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Arduino Powered CNC Plotter

Aishwarya Gangad, Prachi Mayanale, Sakshi Thombre
Students, Electronics and Telecommunications
Sinhgad College of Engineering, Pune, India

Abstract: *The growing demand for automation and precision in manufacturing has led to widespread adoption of Computer Numerical Control (CNC) machines across various industries. However, the high cost and complexity of conventional CNC systems present limitations, particularly for academic, research, and small-scale prototyping purposes. This paper presents the design and development of a low-cost, medium-sized CNC plotter capable of performing tasks such as PCB drawing and drilling. The system is built using simple and affordable components, including an ATmega328 based Arduino microcontroller, stepper motors, and a servo motor. The machine operates using G-code instructions, which are generated through open-source software and interpreted by the motor drivers to control the movement along the X, Y, and Z axes. This enables precise sketching or drilling on a variety of surfaces. The proposed CNC plotter offers a compact, efficient, and cost-effective solution for applications in educational laboratories, PCB design, and automated sketching, addressing the need for accessible digital fabrication tools.*

Keywords: CNC, Arduino microcontroller, G-Code, IDE

I. INTRODUCTION

In recent years, the advancement of automation and digital control systems has significantly transformed modern manufacturing practices. One of the most impactful technologies contributing to this transformation is Computer Numerical Control (CNC). CNC refers to the automated control of machining tools and 3D printers by means of a computer, allowing for precise and repeatable manufacturing processes with minimal human intervention. The primary advantage of CNC systems lies in their ability to follow pre-programmed sequences of commands—typically written in a standardized language known as G-code—to perform tasks such as cutting, milling, drilling, and drawing with high accuracy.

CNC technology was first introduced in the mid-20th century as an evolution of numerical control (NC) systems, which used punched tape to direct machine movements. With the integration of microcontrollers and personal computers, CNC systems have since become more versatile, accessible, and efficient. Today, CNC machines are widely used in industries ranging from aerospace and automotive to electronics and prototyping. Despite their widespread use, many commercial CNC machines remain cost-prohibitive for educational institutions, small workshops, hobbyists, and research environments. This creates a demand for simplified, low-cost CNC alternatives that retain essential functionality while being easier to operate, maintain, and customize.

In this context, the current research focuses on the design and development of a CNC plotter—a machine capable of drawing and performing basic sketching tasks. The plotter is controlled by an Arduino-based ATmega328 microcontroller, which interprets G-code instructions and coordinates the movements of stepper motors along the X, Y, and Z axes. The Z-axis also includes a servo motor that manipulates the pen bit vertically. The use of open-source hardware and software platforms reduces development costs and allows for flexibility in design and future upgrades.

The plotter receives input in the form of G-code, a machine level programming language that defines tool paths, speeds, and movement patterns. This code can be generated using software such as Inkscape that convert 2D designs into machine-readable instructions. The machine then executes these instructions to draw images on various surfaces. Such a system is especially valuable for rapid prototyping of PCBs, educational demonstrations, and custom artistic or design applications.

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The motivation behind this work is to provide a cost-effective CNC plotter that meets the functional requirements of PCB fabrication and general-purpose plotting. By utilizing affordable components and straightforward construction techniques, this project offers a practical solution for individuals and institutions looking to explore CNC technology without the financial and technical barriers typically associated with commercial systems.

II. PROPOSED SYSTEM

The proposed system is a compact and cost-effective CNC plotter designed for basic drawing and PCB prototyping tasks. It is built using affordable and widely available components, with a focus on simplicity, efficiency, and ease of use. The primary function of this system is to automate the drawing or drilling of precise patterns based on predefined G-code instructions.

At the core of the system is an Arduino Uno microcontroller, which acts as the central processing unit. It receives G-code commands from a computer via a USB connection and interprets them to control the movement of stepper and servo motors. The machine operates across three axes: X, Y, and Z. The X and Y axes manage the horizontal motion, while the Z axis controls the vertical movement of the drawing tool.

