DrawBot: Low Profile, Economical 3D Printed CNC Plotting Machine designed using CATIA Modelling

This Project Report is submitted in partial fulfillment of the requirements for the certification in

Finishing School Program on 3D Printing & Additive Manufacturing Technology

Programmed by

Ministry of Electronics and Information Technology (MeitY), Government of India

Implemented by

Centre for Development of Advanced Computing (C-DAC), Kolkata

Under the supervision of

Dr. Mrinmoy Chakraborty (Center Coordinator)
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MINISTRY OF
ELECTRONICS &
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Certificate of Approval

This project report entitled **"DrawBot: Low Profile, Economical 3D Printed CNC Plotting Machine designed using CATIA Modelling"** by **Puja Kumari (FSO5A0030)** is approved for the certification course on **Finishing School Program On 3D Printing & Additive Manufacturing Technology** of **Centre for Development of Advanced Computing (C-DAC), Kolkata.** It is understood that the Project Report is only approved for the purpose for which it is submitted.

Place: **Centre Coordinator**

Date: **Final Examination for Evaluation of the Project Report**

Certificate of Recommendation

We hereby recommend that the Project Report prepared under our supervision by Puja Kumari (FSO5A0030) entitled "**DrawBot: Low Profile, Economical 3D Printed CNC Plotting Machine designed using CATIA Modelling"** be accepted in partial fulfillment of the requirement for the certification on **Finishing School Program On 3D Printing & Additive Manufacturing Technology** of **Centre for Development of Advanced Computing (C-DAC), Kolkata.**

Asit Kumar Singh

Chief Investigator Finishing School Program On 3D Printing & Additive Manufacturing Technology Centre for Development of Advanced Computing (C-DAC), Kolkata Ministry of Electronics and Information Technology (MeitY), Government of India

Place:

Date:

Declaration

We, hereby declare that the work embodied in this project report under the title **"DrawBot: Low Profile, Economical 3D Printed CNC Plotting Machine designed using CATIA Modelling"** is an original work carried out under the program **Finishing School Program On 3D Printing & Additive Manufacturing Technology** of the **Centre for Development of Advanced Computing (C-DAC), Kolkata** with exception of guidance and suggestions received from our faculties. The data and the findings discussed in the project report are the outcome of our research work. This project report is being submitted to **Centre for Development of Advanced Computing (C-DAC), Kolkata,** for the partial fulfillment of the requirements for the certification of **Finishing School Program On 3D Printing & Additive Manufacturing Technology.**

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Acknowledgement

The successful completion of any project is a collaborative effort, and we are grateful for the invaluable contributions and support of numerous individuals. Their assistance and guidance have been crucial in bringing this project to fruition.

First and foremost, I would like to express my heartfelt appreciation to **Shri Asit Kumar Singh, Chief Investigator of the Project & Dr. Mrinmoy Chakraborty, Centre Coordinator, Dr. B.C. Roy Engineering College, Durgapur** of the Program "**Finishing School Program On 3D Printing & Additive Manufacturing Technology**". Their unwavering support and kind encouragement have been instrumental in our learning journey. We would also like to thank our supervisors **Monalisa Pal (Senior Faculty), Ritika Chatterjee (Assistant Faculty) and Sayan Mukherjee (CAD/CAM Designer)** for their valuable advice and guidance whenever we required. We are sincerely grateful for his mentorship and the availability of his invaluable advice whenever we sought it.

Abstract

This project involves the design and development of a **low-cost CNC plotting machine using 3D printing**. The main goal was to create a compact and accurate machine capable of drawing on flat surfaces for educational and creative purposes. The structure of the machine was built using 3D- printed parts, while movement along the X, Y, and Z axes was controlled using stepper motors, an Arduino Uno, and a CNC shield. Images were converted into G-code, which guided the pen or tool to draw precise patterns. The final prototype performed well, showing good accuracy and repeatability in plotting. Using 3D printing reduced the overall cost and made the machine easy to assemble and maintain. This project demonstrates that 3D printing can be effectively used to create affordable and functional CNC machines for small-scale applications such as learning, prototyping, and basic design work.

