BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 318 (January 2023)

Control System 1 Laboratory

Final Project Report

Section: A1 Group: 01

Multi-functional CNC: Pen Plotter, Cutter and Engraver

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Academic Honesty Statement:

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"In signing this statement, we hereby certify that the work on this project is our own and that we have not copied the work of any other students (past or present), and cited all relevant sources while completing this project. We understand that if we fail to honor this agreement, we will each receive a score of ZERO for this project and be subject to failure of this course."

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1 Abstract

The primary engineering challenge we set out to address was the development of a CNC machine capable of precise fabric cutting, a task significantly more intricate than the common CNC machines that solely draw with pens. This problem complexity arises from the multifaceted nature of fabric, a flexible and delicate material that requires specialized handling to ensure clean cuts and intricate designs. The engineering challenge involves intricate mechanical design, sophisticated electronics for precise control, and adaptable software to accommodate various fabric types. Alternative solutions might include retrofitting existing CNC machines, but such approaches often lack the precision and versatility required for fabric cutting, making the development of a dedicated, multifunctional CNC machine the optimal solution.

2 Introduction

Our initial objective was to create a CNC (Computer Numerical Control) machine capable of executing precise fabric cutting with intricate designs, a task that extends beyond the capabilities of conventional CNC machines that primarily draw with pens. The challenges are to be focused on:

- **Material Complexity**: Fabric is a versatile material with various properties, including elasticity, thickness, and texture, which can vary significantly from one type to another. Achieving precise and clean cuts while preserving the fabric's integrity is a challenging task that demands a sophisticated engineering solution.
- **Mechanical Precision**: To ensure the quality and precision of fabric cutting, the mechanical components of the CNC machine must be designed with utmost precision. The machine's rigidity, accuracy of movement, and toolhead attachment mechanisms all contribute to the complexity of the engineering problem.
- **Electronic Control**: Achieving precision in fabric cutting requires precise control of motors, toolheads, and other mechanical components. Developing an electronic control system that can accommodate different cutting methods while ensuring safety and accuracy is a non-trivial engineering challenge.

With these challenges to be faced, we moved forward without project.

3 Design

3.1 Problem Formulation

In the modern landscape, the need for exacting design plotting and precision-driven shape cutting resonates across a across many different industries, underscoring the critical need for consistent accuracy in these tasks. A lack of precise accuracy can lead to final products that look unpolished or substandard.

To overcome this pivotal challenge, the adoption of automated machinery emerges as the essential solution. Amidst these, CNC (Computer Numerical Control) machines emerge as ultimate high point of precision and automation, combining elements to create powerful blend of cutting-edge technology and craftsmanship. Hence, we present a project targeted to execute these tasks with very high precision level.

3.1.1 Identification of Scope

Our project is about making a versatile CNC machine that can draw, cut and engrave for different kinds of businesses. We'll work on designing, building, and testing the machine to make sure it works well and is easy for people to use.

Stakeholders (including companies) that need precise machines, people who like to tinker as a hobby, small businesses, and schools that want an affordable way to do detailed work. The machines available right now often can't do all three tasks well, and they can be too expensive for smaller users. We have got a great scope because our goal is to create a CNC machine that's easy to use, affordable, and can do it all.

3.1.2 Literature Review

Computer Numerical Control (CNC) machines have transformed manufacturing across industries. They're automated, precise tools guided by computer programs. Our project focuses on designing a versatile CNC machine for plotting, cutting, and engraving.

CNC machines are incredibly important in various fields like aerospace, automotive, healthcare, woodworking, and education. They help with fast prototyping, making a lot of things quickly, and creating detailed crafts. In our project, we're mainly concentrating on improving detailed craftsmanship. This means we want to make it easier for artists and craftsmen to create very intricate and precise designs using our CNC machine. Our project's main goal is to provide a CNC machine that's perfect for these kinds of creative tasks, making them easier and more precise.

3.1.3 Formulation of Problem

The issue we intend to address revolves around the drawbacks of current CNC machines. These drawbacks include their limited versatility, high costs that can be difficult for smaller users, and usability challenges.

Traditional CNC machines excel at specific tasks but often force users to purchase separate machines for different jobs like drawing, cutting, and engraving. Additionally, their high prices and complicated interfaces make them less accessible.

This problem is significant because there is a growing need for precise craftsmanship and intricate designs across different industries and creative fields. Our project's overarching goal is to mitigate these limitations by designing and developing an all-encompassing CNC machine. This machine will offer versatility, affordability, and ease of use, empowering artisans, hobbyists, and small-scale manufacturers to enhance precision craftsmanship and expand their creative possibilities.

3.1.4 Analysis

- **Technical Feasibility and User Experience:**

  To ensure our project's technical feasibility, we're carefully studying the stuff we need, like parts and how to make the CNC machine. This also includes picking the right parts, making sure everything works precisely, and making the software and hardware work together smoothly. At the same time, we're looking into how users will use our CNC machine. We want it to be super easy to operate, allow for customization, and just be friendly for users.

- **Market Research and Compliance:**

  We're also checking out what's already in the CNC machine market to see what's popular and where there might be room for something new, like ours. We're making sure our project follows all the rules and safety stuff for CNC machines. Plus, we're keeping an eye out for any problems or challenges that could pop up along the way. Lastly, we're thinking about how our project might affect the environment, like using energy wisely and making materials that can be recycled.