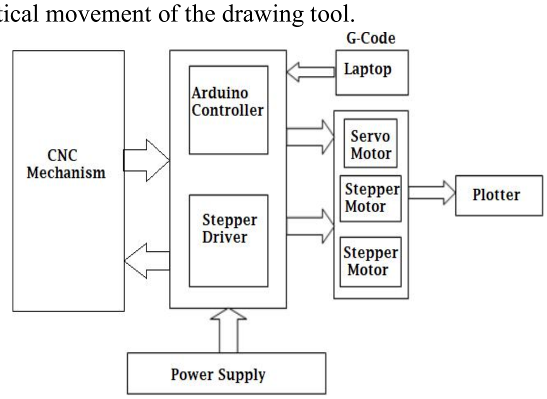

Fig 1. Block Diagram

III. PROCESSING STEPS

The development of the CNC plotter involves both mechanical assembly and electronic integration, which work together to form a functional plotting machine. This section elaborates on the physical construction of the machine and the electrical connections necessary for its operation.

A. Mechanical Assembly

The mechanical structure of the CNC plotter has been designed to be compact, modular, and efficient for precise two-dimensional sketching on an A3-size sheet. The entire frame is custom-built using a combination of 3D-printed components, steel guide rods, and threaded lead screws to ensure smooth linear motion across both X and Y axes.

Frame and Build Platform

The plotter frame is supported by a sturdy base, large enough to accommodate an A3 sheet for plotting. The frame itself is assembled using smooth steel rods that act as linear guides for both axes. These rods are anchored into 3D-printed end supports, which were designed to maintain alignment and reduce vibrations during motion.

X and Y Axis Movement

The movement along the X and Y axes is achieved using two NEMA 17 stepper motors, each coupled with a threaded rod (lead screw). These lead screws rotate to drive the motion of the carriages, which glide along the parallel smooth rods. The precision of this setup allows the pen to travel accurately to specific coordinates on the plotting area.

- The X-axis moves the pen assembly left and right.
- The Y-axis moves the entire X-axis assembly forward and backward, allowing for two-dimensional control.

Both axes use GT2 timing belts attached to the stepper motors and secured on the carriages using 3D-printed belt holders.

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Z Axis – Pen Lifting Mechanism

The Z-axis is controlled using a micro servo motor mounted on the pen holder. The servo is programmed to lift or lower the pen by rotating to a specified angle, effectively engaging or disengaging it from the paper surface. This allows for precise control over sketching without physically damaging the sheet.

Hardware Integration

• The motors and pen assembly are wired and controlled through a CNC V3 Shield mounted on an Arduino Uno, visible in the image.

• The components are powered via a DC step-down module, and the connections are made using jumper wires for modularity and ease of troubleshooting.

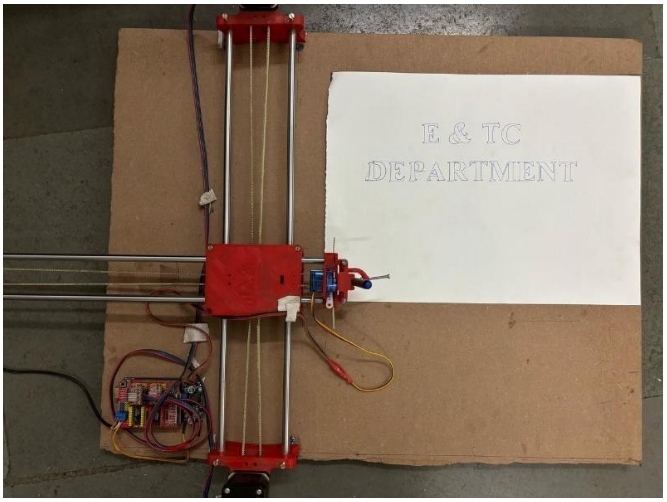

Fig 2. Hardware

B. Electronic connections

The electronic system of the CNC plotter serves as the backbone that drives its precision and functionality. Each component is carefully selected and connected to enable accurate control over the mechanical movements of the plotting machine.

1. Control Unit

At the heart of the system is an Arduino Uno microcontroller, which processes G-code instructions and sends control signals to the motors. Mounted on top of the Arduino is a CNC Shield V3, which acts as an interface between the microcontroller and the stepper motor drivers.

Stepper Motor Control

• Two A4988 stepper motor drivers are installed in the X and Y slots of the CNC shield.