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1. Introduction

The 3D printed CNC plotting machine is a machine that combines mechanical components made with 3D printing technology with precise computer-controlled movement. By using this method, one can create a dependable and adaptable plotting equipment for a comparably cheap price. Using 3D printing to create structural elements like frames, supports, and pen holders facilitates quick assembly and simple design modification. The machine typically uses stepper motors, to regulate movement along the X, Y and Z axes, while a little servo motor controls the pen's vertical and horizontal motion for drawing or writing.

CNC plotters are prized in today's creative and manufacturing sectors for their capacity to precisely reproduce digital designs on a variety of materials, including paper, fabric, and plastic sheets. The use of 3D printed components in CNC plotters lowers the total manufacturing cost, makes CNC technology more accessible to small-scale producers and educational users, and promotes experimentation with machine design.

The machine is controlled by an Arduino microcontroller that works in conjunction with a CNC shield and stepper drivers to translate G-code commands into movements with great accuracy. Linear rails, belts, pulleys, and limit switches are used to guarantee a smooth and repeatable operation inside the specified workspace. The modularity of 3D-printed components makes maintenance, upgrades, and customization easier. These CNC plotting machines are especially well-suited for education, prototyping, low-volume production, and creative uses where inexpensive, adaptable, and accurate mechanical equipment is needed. By combining 3D printed parts with CNC controls, this technology demonstrates how additive manufacturing improves traditional processes, promotes sustainable, cost-effective production, and increases accessibility in digital fabrication.

2. Problem Statement

Although 3D printing and CNC machining are two contemporary manufacturing methods that each have their own advantages, they also have significant drawbacks. Traditional CNC machining is well known for its great precision and strength, but it is limited by material constraints and necessitates costly retooling with each design iteration. However, 3D printing typically lacks the precision, structural strength, and surface finish necessary for high-performance functional components, even if it offers more design freedom and shorter setup times.

Furthermore, cost and efficiency are issues that plague both traditional and contemporary manufacturing systems. The significant upfront expenditures in tooling, molds, and materials make CNC machining and molding unviable for small-volume or specialized production. On the other hand, 3D printing can be much slower, particularly for complicated or big components, resulting in delays in industries where a quick turnaround time is essential. Although 3D printing can handle a wide variety of materials, it frequently fails to match the strength and longevity of machined components, which further restricts its use in real-world, load-bearing applications.

Furthermore, many current systems are labor-intensive and lack automation, raising the risk of human mistake and lowering manufacturing efficiency. Hybrid machines that combine 3D printing and CNC technologies are frequently difficult to operate and maintain because they need expertise in both fields. Consequently, it is difficult for manufacturers to provide the right balance of precision, flexibility, and speed required for customized, small- batch manufacturing. The main challenge is, therefore, to create a 3D-printed CNC plotter that makes use of the best aspects of both technologies—accuracy, flexibility, and cost-effectiveness—while being simple to use and appropriate for the demands of high-speed, low-volume production.

3. Objective

3.1 Reduce the total cost of production and assembly by creating a low-cost CNC plotting machine that makes use of 3D printed structural elements. The aim is to lower the cost of materials and tooling by switching out conventional machined components for bespoke 3D printed ones. This method enables quick prototyping and simple modification to meet the needs of each project.

3.2 By automating movements along the X, Y, and Z axes using computer-controlled G-code commands, one can create accurate and dependable 2D plots of pictures, designs, and text. Using stepper motors and microcontroller-based control, the system guarantees the precise translation of digital patterns onto physical media. Even with complicated illustrations and repetitive activities, the plot remains consistent in quality.

3.3 Reduce human involvement in drawing activities by increasing automation and repeatability to enhance productivity and consistency of results. Once given a design file, the plotter may handle drawing operations on its own, lessening reliance on manual labor. In addition to saving time, automation significantly lowers the chance of human mistake when in use.

3.4 By allowing simple tool switches (such as pens and markers) and enabling quick component changes for various uses and surfaces, increase flexibility and customization. The machine may be easily changed to perform a variety of tasks, including sketching, labeling, and technical drawing, using interchangeable tool modules and modular 3D-printed mounts. Rapid adaptability allows the same platform to support new workflows or materials without significant reengineering.

