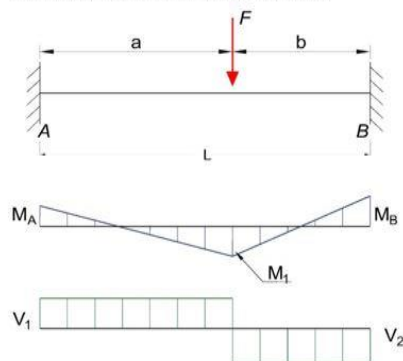
Now to find deflection: -
 $\delta_F^1 = F^1 a(3L^2 - 4a^2) / (24EI)$
 $\delta_F^1 = 63000 \times 45(3 \times 500^2 - 4 \times 45^2) / (24 \times 71000 \times 4.072 \times 10^4)$
 $\delta_F^1 = 30.312 \text{ mm}$

As the deflection is calculated for the yield stress value of the material, it is found that the material starts yielding if the deflection exceeds 30.312 mm but in our working condition, the deflection is calculated to be 0.024 mm which is very less and hence the design is safe.

GUIDE ROD CALCULATION

Considering the fixtures on the rod to be stationary and assuming its weight considering the FOS as 50 N, since the load acts for a short length of the rod, it is assumed as point load. Considering it as a fixed beam, it can be represented as follows

Beam Fixed at Both Ends - Single Point Load



a = b = 250 mm.
L = 500 mm.
F = 50 N

Moment at points A and B: -
 $M_A = M_B = -Fa^3/L^2 = -50 \times 250^3/500^2 = -3125 \text{ N-mm.}$

Moment at loading point: -
 $M_F = 2Fa^4/L^3 = 2 \times 50 \times 250^4/500^3 = 3125 \text{ N-mm.}$

For stainless steel material, E = 2 x 10⁵ MPa and for circular cross section I = $\pi d^4 / 64$.

Deflection at the loading point: -
 $\delta_F = Fa^6 / 3L^3EI.$
 $\delta_F = 50 \times 250^6 / 3 \times 500^3 \times 2 \times 10^5 \times \pi \times d^4 / 64$

For the deflection to be less than 1 mm,
 $1 = 50 \times 250^6 / 3 \times 500^3 \times 2 \times 10^5 \times \pi \times d^4 / 64$
 $d = 7.588 \text{ mm}$
d = 8 mm (standard diameter)

Compressive yield strength $\sigma_y = 250 \text{ MPa.}$
 The force applied for this value is
 $F^1 = \sigma_y \times \pi \times d^2 / 4$
 $F^1 = 250 \times \pi \times 8^2 / 4$
 $F^1 = 12566.37 \text{ N}$

The deflection for this value is
 $\delta_F^1 = F^1 a^6 / 3L^3EI.$
 $\delta_F^1 = 12566.37 \times 250^6 / 3 \times 500^3 \times 2 \times 10^5 \times \pi \times 8^4 / 64$
 $\delta_F^1 = 203.45 \text{ mm}$

Reaction forces $RA = RB = 4Fa^3 / L^3$
 $RA = RB = 4 \times 50 \times 250^3 / 500^3 = 25 \text{ N}$

It is found that at the yielding point the deflection has to be 203.45 mm but in our operating conditions, a maximum deflection of 1 mm is allowed, hence the design is safe.

BELT CALCULATION

Pulley diameter, $d = 10 \text{ mm}$.
 Speed of motor, $n = 300 \text{ rpm}$.

Coefficient of friction for aluminium pulley and leather belt, $\mu = 0.35$
 w for leather = $10 \times 10^{-6} \text{ N/mm}^3$

Velocity, $v = \pi d_1 n_1 / 60$
 $v = \pi \times 10 \times 10^{-3} \times 300 / 60$
 $v = 0.157 \text{ m/s}$

Centrifugal stress,
 $\sigma_c = w \times v^2 / g \times 10^6$
 $\sigma_c = 10 \times 10^{-6} \times 0.157^2 / 9810 \times 10^6$
 $\sigma_c = 2.512 \times 10^{-5} \text{ Mpa}$

$\Theta = \pi - 2\sin^{-1}((D-d)/2c)$
 $\Theta = \pi$ radians
 $\Theta = 3.14$ radians