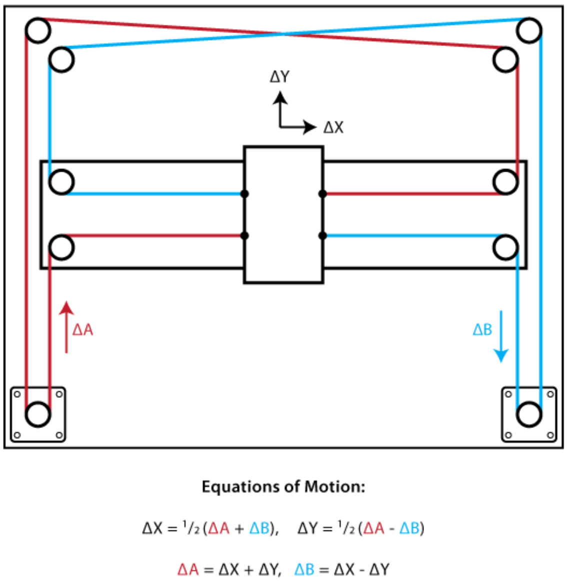
3.2 Design Method

The electrical part is composed of:

- Arduino UNO (well, a clone)
- CNC Shield V3
- 2x Stepper motor SL42STH34–1334A
- 2x Pololu stepper driver A4988

Here we used the GBRL vo.9i version to run the Arduino which is a firmware standard for CNC machine.

The machine is using a COREXY kinematics system, where there is just one belt to move the two axis. So the two motor needs to work together with a specific math equation. It seems a common standard in 3D printer as well.

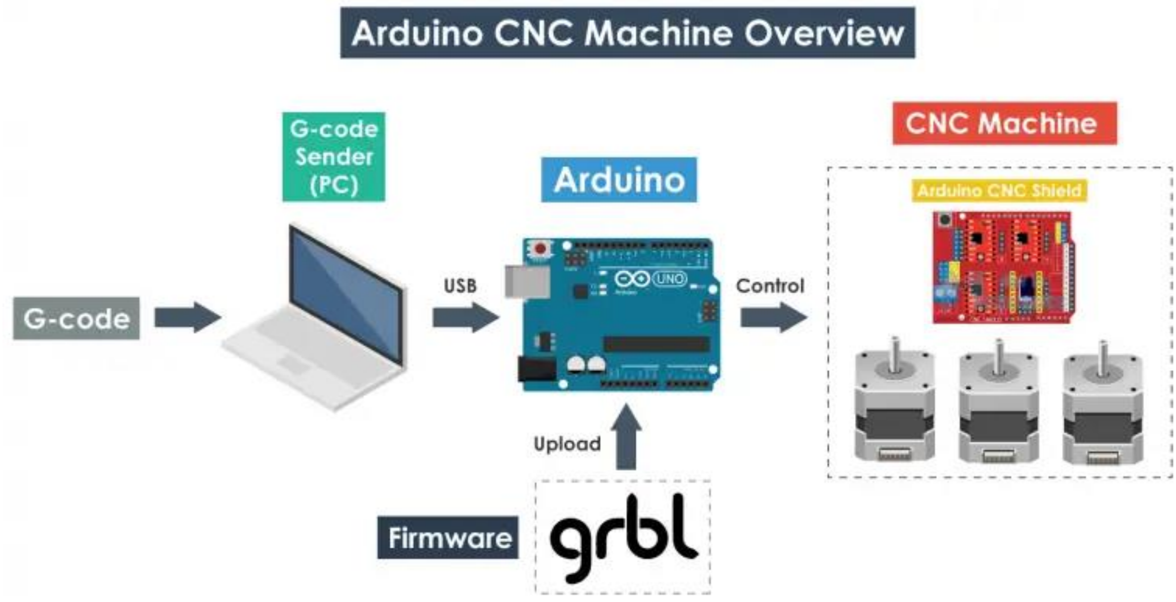


The next step involved making the servo pen operational, which required modifying the GRBL code source to incorporate servo support. Lastly, the GRBL settings had to be adjusted.

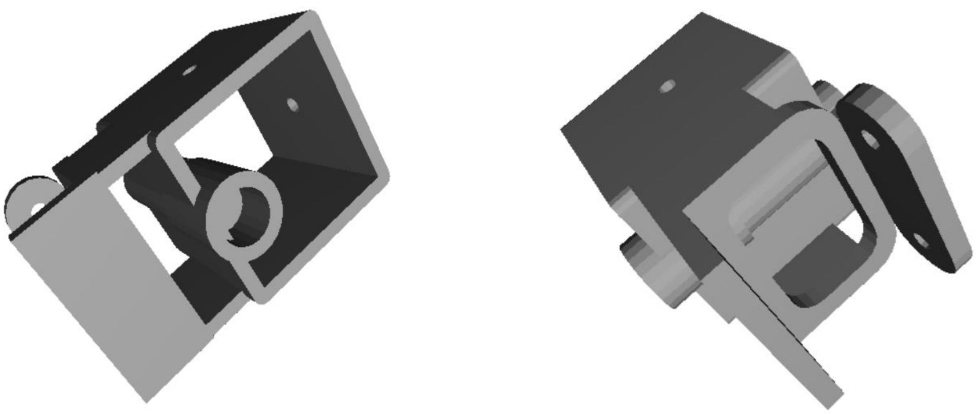
To print something, G-code, a straightforward numerical control language, must be transmitted.