3.5 Create a small, lightweight device that is optimized for workplace productivity and mobility. Due to the use of lightweight 3D printed materials, the plotter is simple to relocate, set up, or store as necessary. Because of its compact footprint, it may be used effectively in restricted areas such as classrooms, offices, or home workshops.

3.6 Provide straightforward assembly, programmability, and hands-on learning about CNC concepts to make it easier for people to use it for instructional and DIY purposes. The project is accessible to students and hobbyists with little technical expertise due to its thorough documentation and user-friendly interfaces. Users learn basic ideas in mechanics, electronics, and automation through constructing and programming the plotter.

4. Literature Review

- Reviewed existing CNC plotting machines to understand standard mechanisms for X, Y, and Z-axis movement using stepper motors and microcontrollers.

- Analyzed various applications of 3D printing in mechanical design, emphasizing its cost-effectiveness, lightweight nature, and customizability.

α. Studied Arduino-based GRBL firmware implementations in low-cost CNC systems for precise control through G-code instructions.

β. Compared traditional CNC machines with hybrid 3D-printed versions to evaluate feasibility in educational, prototyping, and DIY use cases.

χ. Examined material strength, dimensional stability, and print settings to ensure 3D-printed parts could support mechanical stress and repeated movement.

δ. Evaluated slicing software (e.g., Cura) and CAD/CAM tools (e.g., Catia) for generating accurate toolpaths and printable models.

- Referenced successful implementations of compact CNC plotters for tasks such as sketching, engraving, and labeling to benchmark performance expectations.

- Identified key factors like modular design, automation, ease of assembly, and reusability as essential goals for a beginner-friendly CNC plotting system.

5. Methodology

The 3D Printed CNC Plotting Machine integrates a number of cutting-edge technologies, processes, and equipment to provide exceptional precision, versatility, and customization in production. A thorough analysis of the tools, methods, resources, and procedures utilized is provided below:

5.1 Tools and equipment that are used:

- The 3D Printed CNC Plotting Machine uses a CNC controller with stepper or servo motors and linear actuators to control precise movement along X, Y, and Z axes. A 3D printer extruder deposits material layer by layer, guided by software and digital models. End mills are used for cutting and engraving in the CNC mode. Some setups also include a rotary table for multi-axis machining of complex parts.

5.2 Procedures Employed:

- The machine uses subtractive CNC machining to remove material with high precision, ideal for detailed and rigid parts. Additive 3D printing builds complex shapes layer by layer, suitable for intricate geometries. Hybrid fabrication combines both, using 3D printing to form rough shapes and CNC for precision finishing. This maximizes both design flexibility and accuracy.

- **The Resources Utilized:**

- The machine works with various materials including plastics like PLA for easy prototyping, ABS for durability, and nylon for strength and flexibility. Metals such as aluminum and stainless steel are used for strong, corrosion-resistant parts. Additionally, composite materials like carbon fiber reinforced filaments provide high strength-to-weight ratios for advanced applications in aerospace and automotive industries.

5.4 Factors Tested:

The machine works with various materials including plastics like PLA for easy prototyping, ABS for durability, and nylon for strength and flexibility. Metals such as aluminum and stainless steel are used for strong, corrosion-resistant parts. Additionally, composite materials like carbon fiber reinforced filaments provide high strength-to-weight ratios for advanced applications in aerospace and automotive industries.

5.5 Software Instruments:

The software tools used include CAD programs like CATIA to create detailed digital models essential for both CNC machining and 3D printing For 3D printing, slicing software like Cura converts CAD models into layered instructions, allowing adjustments for print settings such as layer height and speed. These tools together ensure accurate design translation and precise manufacturing.

6. DESIGN & IMPLEMENTATION

6.1 Design Overview

- The CNC plotter was designed to perform precise 2D and 3D movements for plotting and part printing tasks. The structure and control system were carefully developed to ensure smooth motion, stability, and accurate output. The design includes three axes (X, Y, Z) for movement, a print head or pen holder for extrusion or drawing, and a microcontroller-based control system.

