2D CNC LASER ENGRAVING MACHINE

By

Capt Muhammad Bilal Mustafa

Capt Saud Bin Tariq

Capt Ahtesham AD

Capt Sabahat Lateef

Maj Shahid Ali

Supervised by:

Lt Col Muhammad Imran Javed

Submitted to the faculty of Department of Electrical Engineering,
Military College of Signals, National University of Sciences and Technology, Islamabad,
in partial fulfillment for the requirements of B.E Degree in Electrical (Telecom) Engineering.

June 2022

In the name of ALLAH, the Most benevolent, the Most Courteous

CERTIFICATE OF CORRECTNESS AND APPROVAL

This is to officially state that the thesis work contained in this report

"2D CNC LASER ENGRAVING MACHINE"

is carried out by

Capt Muhammad Bilal Mustafa

Capt Saud Bin Tariq

Capt Ahtesham AD

Capt Sabahat Lateef

Maj Shahid Ali

under my supervision and that in my judgement, it is fully ample, in scope and excellence, for the degree of Bachelor of Electrical (Telecom.) Engineering in Military College of Signals, National University of Sciences and Technology (NUST), Islamabad.

Approved by

Supervisor
Lt Col Muhammad Imran Javed
Department of EE, MCS

Date: 30/05/2022

DECLARATION OF ORIGINALITY

We hereby declare that no portion of work presented in this thesis has been submitted in support of another award or qualification in either this institute or anywhere else.

ACKNOWLEDGEMENTS

Allah Subhan'Wa'Tala is the sole guidance in all domains.

Our parents, colleagues and most of all supervisor Lt Col Muhammad Imran Javed without your guidance. The group members, who through all adversities worked steadfastly.

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Capt Bilal Mustafa

00000280755

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Capt Saud

00000280722

_____.

Capt Ahtesham

00000280753

_____.

Capt Sabahat

_____.

Maj Shahid

00000280767

_____

Signature of Supervisor

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ABSTRACT

The modern world is turning into a new age of technology and advancement. Old conventional CNC machines are heavy and laborious to transport providing less accurate and precise work according to the modern era. Our project relates to the idea of engraving, cutting, and image printing on hardware using eco-friendly methods of laser working using less amount of electrical power and also with the novelty of portable handy machines for workers to work and transport. The idea emerges with the folding of one axis with accordance to the other axis, having the size of a 1.5 by 1.5 feet CNC machine. Using stepper motors and tooth pulley we precise the motion of laser. By this laser CNC, we are engraving on objects with changing height. Image engraving and printing are done by open-source software of Inkscape and Universal G-code sender. The final project is working and providing a great deal of precision and engraving on a vast variety of objects.

1. INTRODUCTION

1.1 BRIEF OVERVIEW

The computer numerical control(CNC) machining process is generally utilized by companies in order to produce machined tools, goods, objects, and so on. Computer Numerical Control is utilized by CNC machines to regulate industrial equipment such as lathes, drills, grinders, and mills. CNC is distinct from the standard Application software used to operate a device. It is uniquely designed and programmed using G-Code, a particular CNC machine programming language that permits fine control over characteristics like pace, position, coordination, and flow rate.The automated machining process is driven by specialized software. An illuminated desktop PC houses the G-code-enabled software. A coder at the laptop panel may handle the same amount of machine labor as numerous workers at lathes, grinders, drills, mills, and fitters. The automatic machining approach can do tasks that are normally inefficient for human workers and traditional equipment. Numerous CNC machines have the benefit of numerous axes, which can accommodate tight curves and facilitate the cutting of problematic materials. The cutting mechanisms along the X and Y axes of fundamental devices can act autonomously and synchronously. Modern devices have more than 5 dimensions that execute identical functions and can rotate and twist the part. CNC machines can automate tasks requiring multiple cuts. Similar to a drill bit, a cutter or spindle rotates to accomplish the cutting process. A genuine drill bit cuts only at the end, whereas a router bit cuts practically all of the substance. The coding of CNC machines combines all the dimensions and high-velocity motions necessary to make the product, as well as permits extensive customisation. CNC machining is growing in popularity as a method for fabricating both metal and plastic components, as it enables the maker to construct complicated designs that would be practically difficult to construct physically. Numerous factories view CNC machining as advantageous for manufacturing predictable outcomes in metal and plastic and intricate machining procedures.

1.2 PROBLEM STATEMENT

When hard metals and alloys are machined with traditional methods, more time and energy are needed, which drives up costs. The traditional way wastes a lot of material during fabrication and as the difficulty increases, the cost also increases.CNC machine builds up with simple mechanical assembly so if we can add more hardware and enhance the effective code for programming help it to use over broad areas.

1.3 PROPOSED SOLUTION

Devise a method that allows us to fabricate objects with very less material dissipation and printing complex structures on objects with relatively greater accuracy and less time at the same time while being cost and energy-efficient.
They are flexible and give accurate results, so provide better performance facilities over a long period and save human labour.

1.4 OBJECTIVES

- Portable Design.
- Homing
- To engrave on an object
- Laser Power Adjustment

Portable Design:
One of the greatest challenges was to build a CNC machine that is portable and easy to use. Our project deals with a design that is handy to transport and provides a great deal of precision. Along with working in a relatively larger workspace than the ones conventionally available.