Several methods exist for converting "vectorial" content into G-Code. Currently, a combination of canvas-sketch and gcode-file is being utilized, enabling the convenient creation of canvas 2D designs, visualization in the browser, and straightforward generation of G-Code from these designs.

3.3 Overall Project Block Diagram



3.4 CAD/Hardware Design



CAD of the laser holder

3.5 Full Source Code of Firmware

We used open source CNC shield supported stepper motor controlling code call GRBL.

i. For pen plotting we used GRBL v0.9j

https://github.com/robottini/grbl-servo

ii. For laser cutting and engraving, we used GRBL v1.1h with laser support

https://github.com/gnea/grbl/releases/tag/v1.1h.20190825

4 Implementation

4.1 Description

To implement the whole project, first we had to collect the parts. We bought all the parts from several sources. Mostly the things were bought from online shops.

Fig: Parts of CNC machine

In the visual representation provided, various components crucial to the project's construction become evident. These essential components encompass 3D printed plastic structures, servo motors, aluminum rods, screws, wires, and Arduino microcontrollers. Collecting these diverse parts marked the initial phase of the project's preparation.

Subsequently, the assembly process unfolded systematically, with each component being meticulously integrated into the project's framework. This step-by-step assembly approach ensured the seamless incorporation of all parts, contributing to the project's overall functionality and success.

During the assembly phase, we encountered several notable challenges. The initial hurdle revolved around the precise alignment of components, demanding meticulous attention to detail to ensure proper integration. A significant obstacle emerged during the incorporation of the laser component, as it initially proved incompatible with the machine's existing structure. To overcome this, we took the initiative to design and manufacture a custom 3D printed laser holder, facilitating the successful integration of the laser. Mounting screws into the 3D printed parts posed another challenge, necessitating a careful and precise approach.

Additionally, the specialized wire used for the main power supply presented connectivity issues with standard sockets, leading us to develop alternative port solutions. Handling the timing belt added complexity to the assembly process, requiring both time and attention to detail. These challenges demanded iterative problem-solving, resulting in successful resolutions and an improved final assembly.

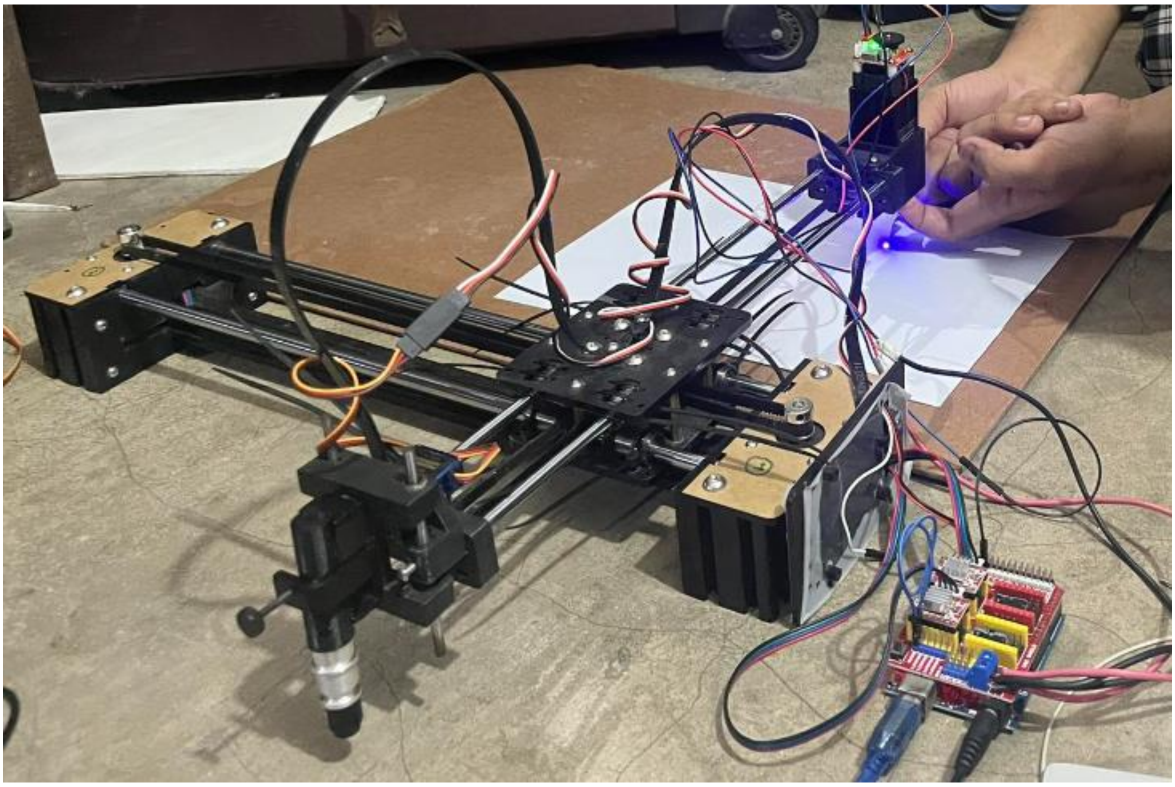
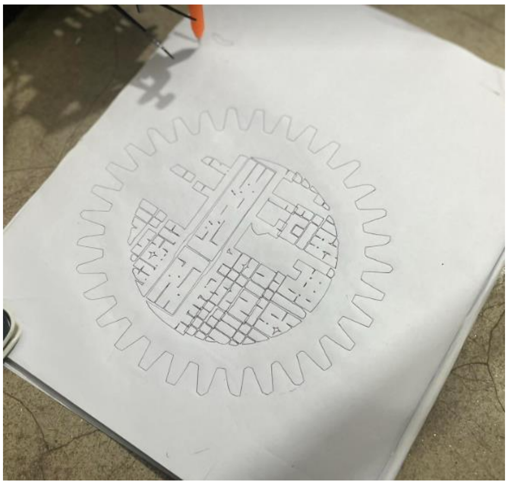