6.2 Mechanical Design

- Frame Structure: Made using lightweight aluminum profiles, acrylic sheets, or wooden baseboards depending on availability. Designed to maintain rigidity and reduce vibrations during motion.
- Axis Mechanism: X and Y Axes: Designed with GT2 timing belts, pulley systems, and stepper motors mounted on linear rods. Z Axis: Built with a lead screw mechanism to ensure precision in vertical movement, suitable for controlling the pen or extruder height.
- Print/Plotting Head: Can switch between a pen holder (for CNC plotting) and a mini extruder (for filament-based printing) using 3D printed mounts.

6.3 Electronic Implementation

Microcontroller: The system is controlled by an Arduino UNO , programmed with ARDUINO-IDE.

Motor Drivers: Used ULN2003A Driver Module Stepper Motor Driver to control the stepper motors.

Stepper Motors: 28BYJ-48 Stepper Motor DC 5V were used for all three axes, ensuring adequate torque and accuracy.

Power Supply: A 5V DC power supply was used to power the motors and the controller board.

6.4 Software Integration

G-code Generation: Design files were created using JSCUT.

Control Software: The CNC plotter was operated via Universal G-code Sender (UGS) Calibration & Testing.

Calibrated each axis to ensure correct steps/mm movement.

Adjusted belt tension and alignment to prevent skipping.

Tested movement using basic shape plotting (square, circle) before moving to full part printing.

For 3D printing, the extruder temperature and bed leveling were tested manually to ensure print quality.