$K = \frac{e^{u\Theta} - 1}{e^{u\Theta}}$
 $K = \frac{e^{0.35 \times 3.14} - 1}{e^{0.35 \times 3.14}}$
 $K = 0.666$

From standard table, tensile strength,
 σ_u for belt = 24.5 Mpa
 $\sigma_1 = 24.5/10 = 2.45 \text{ Mpa}$

$\text{Power/mm}^2 = (\sigma_1 - \sigma_c) \times K \times v$
 $\text{Power/mm}^2 = (2.45 - 2.512 \times 10^{-5}) \times 0.66 \times 0.157$
 $\text{Power/mm}^2 = 0.253 \text{ W}$

Area of cross section of belt = Total power /
 $\text{power/mm}^2 \times \text{service factor}$

Total power, $P = F \times v / 1000 \times C_s$
 Service factor for pulley $C_s = 1$

$P = 5 \times 5 \times 0.157 / 1000 \times 1$
 Total power, $P = 4 \text{ W}$

$\text{Area} = 4 / 0.253 = 15.81 \text{ mm}^2$
 $\text{Area} = b \times t$

Taking thickness of the belt as, $t = 2.5 \text{ mm}$
Belt width, $b = 6.32 \text{ mm}$

MOTOR TORQUE CALCULATION

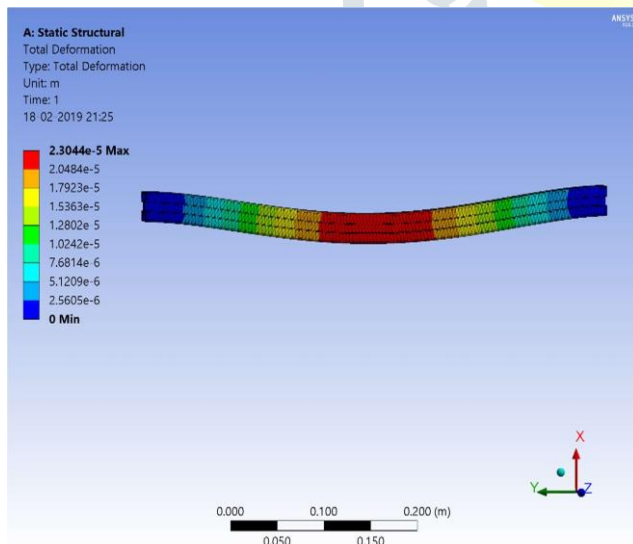
With guideway: -
 Mass is 2.5 kg and diameter of the pulley is 3 cm .
 Acceleration = $0.5/0.1 = 5 \text{ m/s}^2$

$F = 2.5 \times 5 = 12.5 \text{ N}$
 $T = 12.5 \times 0.015 = 0.1875 \text{ N-m}$.
 $T1 = 1.875 \text{ Kg-cm}$
 $T2 = 1.125 \text{ Kg-cm}$

IV. ANALYSIS

The major components needed for fabrication are designed and the analysis is done using the software Ansys Workbench and the maximum deflection is noted which is found to be within the standard limits. The Ansys results are found to be matching with the theoretical calculations.

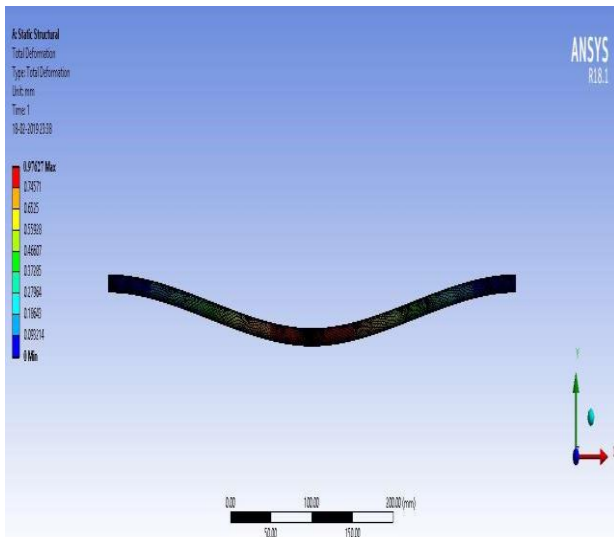
1. Analysis of 30 x 30 mm Aluminium bar



Component	30x30mm Frame Bar
Material	Aluminium 6105-T5
Mass	0.4276 Kg
Youngs Modulous	71,000 Mpa
Poisson's Ratio	0.33
Moment Of Inertia	4.07cm^4
Length Of Bar	0.5m
Mesh Statistics	
Nodes	130272
Elements	73443