• These drivers control two NEMA17 stepper motors, responsible for moving the gantry along the X and Y axes.

• Each motor receives step and direction signals from the Arduino through the shield to produce precise linear movement.

Z-A xis Mechanism

• A servo motor is connected to the Z-axis pin on the CNC shield.

• It controls the vertical movement of the pen, allowing it to lift and drop as needed during plotting.

2. Power Supply System

The system is powered using a DC-DC buck converter, which regulates the input voltage to suit the components:

• It takes input from a 12V DC adapter and steps it down to a suitable voltage for the CNC shield and stepper drivers.

• The output of the converter is connected to the power input terminal of the CNC Shield, ensuring stable and reliable power delivery to the system.

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This setup protects the components from voltage fluctuations and overheating while maintaining consistent performance.

3. Wiring and Connectivity

• The stepper motors are connected to the CNC shield using four-wire connectors for each axis.
• The servo motor is connected via three jumper wires (signal, VCC, and GND).
• All wiring is routed neatly to minimize tangling and to keep the assembly clean and functional.
• The Arduino Uno is connected to a computer via USB, which allows firmware uploads and G-code communication through software like Universal G-code Sender (UGS) or similar.

4. Integration with Mechanical Assembly

The electronic components are placed externally to the mechanical structure for easy access and cooling. Long wires connect the motors to the shield, allowing free movement of the plotting arm without restriction. This modular design ensures ease of assembly, maintenance, and future upgrades.

C. Software Implementations

The software component of this CNC plotter project is centred around the use of Universal G-code Sender (UGS). UGS is a powerful, open-source interface that communicates directly with the microcontroller running GRBL firmware, sending it G-code instructions to drive the plotting machine.

Universal G-code Sender (UGS)

Universal G-code Sender (UGS) serves as the only software interface used in this project. It is used to control the CNC plotter by streaming G-code commands to the Arduino Uno via a USB connection.

Workflow:

1. The required design is first converted into G-code using external tools (e.g., online SVG to G-code converters or pre-generated files).
2. This G-code is loaded into UGS.
3. UGS transmits the G-code line by line to the Arduino.
4. GRBL interprets the commands and moves the stepper motors accordingly to replicate the drawing.
5. The servo motor (connected to the Z-axis) controls the pen's up/down motion.

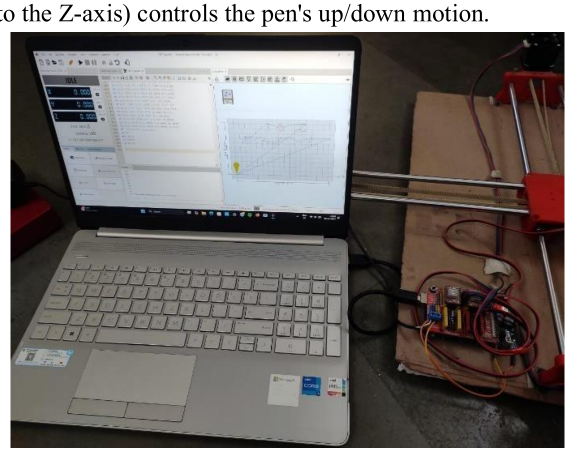

Fig 3. Software

IV. CONCLUSION

This project successfully demonstrates the design and implementation of a low-cost, compact CNC plotter using open-source hardware and software. The mechanical assembly, constructed using 3D-printed components and steel rods, provides a sturdy and modular structure capable of precise 2D motion over an A3-sized surface. The electronic system, based on the Arduino Uno and CNC shield, along with stepper drivers and a servo motor, efficiently controls the plotting operations.

The software side is streamlined using Universal G-code Sender (UGS), which communicates with GRBL firmware on the Arduino to interpret and execute G-code instructions. This setup allows for accurate plotting of digital designs with minimal hardware complexity and a user-friendly interface.

Overall, the project demonstrates a practical and scalable approach to CNC automation, with potential applications in education, DIY manufacturing, prototyping, and custom artwork. It also lays a strong foundation for future enhancements such as laser engraving or 3D printing capabilities.

V. ACKNOWLEDGMENT

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