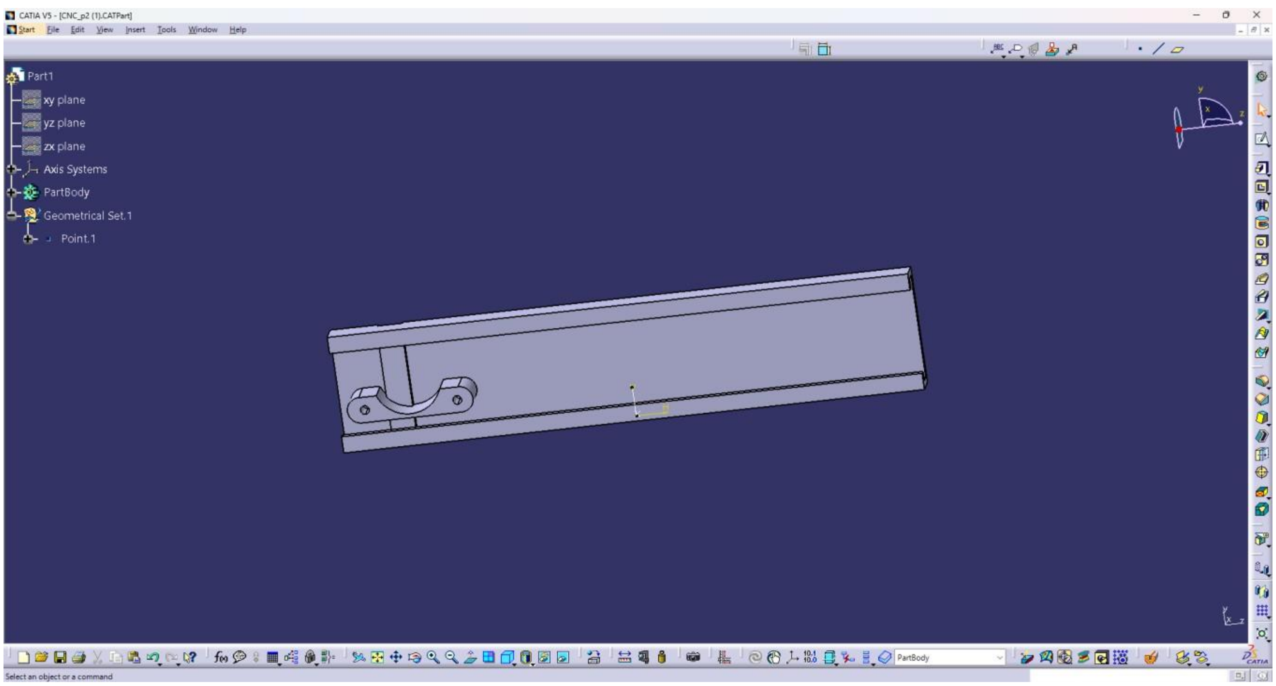


Fig 1 : 3D Printed CNC Plotting Machine- Parts

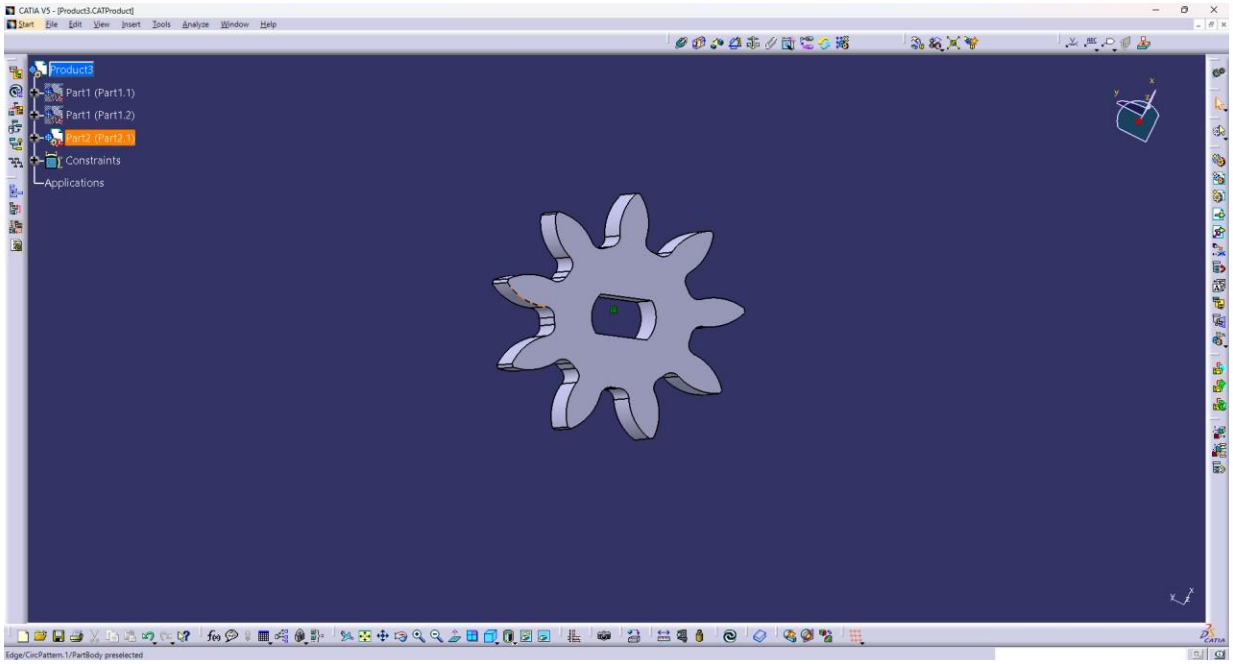


Fig 2 : 3D Printed CNC Plotting Machine- Parts

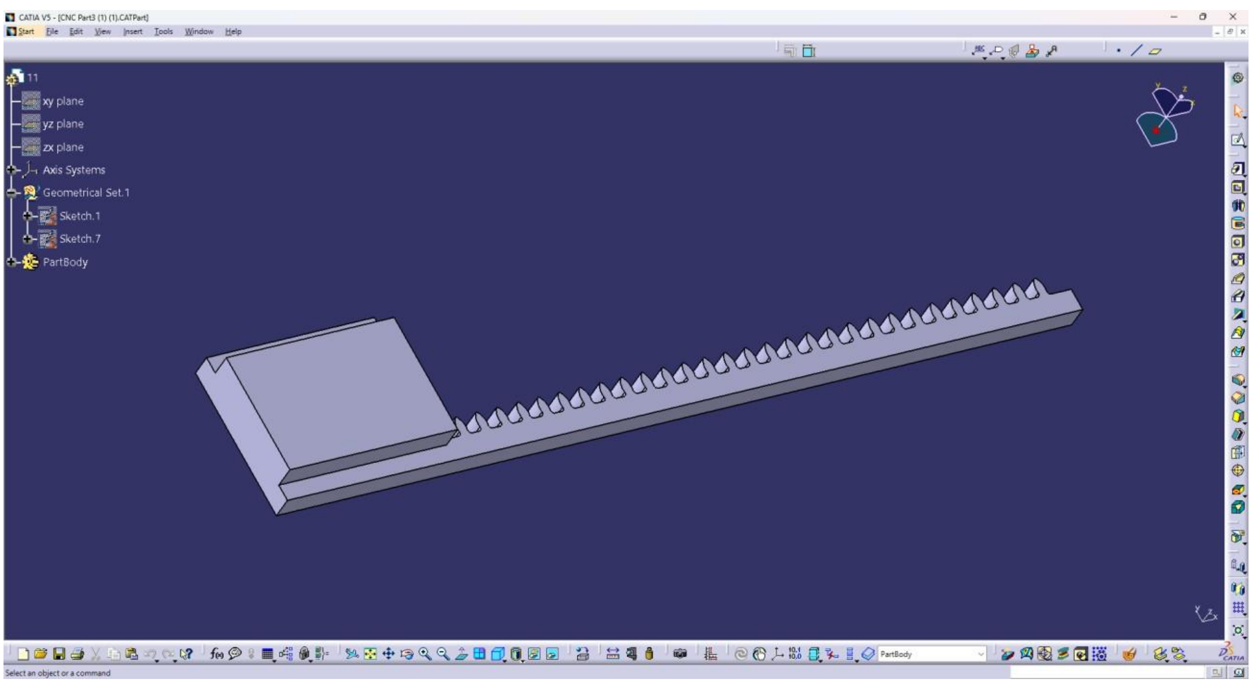


Fig 3 : 3D Printed CNC Plotting Machine- Parts

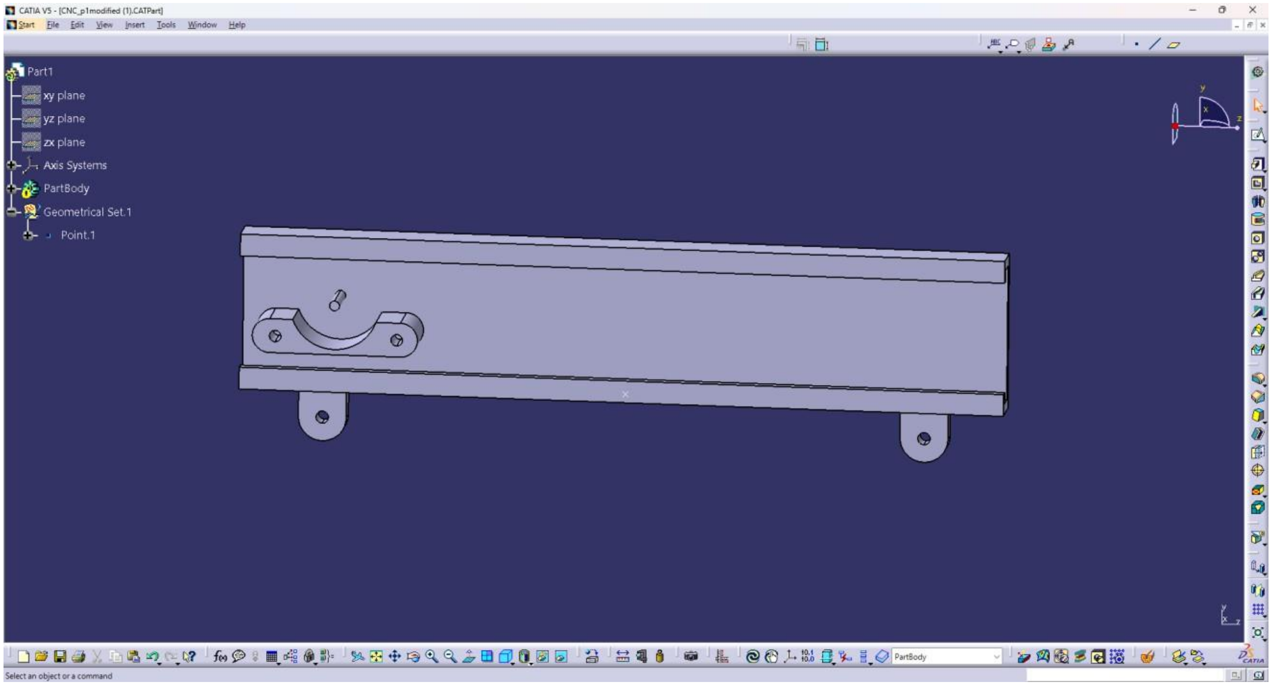


Fig 4 : 3D Printed CNC Plotting Machine- Parts

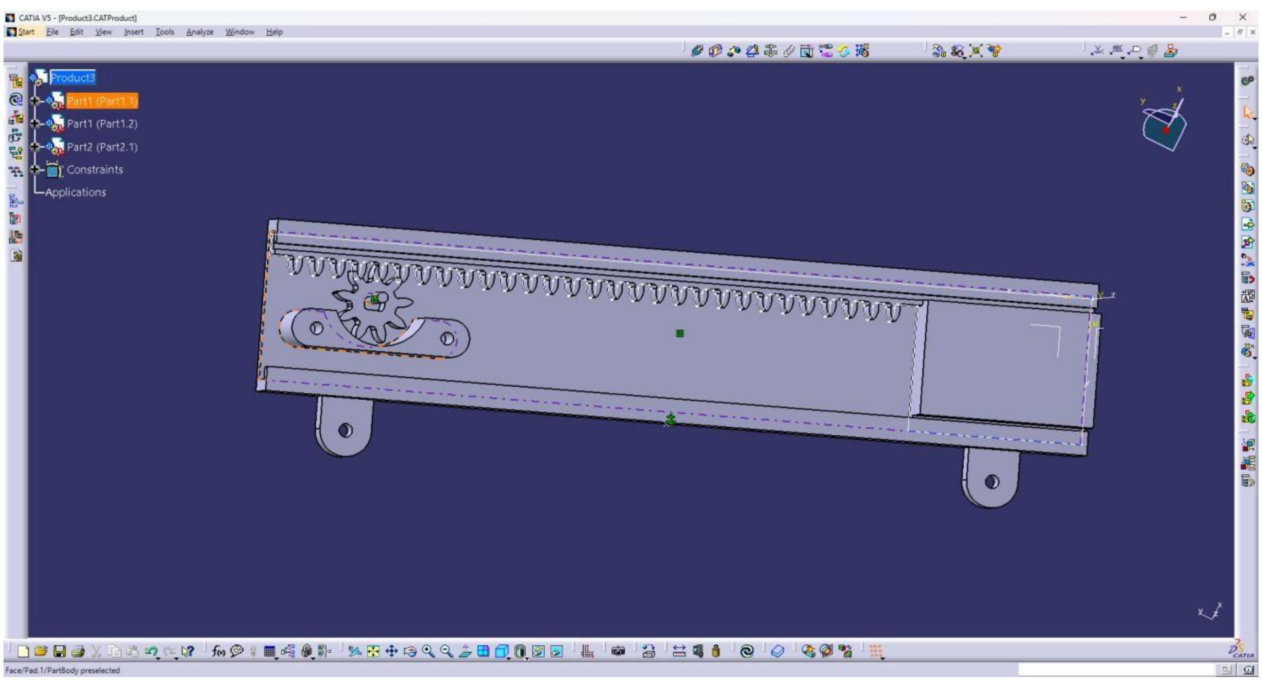


Fig 5 : 3D Printed CNC Plotting Machine- Assembly Design

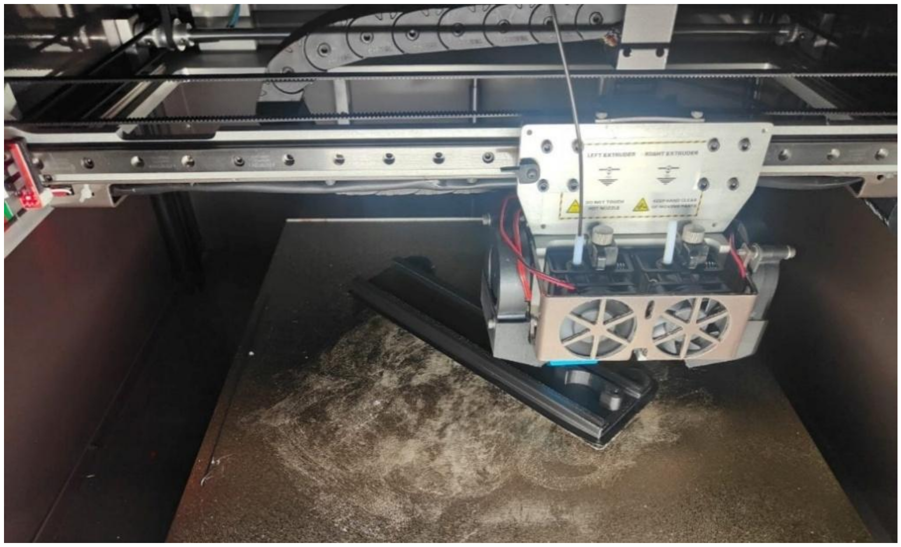
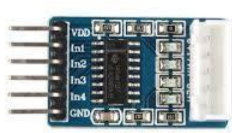


Fig 6 : Printing of part 7

Fig 7 : 3D Printing CNC Plotting Machine- Parts in 4DS

Components required:

S. No.	Components Name	Quantity
1.	 28BYJ-48 Stepper Motor DC 5V	3
2.	 10CM Female to Female Breadboard Jumper DuPont 2 Point 54mm 1P-1P Cables 40 pieces	1
3.	 ULN2003A Driver Module Stepper Motor Driver	3