Figure 5: Analysis of Frame bar

2. Analysis of 8 x 500 mm Stainless Steel rod



Component	8x 500mm Rod
Material	Stainless Steel
Mass	0.19478 Kg
Youngs Modulous	193000 Mpa
Poisson's Ratio	0.33
Length Of Bar	0.5m
Mesh Statistics	
Nodes	33374
Elements	15868

Figure 6: Analysis of Stainless Steel rod

V. PRODUCT DESIGN

The entire model is designed and assembled using Autodesk fusion 360 software before fabrication. After designing, the model is transferred to Keyshot 6.64 software for rendering process using appropriate materials.

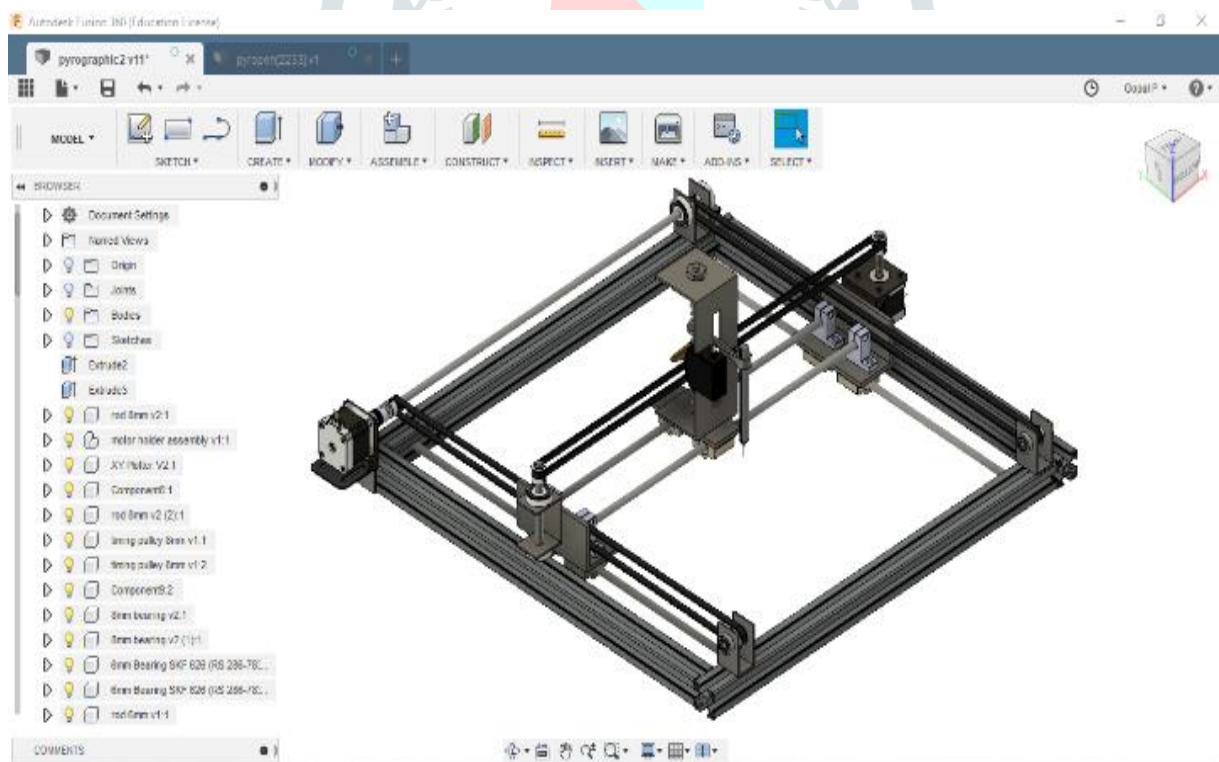


Figure 7: Product design using Autodesk Fusion 360

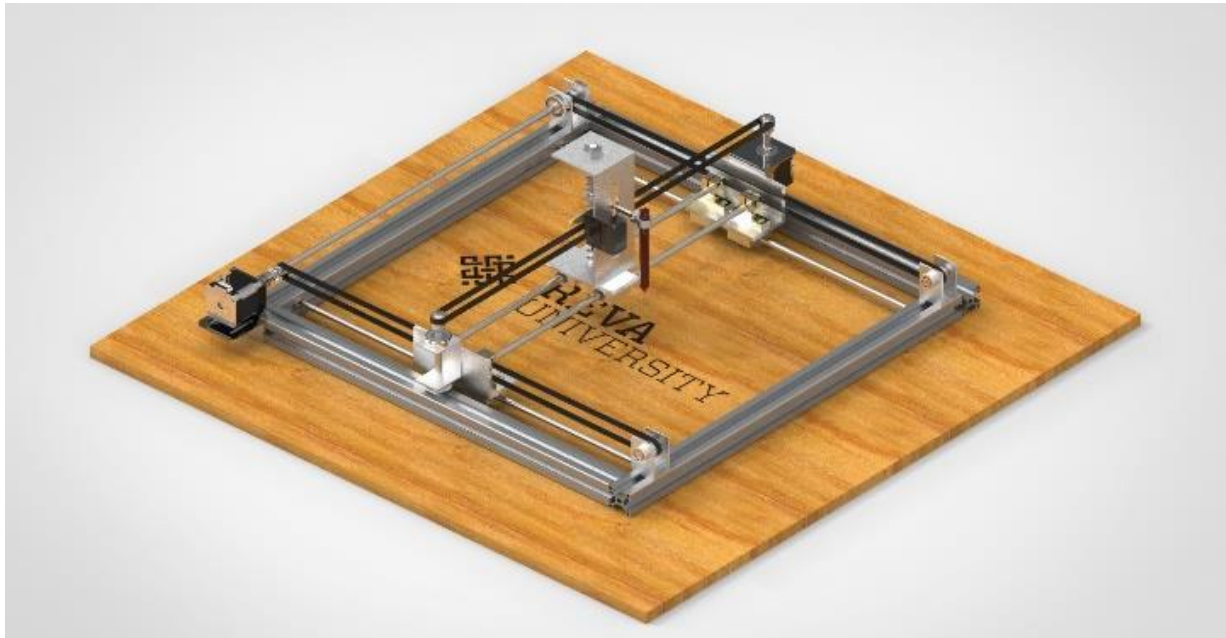


Figure 8: Rendered image of CNC pyrography using Keyshot 6.64

VI. METHODOLOGY

First step is to do a literature survey based on our project. Then design the components of the CNC pyrography in a CAD software. Analyse the components with the required boundary conditions in ANSYS software. Do the required calculations manually and compare it with Ansys results; If successful, go ahead with next step. Procure the required components in order to assemble and fabricate the remaining. Assemble and attach all the parts to get the final model, use screws and nuts to assemble. Type the exact code into the Arduino software and compile, if no errors are found, dump it into the Uno board. Connect the Uno with drivers to the 2 stepper motors using jumpers and normal wires and also from Uno to the servo motor to control the movement of pen. Choose a software in order to scan the image and which is compatible with Arduino. Upload a file into the software to scan. Once scanned, generate the G-codes and M-codes for that particular scanned image; if no errors are found, dump the code into the Arduino. Then align the x-axis, y-axis of x-y plotter as well as other necessary parameters from the software itself. Arrange a demo flat workspace to test the pen. Use a normal pen 1st to check the efficiency of the CNC, if not, do the required arrangement/alterations with respect to model, workspace, software and the code. Then procure an ideal pyrographic pen and replace the writing pen with the pyrographic pen. Place a smooth flat wooden plank onto the workspace and adjust the height of the plotter and again check for the efficiency as described before. Once everything is in place, reset the Arduino and run the program. The required image would be burned onto the wooden workpiece at a very low feed-rate. Check how smooth is the engraved/burnt image; if it did not meet the expectations, make the required changes in the software and engrave the image again. Once satisfied, scan a different image with the G-code and M-code and dump it into the Arduino and check the result in the wooden workpiece. Once perfected, the CNC pyrography is completely ready.