Fig: Final Machine

4.2 Experiment and Data Collection

Initially we made the CNC plotter. And we tried to experiment with some images. Here are the outputs –



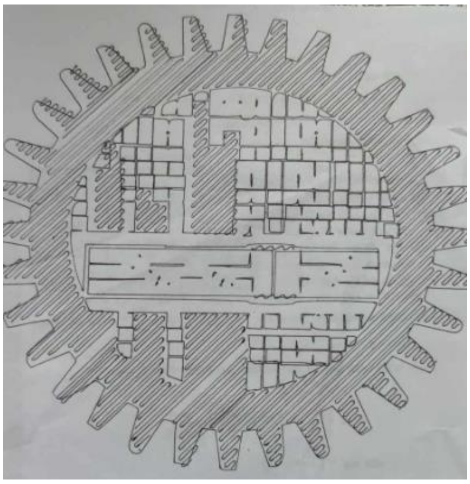


Fig: CNC machine plotting BUET logo

After the plotter was done, we mounted laser cutter in the machine. And here is what we got-

On Cardboard

On Paper

Cutting Cloth

4.3 Data Analysis and Results

When evaluating the machine's performance, notable observations have emerged. Laser application on paper results in a minor degree of scorching, whereas it demonstrates optimal functionality on solid wooden surfaces, yielding precise outcomes. Additionally, our machine successfully incorporates a cutting feature, delivering favorable results in various applications.

However, a particular challenge arises when cutting textiles, as the resultant edges lack the desired level of smoothness. This issue warrants further attention and refinement to ensure the machine's versatility across a wide range of materials and applications. Ongoing efforts in addressing this concern will contribute to the overall enhancement of the machine's performance and its suitability for diverse tasks.

5 Design Analysis and Evaluation

5.1 Novelty

Designing, analyzing, and evaluating a multi-functional Computer Numerical Control (CNC) machine involves a comprehensive process that considers various aspects, including machine specifications, functionality, efficiency, safety, and cost-effectiveness.

5.2 Design Considerations

5.2.1 Considerations to public health and safety

This CNC machine was equipped with safety features such as emergency stop buttons, interlocks, and safety guards to prevent accidents and mitigate risks.

We conducted a thorough risk assessment to identify potential hazards associated with the specific CNC machine and its intended use.

5.2.2 Considerations to environment

CNC machines can consume a significant amount of electrical energy. We considered investing in energy-efficient models or retrofitting existing machines with energy-saving features.

Software and hardware optimizations were implemented to reduce idle time and minimize energy consumption during non-cutting operations.

5.2.3 Considerations to cultural and societal needs

Different cultures may have varying safety norms and practices. It was ensured that the CNC machine adheres to international safety standards while allowing for customization to align with local safety expectations. We have designed an intuitive user interface that is easy to understand and use, even for individuals with limited technical background or literacy.

Designs or features that may be offensive or culturally insensitive were avoided and paid attention to symbols, colors, and any cultural taboos in the design and user experience.

5.3 Investigations

5.3.1 Literature Review

Designing, analyzing, and evaluating a multi-functional CNC machine is a complex process that requires careful planning, engineering expertise, and a commitment to meeting performance, safety, and efficiency goals. Continuous improvement and adaptation to changing needs are essential for long-term success.

5.4 Limitations of Tools

A CNC machine that can engrave on plywood, plot with a pen, and cut with a laser typically uses a combination of different motors and tools. Each of these components may have its own limitations, and it's essential to understand them to get the best performance and avoid potential issues. Here are some possible limitations of the motors in such a CNC machine:

1. **Stepper Motor Limitations:**
   - Torque: Stepper motors used for CNC applications have a maximum torque they can provide. If the load on the tool exceeds this torque, you may experience missed steps or stalled movements.
   - Speed: Stepper motors have a maximum speed at which they can operate effectively. Going beyond this speed may result in reduced accuracy and torque.
   - Microstepping: While microstepping can provide smoother motion, it may reduce the available torque, so you need to balance between smoothness and torque for different tasks.
   - Overheating: Stepper motors can get hot during extended operation, especially if they're pushed close to their torque limits. Overheating can lead to motor damage or missed steps.