Homing:
In homing the tool adjusts its position by re-setting the motors to the initial positions and getting the tool back to the starting point.

Actuation:
Once the device is homed the tool must be repositioned within the frame to keep it on the plan. It can be done by dividing it into two parts.
Control challenge.
Mechanical challenge.

Laser Power Adjustment:
The power of the laser can be adjusted according to the material and purpose. As in the case of cutting more power is used then engraving. Also engraving on different objects uses a different amount of energy to do the work hence allowing us to save energy intelligently.

1.5 SCOPE OF WORK

We intend to use the CNC machine for sketching 2D graphics by operating it with a Computer, giving it with G-code, and then transmitting that information to the CNC machine so that it may manufacture a real replica of the thing sketched. Thus, the primary goal of this work is to give an alternative to conventional physical charting activities performed by a manually driven system.

1.6 SIGNIFICANCE OF RESEARCH

Traditional machining processes typically involve altering the figure of a product as desired by physical contact of the tool and workpiece. The tool must have superior properties as compared to the workpiece to be machined. In terms of accuracy and edge smoothness, laser cutting machines outperform traditional CNC machines by an order of magnitude. When cutting or printing, it consumes less power. CNCs, unlike manual lathes and milling machines, can be operated by people with little or no engineering training.
The CNC machines are programmed with a layout which can be produced vast numbers of times. Each manufactured item will be identical. By updating the system used to control CNC machines, it is possible to modernize these equipment.

2.1 LASER

The laser is an acronym for Light Amplification by Stimulated Emission of Radiation. It's not like regular light because all of its photons have the same frequency and phase and emit light coherently. Spatial coherence makes it possible to concentrate a laser on a tiny patch, which lets it be used for things like laser cutting and lithography. Photons of normal light are sent out in a random way, but laser light is set up so that each photon goes in the same direction as the others.Laser light is monochromatic because all of its wavelengths are the same, which is based on how much energy it gives off. For cutting metals and other solid materials, lasers can also be utilized, but the amount of power needed is significantly greater. Lasers can cut wood and plastic up to roughly 10mm with 60 watts, however some woods give poor results due to the combustion and scorching of the sap and resins in the timber.

2.2 LASER CUTTERS

Laser cutting is the next generation of cutting and printing technology. Prior to striking the workpiece, a lens focuses the laser. In addition to focusing on the head of the paper, the two most significant criteria in laser cutting are the laser's operating strength and the cutting head's velocity. The greater the thickness of the sheet, the more energy is required.

2.3 LASER ENGRAVING MACHINE

Using a laser, extremely precise and clear printing can be accomplished. This project aims to construct a laser engraving machine capable of performing the required task at a minimum price. It is controlled by an Arduino UNO, which serves as the machine's primary control center. The engraving model is linked to the X-axis so that it operates only in the X axis, whereas the laser is connected to the Y-axis so that it works only in the Y direction. The Y-axis was moved by two stepper motors and the X-axis by one stepper motor. It still has significant restrictions that make it ideal only for engraving modest quantities and sizes of objects. It takes time for the laser to melt the surface of an object. Using a low-powered laser lengthens the printing procedure.

2.4 TYPES OF LASER

1. Gas Laser
2. Semiconductor Laser
3. Solid-State Laser

2.4.1 GAS LASER

Gas lasers use a moderate gaseous medium as active media. Solid-state and semiconductor lasers have substantially wider line lengths; diode lasers have much smaller ones. This type of gas laser can be composed of either non-ionic atoms (He-Ne, for example) or ionized atoms (such as Ar^+) (e.g. CO_2).

2.4.2 SEMICONDUCTOR LASER

Semiconductor lasers are currently among the most essential forms of lasers. Solid-state lasers can also be pumped using these devices. Radiation wavelengths range from 630 to 1600 nanometers. The large bulk of semiconductor lasers utilize compounds of III-V elements (Al, Ga, In... – N, P, As, Sb...), whereas II-IV compounds produce smaller wavelength and IV-VI compounds produce wider wavelengths.

2.4.3 SOLID STATE LASER

High-density solids are used as active laser materials in solid-state lasers. In compounds such as crystalline or glass, ions are injected as contaminants.

2.5 COMPONENT OF LASER

The following are the three primary constituents that make up a laser, as seen in figure 2.1.

- Lasing substance (crystal, gas, and semiconductor)
- Pump source (adds energy to the lasing material, e.g. flash lamp, electrical current to cause electron collisions, radiation from a laser, etc.)
- Optical cavity made up of reflectors that will serve as the feedback system for the light amplification process.

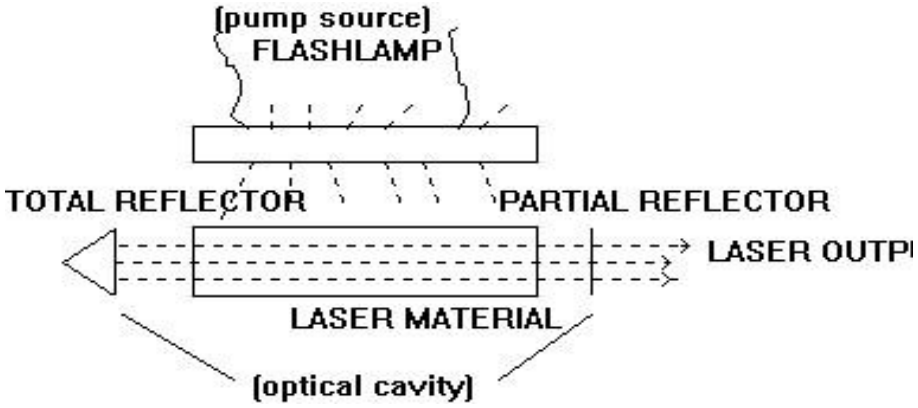


Fig 2. 1 LASER

Lasing materials typically have atoms with lower energy levels than those in the surrounding environment. A phenomenon known as population inversion occurs when the electrons of the laser pulses material are stimulated to a higher energy state by the light energy from the flash lamp. These electrons are in an unsustainable state as a result of this. They will only last a brief time in this condition before reverting to their natural state of energyThere are two types of deterioration in this