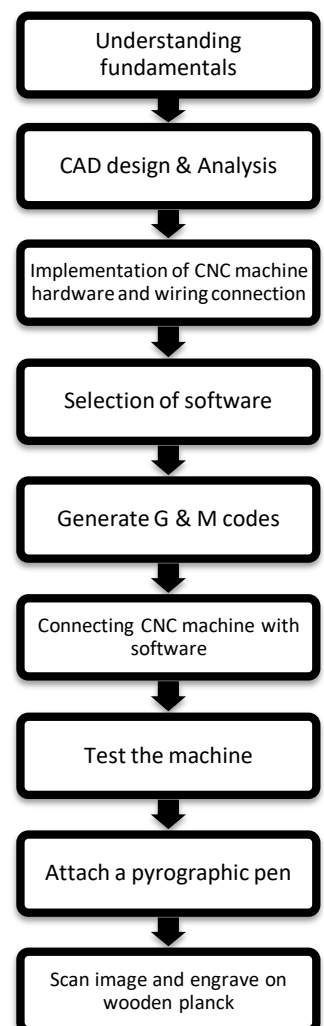


Figure 9: Process Flowchart

VII. SOFTWARE USED

Engineering as a discipline often requires more integration than large amounts of original development. In a typical project, writing new code presents significant challenges, and the number of features shared between projects means that it is possible to create shared components which implement common features. A library or an existing module allows the use of well developed and tested components, which saves significant resources in the implementation of the project. The programs and tools we choose for this project are all open source, and use international standards which allowed us to rapidly develop the features needed.

The project software system consists of:

1. Inkscape (version 0.92.3)
2. CAMotics
3. ARDUINO IDE
4. Universal G-Code Sender

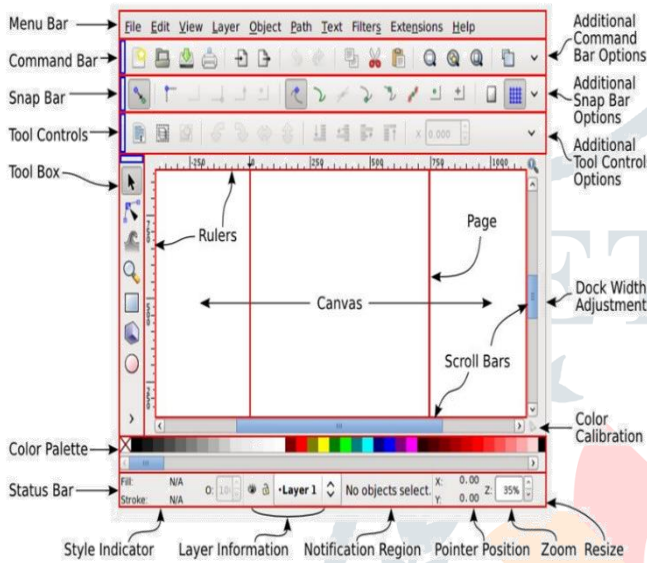


Figure 10: Inkscape window

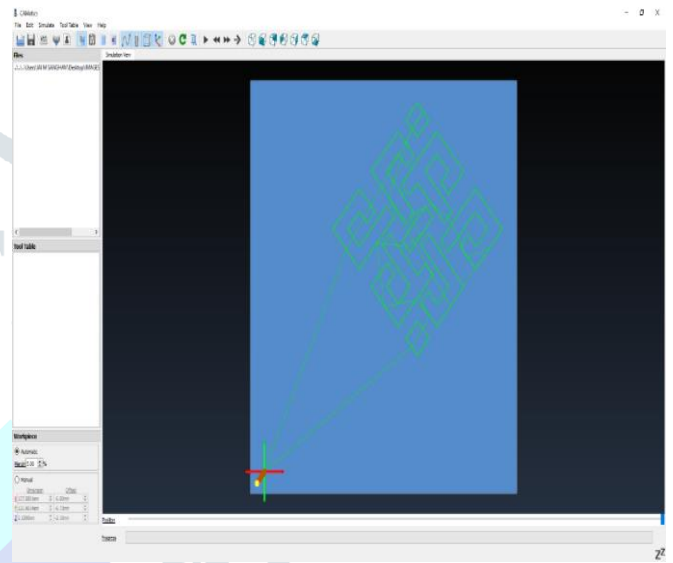


Figure 11: CAMotics

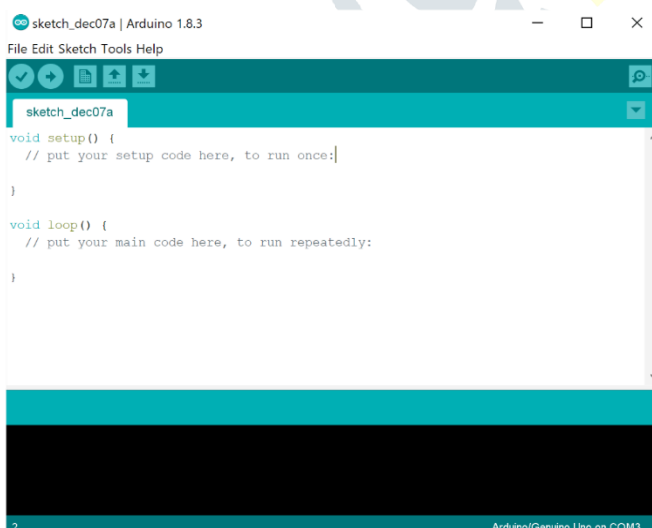


Figure 12: Arduino ide window

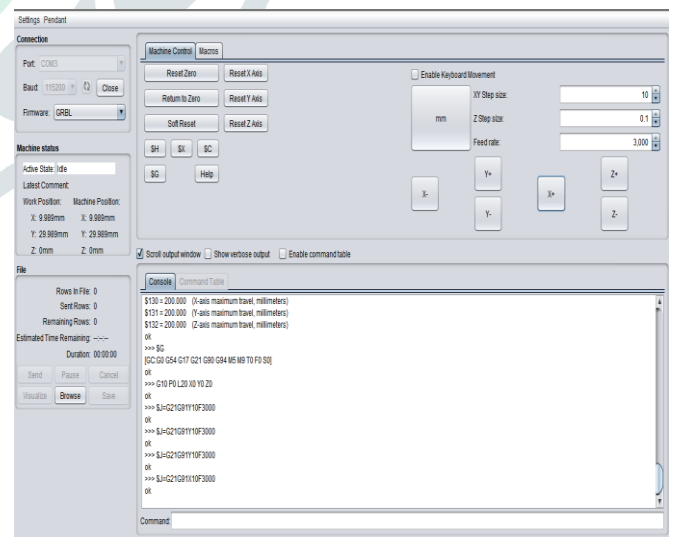


Figure 13: UNIVERSAL G-Code Sender Window

VIII. TESTING AND CALIBRATION

After finishing the complete build-up of the machine, it is necessary to calibrate the movement of the axis. This equation is helpful in determining how many steps our stepper motor requires to move one full revolution:

Most stepper motors, including the ones we have used, move 1.8 degrees per step, or 200 steps per revolution.

$$\frac{\frac{360 \text{ Degree}}{1 \text{ Revolution}}}{\frac{\text{Degree}}{\text{Step}}} = \frac{\text{Step}}{\text{Revolution}}$$

$$\frac{360 \text{ Degree}}{1.8 \frac{\text{Degree}}{\text{Step}}} = 200 \frac{\text{Step}}{\text{Revolution}}$$

Test code for stepper motor is used where steps per revolution is 200 steps were allowed for the motor to move. On running the code, it is found that the motor is travelling 10 mm which is indicating that the stepper motor takes 20 steps to cover 1mm. This is calibration for both X and Y axis.

IX. CONCLUSION

This project is a XY-Plotter that is even a portable mini CNC machine. This CNC machine is connected to specialised computer software programmes which are responsible for sending the necessary plotting dimensions or designs in order to command the pyrographic pen to produce the burning. From this project, we can generate several applications like using it for plotting braille language etc and substituting pen with laser for cutting operations. By replacing servo with stepper, this project can be modified into three axis movement which can be used as a 3D printer.



Figure 14: REVA University logo done in CNC Pyrography setup.

X. REFERENCE

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