2. **Pen Plotter Limitations:**
   - Pen Pressure: The pen mechanism's limitations can affect the quality of plotting. If the pen cannot apply enough pressure or too much pressure, it can impact line quality and consistency.
   - Position Accuracy: Accuracy in pen plotting depends on the precision of the

mechanical components, including the motor, belts, and guide rails.

3. Laser Cutter Limitations:

- Power and Material Compatibility: The laser's power output may limit the thickness and type of materials that can be effectively cut. Thicker or highly reflective materials may require more powerful lasers.
- Focusing: Proper focusing is crucial for laser cutting. Any misalignment can lead to uneven cutting or burning.
- Safety: Laser cutters pose safety concerns due to the potential for fires and harmful emissions. Proper ventilation and safety measures are essential.

4. Common Limitations:

- Workspace Size:The CNC machine's physical size limits the maximum workpiece dimensions. You may not be able to work on larger materials.
- Rigidity: The machine's overall rigidity affects its ability to maintain accuracy during high-speed or heavy-duty operations.
- Controller and Software: The CNC controller and software play a crucial role in coordinating the different components. Limitations in software or hardware can affect the machine's capabilities.

5.Duty Cycle: Continuous operation for extended periods can lead to overheating of motors and other components. Be aware of the machine's duty cycle and allow for cooling breaks.

6.Maintenance: Regular maintenance is essential to keep the CNC machine in good working condition. Lubrication, cleaning, and belt tensioning are among the tasks that may be required.

Understanding and managing these limitations is crucial for achieving the desired results with your CNC machine. It's also essential to prioritize safety when working with lasers and implement proper safety measures to protect yourself and the environment.

5.5 Impact Assessment

5.5.1 Assessment of Societal and Cultural Issues

Multi-functional CNC projects often represent technological advancements, which can lead to increased productivity and efficiency in various industries. This can result in economic growth and job creation.

The implementation of CNC technology may require upskilling of the workforce. This can lead to a more skilled and adaptable workforce that is better equipped to handle technological changes.

5.5.2 Assessment of Health and Safety Issues

CNC machines can perform repetitive tasks with high precision, reducing the risk of human error. This can lead to improved product quality and reduced safety risks associated with manual operations. CNC machines can handle tasks that might otherwise require manual labor, reducing the physical strain on workers and lowering the risk of musculoskeletal injuries.

On the other hand, Human errors during these phases can lead to accidents if proper training and safety protocols are not followed. Safe procedures and protective equipment are necessary to minimize the risk.

5.6 Sustainability and Environmental Impact Evaluation

Resource Efficiency: CNC machines can be programmed to optimize material use, reducing waste. This is particularly important for sustainability, as it minimizes the need for additional raw materials.

Energy Efficiency: Modern CNC machines are designed to be energy-efficient, which can lead to reduced energy consumption during manufacturing.

Customization: CNC machines enable precise and customized production, which can result in products that better meet specific customer needs and reduce the overall environmental impact associated with mass production and overproduction.

Longevity: Well-maintained CNC machines can have a long operational life, reducing the need for frequent replacements and lowering the environmental impact of manufacturing equipment production.

On the other hand,

CNC machines, especially larger and more complex ones, can consume a significant amount of energy during operation, depending on factors like the material being processed, the tooling used, and the complexity of the parts being manufactured.

The choice of materials used in CNC projects can have a significant impact on sustainability. If non-sustainable or non-recyclable materials are used, this can contribute to environmental degradation.

5.7 Ethical Issues

Multi-functional CNC machines often rely on software and data to operate. Protecting the data used in the CNC system, including design files and operational data, is crucial. Utilizing intellectual property rights and respecting copyright and patent laws are ethical responsibilities.

It was ensured that no unauthorized duplication or use of designs were used in our project. The GRBL code that we used to feed the system is open-source code file where no ethical dilemma took place.

6 Reflection on Individual and Team work

6.1 Individual Contribution of Each Member

1906001: Software control, setting up laser,1st model setup
1906010: Material Collect, 1st model setup
1906013: Debugging, Arduino control
1906026: Assembly of the 2nd model
1906031: Assembly of the 2nd model, , 3D printing of laser

6.2 Mode of Teamwork

6.3 Diversity Statement of Team

6.4 Log Book of Project Implementation

Date /week	Milestone achieved
6th week	Components are bought
7th week	First demo model was built
9th week	Bought the 2nd model components
10th week	Second circuit was assembled and servo ran
11th week	Added laser module
12th week	Wire management with plastic belt

7 Communication

7.1 Executive Summary

We have made a CNC machine that can perform 3 tasks -

- Plotting
- Cutting
- Engraving

Our machine helps us to create intricate designs, precision cuts, and stunning artwork with ease. It will make us say goodbye to manual labor and hello to precision and efficiency.

We have made a CNC machine, a versatile marvel capable of seamlessly executing three essential tasks: plotting, cutting, and engraving. This project empowers users to effortlessly craft intricate designs, achieve precision cuts, and produce stunning artwork, all while bidding farewell to the toil of manual labor. Embracing this technology means embracing precision, efficiency, and limitless creative potential. Say hello to a future where craftsmanship meets automation, and projects reach new heights of excellence.