system: naturally occurring and artificially induced. It will emit energy in the form of photons of light that move in process with the incident photon and in the same path as the emitted photons.
A Q-switch in the light system is a technique for delivering unusually short laser pulses. Q-switching was first provided by a revolving prism-like total reflector. Light can only travel through a rotating object if there is a clean visual path. A previously opaque electro-optical device is increasingly being employed as a Q-switching gadget.During the time when the gadget is applied with a voltage, it becomes invisible, allowing excited electrons to approach the reflector and build up light in the cavity, resulting in a strong peak capacity laser pulse of a few nanoseconds. Syncing the periods of various light modes creates a rhythm effect that interferes with the other patterns. Repetitive pulses are common in pulsed lasers. To evaluate biological impacts, pulse repetition frequency (PRF) and pulse width must be taken into account.

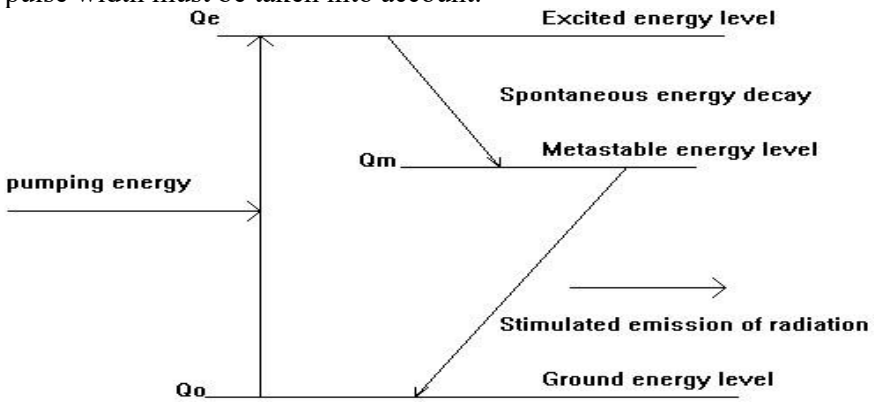


Fig 2. 2 Energy Diagram

3. METHODOLOGY

The Laser Engraver Project is divided into four major sections which are mentioned below as:

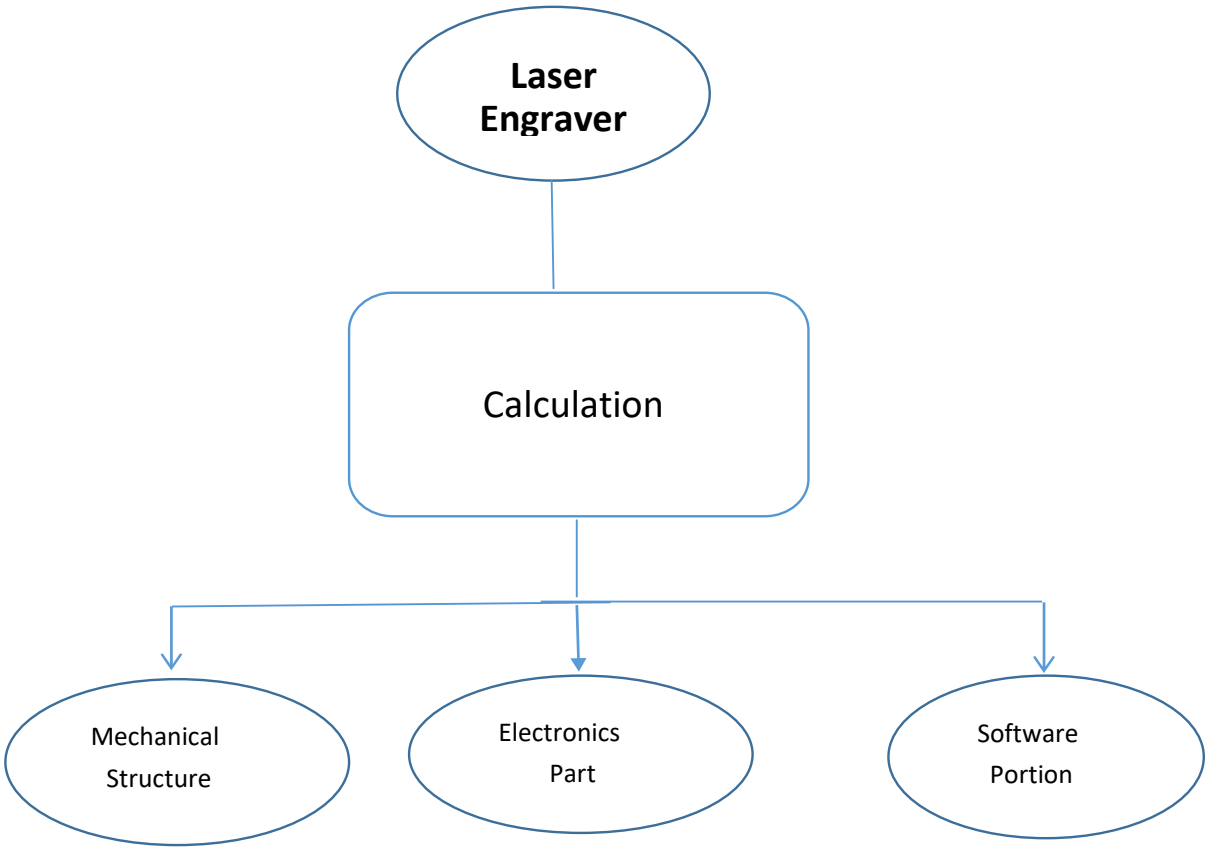


Fig 3. 1 Project Division

3.1 MECHANICAL ASSEMBLING

- All mechanical components are assembled.
- First of all, the Base box is fixed on the base frame.
- Then Linear Precision Rods are inserted in the groves of the base mount.
- After the base mount, carriage holder assembly is placed over linear Precision Rods with the help of Linear Bearing.
- Carriage mounts are then put on the rods to provide a sliding contact motion with linear bearings.
- Center carriage mounts are then fixed on the carriage assembly.
- The X-axis rod is then put into the grooves of the center carriage and fixed on both ends.
- Before tightening the center mount is inserted in the rods to provide controlled motion with the help of linear bearings and timing belt.

- The laser mount is fixed on the carriage to provide space for Laser.

3.2 ELECTRICAL ASSEMBLING

- After step 1 Electronics and remaining mechanical components associated with electronics components are mounted.
- The motor is placed on the outer side of the base motor mount
- Its positioning is done precisely by nut bolts and motor plates.
- On the other end, the toothed pulley is mounted to support the GT2 timing Belt.
- The laser is mounted on Centre mounts and a stepper motor is fixed with it.
- Arduino and CNC shields are placed over the printed box.
- All the cables are patched using heat sleeves and cable trays.
- The main power supply is placed on the base plate and attached with the printed box by a pin cable, to provide power for the whole machinery.

3.3 FINAL ASSEMBLING

- Step 3 involves mechanical fitting and dampers adjustment.
- Base plates are fixed in their groves to provide 1.5x1.5 ft workspace for our project.
- Rods, linear bearings, and radial ball bearings are cleaned by WD-40 and greased to provide better results.
- The whole Assembly is then configured to make it ready for print.

3.4 HOW CNC ENGRAVER WORKS

- First of all, the image or the word to engrave is fed into Inkscape, an open-source software.
- This software then creates a temporary GUI (graphical user interface). A second open-source software Universal G-Code sender (UGS) is also used in the work.
- UGS loads the GUI file and commands stepper motors.
- UGS is also used at the same time to command the laser to engrave.
- UGS is used to manually home the machine using a button interface preinstalled in it.
- Afterwards, the engraving machine automatically homes itself.