4.	 Arduino UNO R3 with Cable	1

7. Future Scope

7.1 Multi-Function Tool Integration: Future versions can incorporate interchangeable tool heads (e.g., laser engraver, PCB drill, cutter) to expand functionality beyond plotting.

7.2 Wireless & IoT Connectivity: Adding Wi-Fi or Bluetooth modules will allow remote control, real-time monitoring, and cloud-based G-code uploads for smarter, connected operations.

7.3AI-Based Error Detection & Calibration: Integrating AI and sensors can enable automatic error detection, self-calibration, and adaptive adjustments to improve precision and reliability.

7.4 Material and Size Upgrades: Using stronger filaments or composite materials will allow printing more durable structural components, supporting larger plots and heavier loads.

7.5 Higher Axis Expansion: Adding additional axes (such as A/B for rotational motion) can allow complex 3D drawing or multi-surface plotting capabilities.

7.6 Educational Kits and DIY Market: With simplified assembly and modular design, the machine can be turned into a kit for students, hobbyists, and makerspaces to learn CNC and 3D printing concepts.

7.7 Eco-Friendly and Recyclable Design: Incorporating biodegradable or recycled 3D printing materials can promote sustainability in manufacturing and prototyping applications.

8. Conclusion & Result

The development of the 3D Printed CNC Plotting Machine successfully demonstrated how low-cost, 3D-printed components can be integrated with CNC technology to create a functional and precise plotting device. Throughout the project, we applied principles of mechanical design, electronics, and automation to build a machine that is not only affordable but also adaptable for various creative and educational applications. The use of Arduino and GRBL firmware proved highly efficient in handling G-code-based operations, and the modular design offered ease of assembly and future upgrades.

The prototype met all defined objectives, including smooth motion control, consistent plotting accuracy, and minimal manual intervention. Testing confirmed the machine's ability to accurately replicate digital designs on paper and similar materials, with reliable repeatability. Overall, the project fulfilled its purpose as a cost-effective alternative to traditional CNC systems, making it accessible for students, hobbyists, and low-volume prototyping needs. With continued enhancements, this machine holds potential for even broader applications.

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