7.2 User Manual

1. *Pen Plotting:*

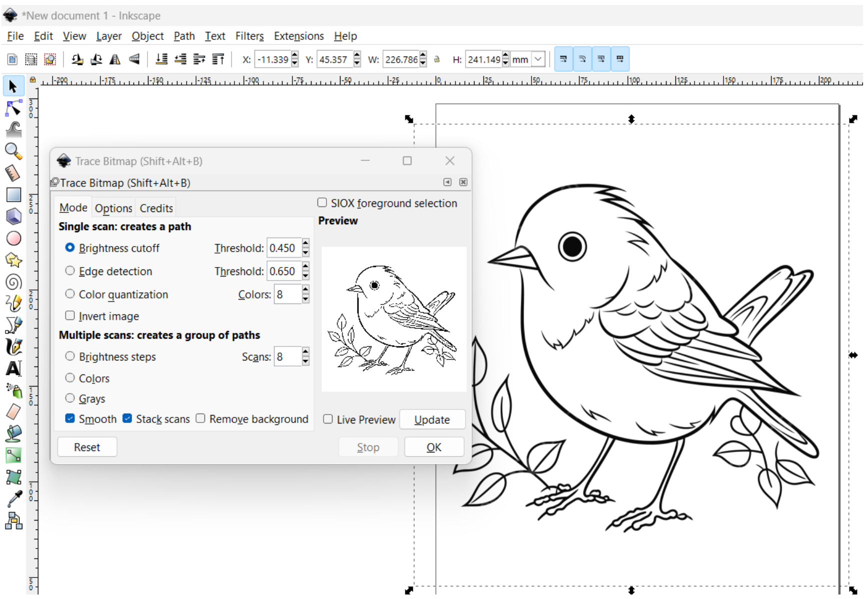
➢ Here we are using 'Inkscape' for generating gcode and UGS (Universal Gcode Sender) for continuously send Gcode to arduino.

- Generating Gcode in Inkscape:

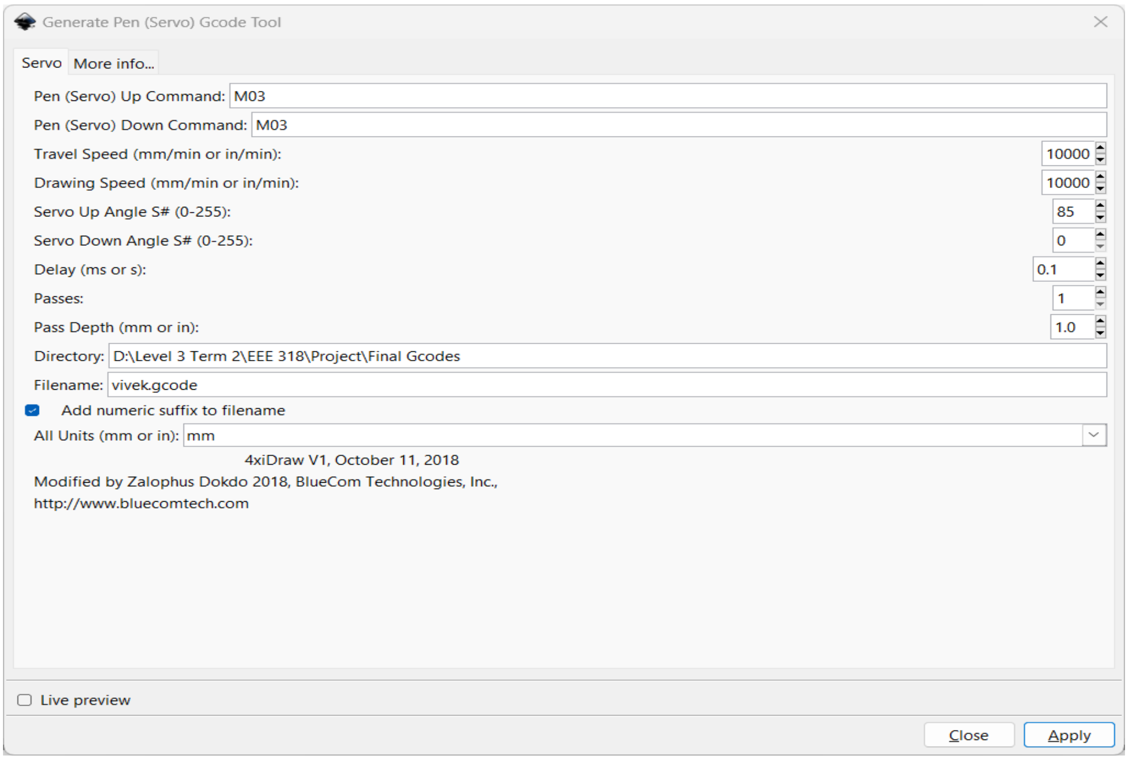
i. Design you design in inkscape

ii. From path tools, select 'Trace Bitmap' to vectorize the image. Here, we have to set how much precision we want.

iii. Selecting the bitmap and dragging it out of the original photo, delete the original photo and keep only the traced bitmap.