3.5 GENERAL BLOCK DIAGRAM OF PROPOSED WORK

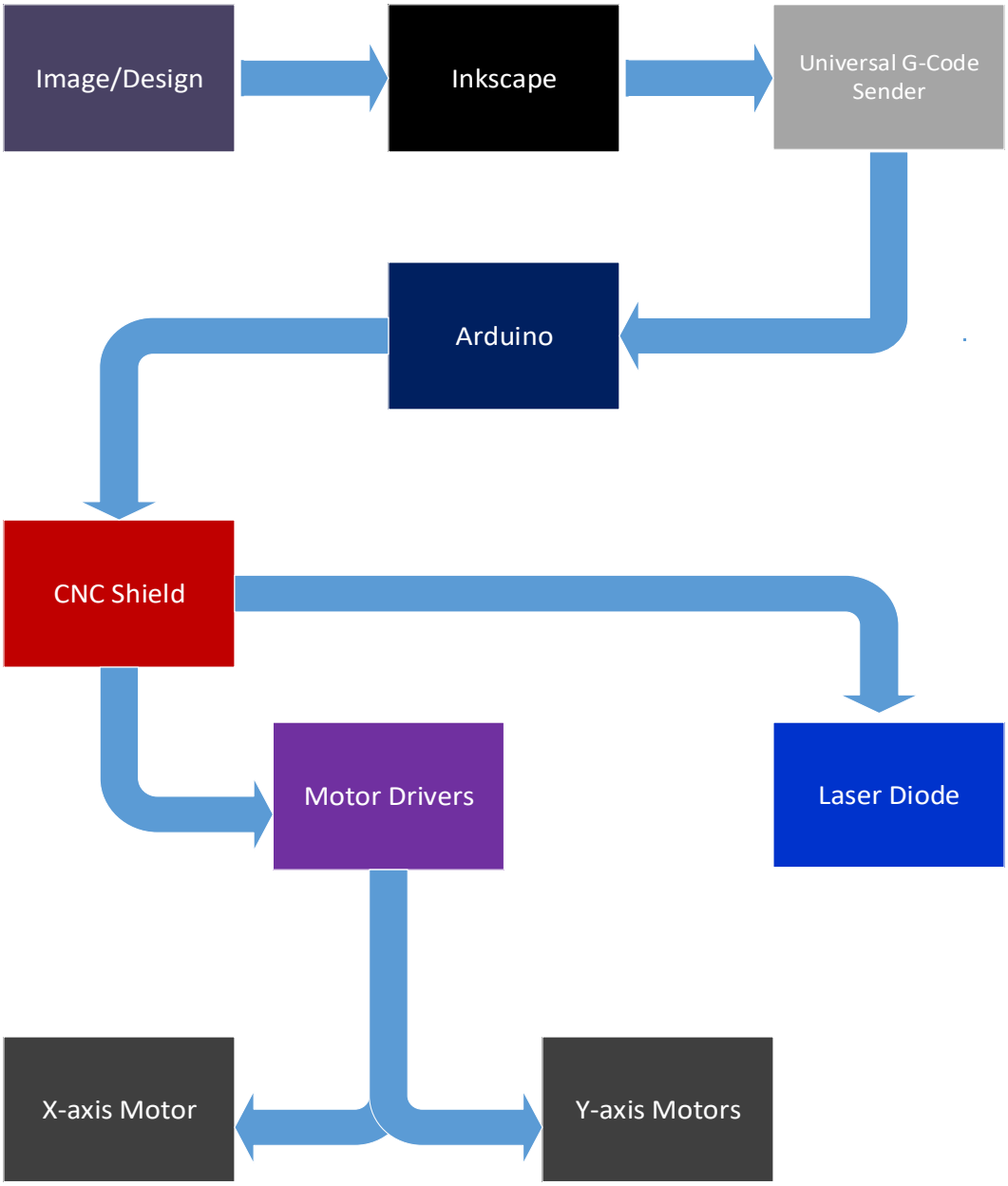


Fig 3. 2 Block Diagram

4. HARDWARE IMPLEMENTATION

4.1 MECHANICAL STRUCTURE

The mechanical structure of our delta printer mainly comprises following components:

- Precision Rods
- Linear Bearings
- Radial Ball Bearings
- Timing Belts
- Toothed Pulleys
- Frame
- Printed Parts

4.1.1 PRECISION RODS

Precision linear rods are meant for automation use. The linear rods we are using are 12mm in diameter and nearly 1.5 feet in length; these are highly precise, hardened and polished stainless steel rods that promise to offer great running life and precision. In terms of reliability, linear rods have the most constant area and level of stiffness along a wide variety of diameters.Carriage assembly will move along these rods with the help of linear bearings.

4.1.2 RADIAL BALL BEARING

A ball bearing is a form of tapered roller bearing that keeps the distance between the bearing races by using balls. A ball bearing's job is to overcome friction during spinning and assist both lateral loads.

4.1.3 TIMING BELT

A timing belt is a mechanical power transmission belt that doesn't slip. It is created as a belt that can bend and has teeth on the inside. It moves over pulleys with teeth that match. When they are properly tightened, they don't slip, and they have been used for motion tracking for archiving or timescale.The GT2 Timing Belt is used in our project. GT2 timing belts and well-matched pulleys are widespread adoptions. The GT2 series of belts are calculated precisely for linear motion. They use a rounded tooth profile that promises that the belt tooth fits effortlessly and exactly in the pulley groove, so when you oppose the pulley course, there is no room for the belt to move in the groove.

4.1.4 TOOTHED PULLEY:

A pulley is a wheel mounted on an axle or shaft that is meant to facilitate the motion and orientation adjustment of a full line or belt around its circle. There are a number of ways pulleys are used to raise objects, apply forces, and transfer electricity.The toothed pulley is used with the timing belt to provide a non-slipping mechanical drive.

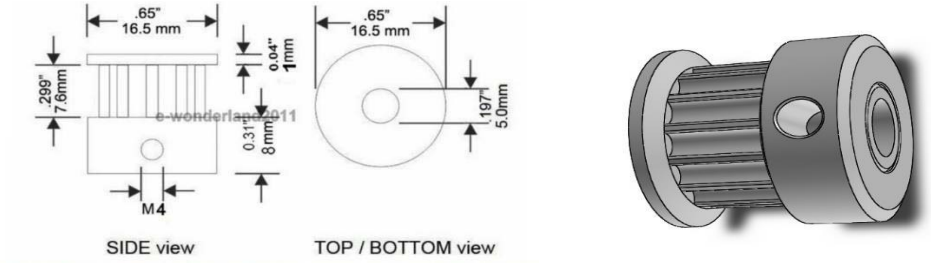


Fig 4. 4 Toothed pulleys

4.1.5 FRAME

The primary purpose and most important design of the frame are that it must be solid. As the end effector and motors move, the robot will shake, and if the frame is wobbly, then accuracy suffers. We have developed our Laser Engraver base design using aluminum for the bottom frame. Aluminum is lighter than metal.

4.1.6 3D PRINTED PARTS

Carriage Mount:

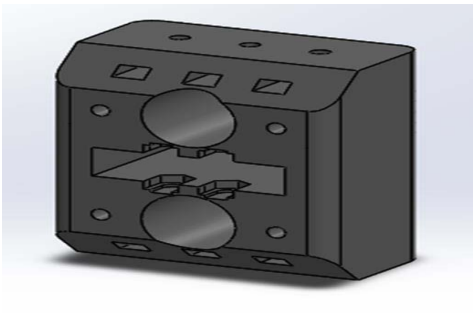


Fig 4. 5 Carriage mount

Carriage Holder:

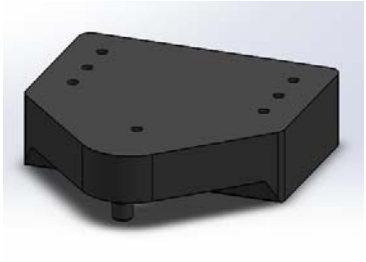
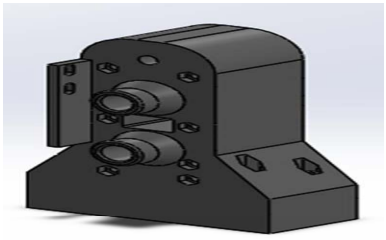


Fig 4. 6 Carriage holder

Base Mount and Center Carriage mount:



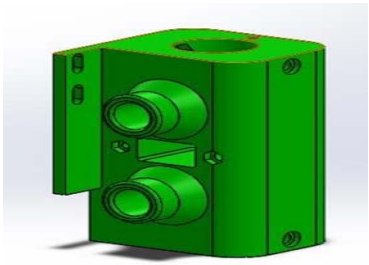


Fig 4. 7 Base mount and center carriage mount

Base Box:

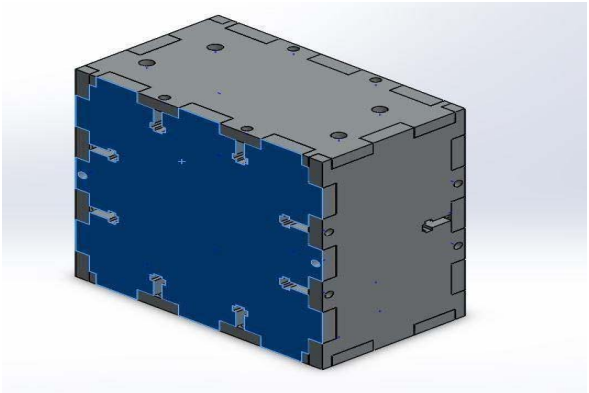


Fig 4. 8 Base box

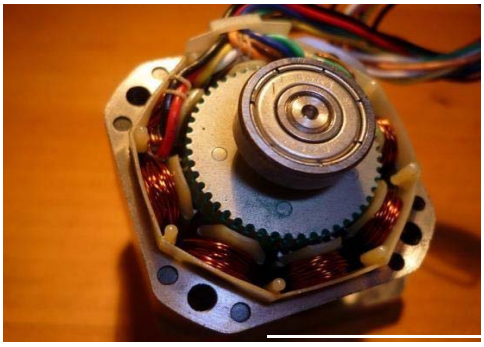
4.2 ELECTRICAL COMPONENTS

The electrical components of our delta printer mainly are:

- Stepper Motors
- Arduino Board
- CNC shield
- Stepper motor drivers
- Laser

4.2.1 STEPPER MOTORS

A stepper motor is a brushless DC electric motor that divides a whole rotation into a series of equal parts. Stepper motors are designed with many "toothed" superconducting magnets grouped around a gear-shaped iron core. A processor or an external driver circuit reinforces the electromagnets. To cause the motor shaft to revolve, electricity is first supplied to an electromagnet, which mechanically attracts the gear's teeth. When the gear teeth are aligned with the first magnets, the next electromagnet somewhat counterbalances them. This means that when the second electromagnet is activated and the first is deactivated, the gear moves somewhat to coincide with the second electromagnet.The method then becomes repeated. Each of these spins is referred to as a "step," with an equal series of phases constituting a complete revolution. Thus, the motor may be revolved at a precise angle.



The motor we are using is a NEMA 17 1.7 ampere stepper motor. This hybrid stepping motor has an accessibility of 1.8 degrees and 200 steps per cycle. Each step entails 1.7 A at 4 V, which permits a sustaining force of 0.045 km. The motor's 4 color scheme wires terminate in plain leads, allowing it to be operated by bipolar motor drivers. When utilized with a bipolar stepper motor driver, the yellow and white center-tap wires can be disconnected (the red-blue pair gives access to one coil and the black-green pair gives access to the other coil).These wires are already detached in our stepper motor.

4.2.2 ARDUINO BOARD

Arduino is a microcontroller hardware and software framework for making electronic projects. It is for anyone who wants to make engaging projects. Arduino gets information from several sensors about its conditions and helps it by managing lights, motors, and other effects. The Arduino UNO is a microcontroller board based on the ATmega32 (datasheet). It has 32 digital input/output pins (of which 15 can be used as PWM outputs).