iv. Using 4ixDrawer Tool at extension, select Gecodes with pen servo tool

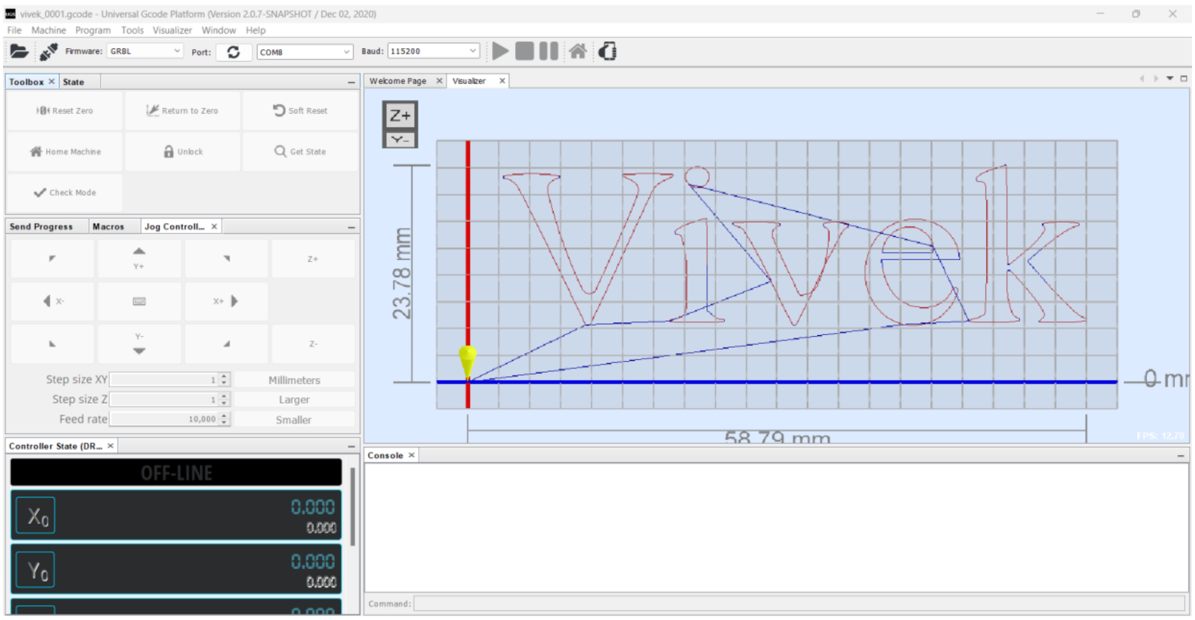


v. Select the appropriate path to save the Gcode and press apply.

vi. We can also set hatch fill to fill up the image on dark region.

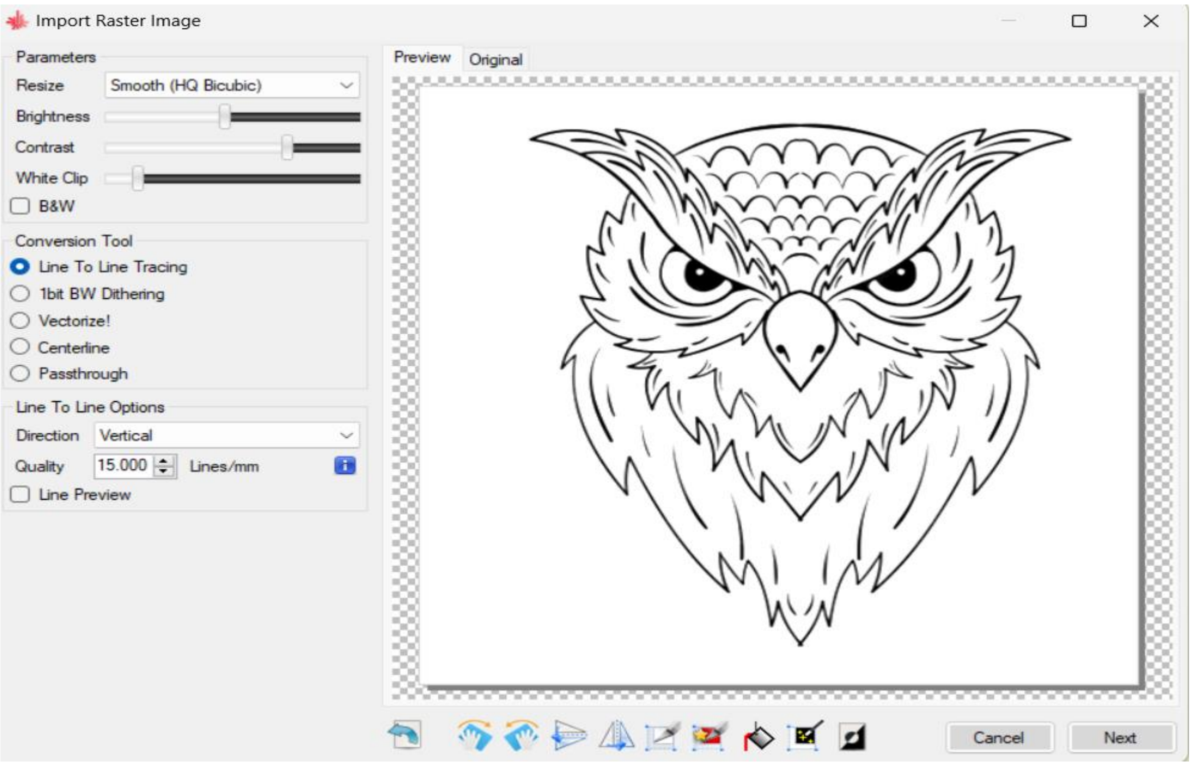
vii. Open UGS. Connect the Arduino and CNC shield to the software. From file tab, open the gcode generated before. We can now see the vectorized path for our pen to move.

viii. Attaching the pen, if we set the run button. Our operation should start.