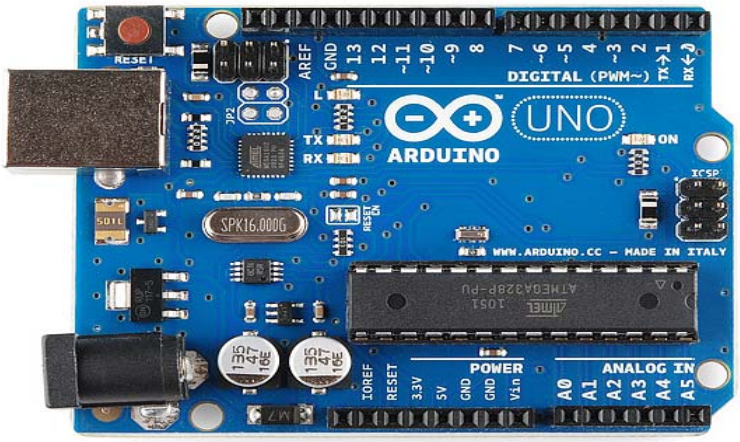


Fig 4. 10 Arduino UNO

4.2.3 STEPPER MOTOR DRIVER

This is a combined motor driver for bipolar stepper motors, and it controls the motor. In order to ensure an effective operation, the technique allows use of H-bridges, voltage sense, regulatory circuits, and a sliding indexer. It is competent in delivering a voltage output of up to 2.5 a full-scale and can be powered by a voltage level ranging from 8.2 V to 45 V. It is also capable of being motorized.

Fig 4. 11 Stepper motor drivers

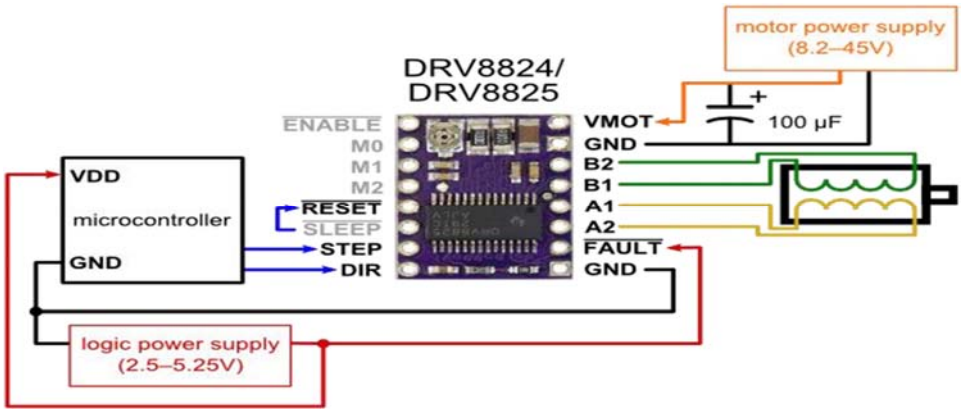


Fig 4. 12 Connection diagram of stepper motor

4.2.4 CNC SHIELD:

Protoneer.co.nz invented the CNC Screen to capitalize on the need for a minimal sensor system for DIY CNC devices. It was developed to be 100 percent compatible with Grbl, the open-source G-Code translator, and to be interoperable with the widely used Arduino Uno. The CNC Shield can be used to manage a variety of CNC machines, such as CNC machining processes, laser printing/cutting machines, drafting machines, 3D scanners, and any project requiring precise stepper motor control. It uses Pololu and equivalent stepper drivers, either the A4988 or the DRV8825 with greater power.

The CNC Shield requires three basic parts to function: 1) CNC Shield, 2) Stepper Drivers, and 3) Arduino UNO.

Fig 4. 13 CNC SHIELD

4.2.5 LASER DIODE

The 5.5 watt (5,500 mW) diode laser is an advanced and sophisticated laser adapter for upgrading your 3d printing or CNC machine, capable of producing exquisite laser designs and cuts. It is incredibly simple to set up and requires no particular skills. It is compatible with nearly all 3D printers and CNC mills. You may print and cut a number of materials with our laser, including:

- Plywood / Wood
- Mdf / Balsa / Hardboard
- Acrylic

- Pla / Abs
- Felt / Fabric / Fiber Cloth / Leather
- Paper / Cardboard
- Stone
- Glass
- Foam

Fig 4. 14 LASER Diode

4 .3 CALCULATIONS

- Force calculations
- Torque calculations
- Pulley selection
- Motor Selection

4.3.1 FORCE CALCULATIONS

The force required moving Center Carriage
we know that

$$F = m_{\text{center carriage}} * g \quad \text{(Equation 4.1)}$$

($m=1.5kg$, $g = 9.81 m/s^2$)
$F = 14.71N$
Stainless Steel coefficient of Static friction

$$F_s = \mu_s * F \quad \text{(Equation 4.2)}$$

μ_s = 0.8)
F_s = 0.8 x 14.7
F_s = 11.76N

Stainless Steel coefficient of kinetic friction

$$F_k = \mu_k * F \quad \text{(Equation 4.3)}$$

μ_k = 0.58
F_k = 0.58 x 14.71
F_k = 8.53N

Force required to move the y-axis

$$F = m_{y\text{-}axis} * g \quad \text{(Equation 4.4)}$$

(m = 4.8kg, g = 9.81 m/s^2)
F = 47N

Stainless Steel coefficient of Static friction
μ_s = 0.8
F_s = 0.8 x 47
F_s = 37.6N

Stainless Steel coefficient of kinetic friction
μ_k = 0.58
F_k = 0.58 x 46.97
F_k = 27.26N

4.3.2 TORQUE CALCULATION

$$T = r * F_{s\ y\text{-}axis} \quad \text{(Equation 4.5)}$$

T = 0.485 * 37.6
T = 18.23 N cm

4.3 3 PULLEY SELECTION

GT2 pulley 16 teeth
D = 0.97 cm
r = 0.485 cm

4.3.4 MOTOR SELECTION

NEMA 17 bipolar
Holding Torque = 0.043 Nm
The motor is selected with larger torque than required torque to avoid any interruptions from external dragging forces.

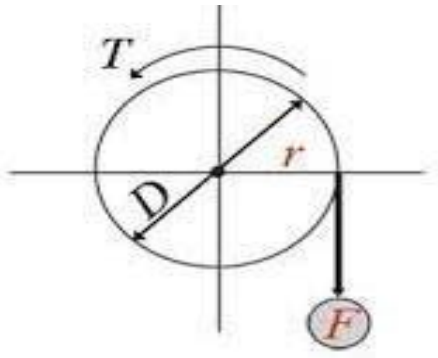


Figure 4.15 Force and Counter Torque

5. CONCLUSION AND FUTURE EXPANSION

5.1 CONCLUSION

The Special Invite for Open-source technology is used to make a CNC printing machine. The 3 axis movements of the free software CNC machine are managed by the GRBL control system, which talks to the Arduino board. The Arduino board, in turn, drives the stepper motor drivers, which run the stepper motor. There was a reasonable tolerance for milling in the estimations of motor loads. In comparison to open systems, the project budget of the system is found to be very premium. Because stepper motors are precisely controlled, it uses little power and has good reliability. Comparatively speaking, this is a very low-cost project for CNC items in general. If you're looking for a specific, selected manufacturing solution, this is it.

The machine is lightweight and portable, thanks to its simple construction concept. We're using a simple algorithm. A pinhead, laser head, or any other instrument can be used in place of the pen for various applications. Accessible and browser software has been used. In terms of size and weight, this is a compact machine that can be transported and erected virtually anywhere. Making a huge pattern on paper will be completely unrestricted. Commands have been issued using G-code. Codes that instruct a device to move to the right, left, or up and down are known as G-codes.

This combination of hardware and G-code provides improved accuracy and decreases the amount of work required. Our moving stepper motors are immediately displayed on the laptop, making it easy to locate all of their places and start or stop the device when necessary. Small machines allow us greater versatility in the workplace.Even more CAD software is available for building as well as production drawing, printing, and plotting of plant, elevation, and other views.

These CNC 2D sketchers can do different building drawings as required by the customer. Modification in drawing can be obtained by making changes in G-code manually or by generating it through Inkscape software. The proposed CNC 2D plotter gives instant printing or sketching of buildings and drawing on an A4 sheet. Further, the application on the proposed CNC 2D plotter can also be extended in the field of printed circuit board (PCB) drawing and drilling. Electrical Discharge Machining, metal removal and fabricating, lettering and logo engraving.

5.2 FUTURE EXPANSIONS

1. Large Scale commercialization of the project for availability.
2. Addition of a third axis (z-axis) for 3D printing.
3. Interchangeable top mount for saw cutter.
4. Touch LCD for direct pictures commands for printing/engraving

REFERENCES

1. **S. Tarnovean, R. Breaz, C. Biris, O. Bologna, Simulation tools for studying the behavior of CNC laser cutting machines in different working regimes. 16th International Conference on System Theory, Control, and Computing (ICSTCC), pp. 1-6, (2012).**

2. **L. Chiang, J. Ramos. CNC control of a laser cutting machine. IEEE International Symposium Industrial Electronics (ISIE), pp. 236-241 (1994). doi:10.1109/isie.1994.333112.**

3. **B. Radu-Eugen, T. Sorin, B. Cristina, B. Octavian-Constantin, Improving the dynamic behavior and working accuracy of the CNC laser cutting machines. 12th International Conference on Control Automation Robotics & Vision (ICARCV) (2012).**

4. **J. Rogelio and R. Baldovino. A PC-based controller for the computer numerically-controlled (CNC) LASER machine. Lecture Notes in Engineering and Computer Science 1, pp. 242-247 (2015).**

5. **P. da Rocha, R. Diogne de Silva e Souza, and M. de Lima Tostes. Prototype CNC machine design. 9th IEEE/IAS International Conference on Industry Applications (INDUSCON) (2010).**

6. **C. Yao, J. Rogelio, R. Baldovino, and F. Caluyo. A fuzzy-pulse width modulation (PWM) control algorithm for a computer numerical control (CNC) LASER machine. Advanced on Mechanical and Manufacturing Engineering Technology (ADMMET), Bandung, Indonesia (2015).**

7. **M. Hosen, A. Khosravi, S. Nahavandi, L. Sinnott. Prediction interval-based ANFIS controller for nonlinear processes. International Joint Conference on Neural Networks (IJCNN) (2016).**

8. **R. Baldovino, E. Dadios. Fuzzy logic control: design of a 'mini' fuzzy associative matrix (FAM) table algorithm in motor speed control. Proc. of the IEEE Region 10 Conf. (TENCON), Macau (2015).**

9. **S. Mesbah, G. Pang. Fuzzy-neural control with application to a heating system. Proc. of the 1999 IEEE Int. Symposium on Computer-Aided Control System Design, Hawaii (1999). doi:10.1109/cacsd.1999.808704.**

10. **E. Dadios, J. Solis. "Fuzzy-neuro model for intelligent credit risk management". Intelligent Information Management, vol. 4, no. 5, pp. 251-260 (2012).**