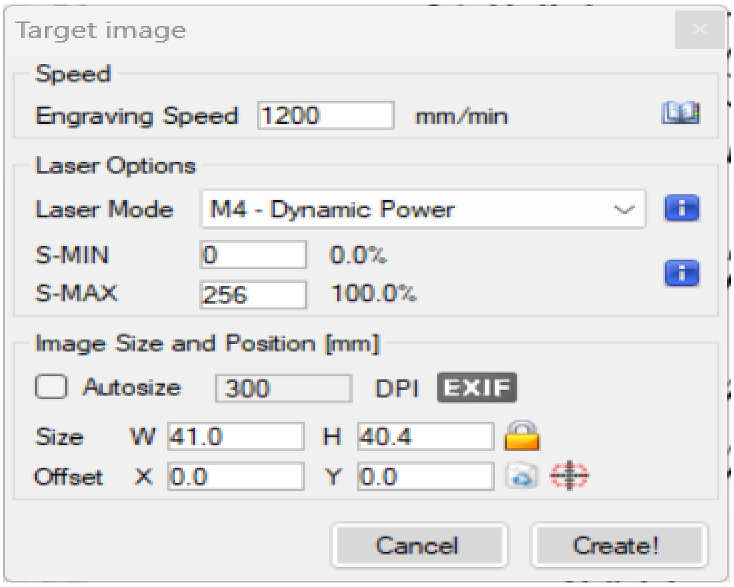
2. Engraving and Cutting:

i. Open laserGRBL. Import an image.



ii. Set Vectorize to cut with laser and Line to line tracing for laser engraving. This would yield best performance from my experience. We can set other options to various design.

iii.



iv. Then we have to set laser speed, engraving area

v. Then we have to connect laserGRBL with Arduino, wear laser protective glass and press run. With an alarm message, the engraving starts. Do not touch the paper until the engraving stops.

Project Management and Cost Analysis

Project Management:

We had a team of 5 members. Each member was in charge of different tasks. Exclusively, one member was made our project manager. He guided everyone's task and managed the overall project very well.

Cost Analysis:

Our initial budget that we thought was 15000 taka overall. But unfortunately, that amount exceeded. This happened because some of the parts of our project had to be ordered from outside of the country. So for the extra shipping charge, our budget exceeded. The total cost for this project was approximately 25000 taka.

7.3 Bill of Materials

Components	Price (Tk)
Stepper motor (NEMA-17) x 2	2200
Servo motor (SG90) x 2	300
CNC shield V3	350
Motor Driver(A4988) x2	360
Main body kit	2500
Laser Module (5500 mW)	8000
Arduino UNO	800
Timing belt	600
3D printing	550
Total	**15660**

8 Future Work

Advanced Material Compatibility:
To research and implement support for a wider range of materials, including exotic metals, composites, and non-traditional materials, and develop specialized tooling and machining strategies for specific materials.

Enhanced Precision and Accuracy:
To investigate and implement advanced calibration techniques aimed at improving the precision and accuracy of the CNC machine. Exploring the use of more precise linear guides, encoders, and sensors can be considered.

Automation and Robotics Integration:
Integrating robotic arms or automation systems for material handling, tool changes, and other repetitive tasks can offer significant advantages. Additionally, implementing computer vision for object recognition and tracking is a valuable consideration.

Multi-Axis Machining:
Extending the CNC machine to support more axes (e.g., 5-axis or 6-axis machining) for handling complex geometries and intricate parts is a viable enhancement. For this purpose, developing software for generating tool paths and controlling multi-axis movements is essential.

Adaptive Machining:
Implementing real-time monitoring and feedback systems to adjust machining parameters based on material properties, tool wear, and environmental conditions, and utilizing machine learning algorithms for predictive maintenance and optimization is a forward-looking strategy.

Remote Monitoring and Control:
Introducing a system for remote monitoring and control of the CNC machine using IoT (Internet of Things) technology is a valuable addition. Additionally, implementing security measures to protect against unauthorized access is essential.

Environmental Considerations:
Exploring more sustainable practices to make the CNC machine environmentally friendly, such as reducing energy consumption and waste generation, is commendable. Consideration of using sustainable materials and cutting fluids is a step in the right direction.

Integration with CAD/CAM Systems:
Improving integration with CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing) software to streamline the workflow from design to machining is a worthwhile endeavor.

Cost Optimization:
Continuously working on reducing production costs to make the machine more accessible to a broader range of users is a fundamental goal.

9 References

- https://www.academia.edu/37889995/Design_and_Analysis_Mini_CNC_Plotter_Machine
- https://www.scribd.com/document/434690956/New-Final-Project-Report-of-cnc-plotter#