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Design and Development of a Low-Cost Arduino-Based 2D CNC Pen Plotter for Precision Drawing Applications

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ABSTRACT

CNC (Computer Numerical Control) systems have become a vital technology in modern manufacturing and automated drawing applications. However, conventional CNC machines are often expensive, complex to maintain, and require skilled operators, limiting their accessibility for educational institutions, hobbyists, and small-scale industries. This study presents the design and development of a low-cost, Arduino-based 2D CNC plotter capable of generating precise graphical drawings using G-code instructions. The proposed system utilizes an Arduino Uno microcontroller, a CNC expansion board (shield), stepper motor drivers, stepper motors for X- and Y-axis motion control, and a servo motor to raise and lower the writing instrument. Inkscape software is used to convert graphic designs into G-code, which is then executed via an interface developed in Processing. The resulting prototype demonstrates precise two-dimensional plotting capabilities while maintaining low manufacturing costs and ease of operation. Experimental evaluation confirms that the system can accurately reproduce text and vector graphics within the defined working area. Comparative analysis indicates that the proposed design significantly reduces implementation costs while maintaining acceptable accuracy for educational and prototyping applications. This CNC plotter offers an affordable solution for automated drawing, rapid prototyping, and introductory training in CNC technology.

Keywords: CNC Plotter, Arduino Uno, G-Code, Stepper Motor, Computer Numerical Control, Low-Cost Automation, Pen Plotter, Inkscape.

I. INTRODUCTION

The growing demand for automated manufacturing and computer-controlled machining systems has accelerated the adoption of CNC (Computer Numerical Control) technology across various

industrial sectors. CNC systems offer high precision, repeatability, and flexibility in manufacturing processes. However, commercially available CNC machines are often associated with high acquisition costs, complex maintenance requirements, and the need for skilled operators. [1]

Recent advances in open-source electronics and embedded systems have enabled the development of affordable CNC platforms using microcontrollers such as Arduino. These systems offer a cost-effective alternative for educational institutions, research laboratories, and small businesses seeking automation solutions.

A CNC pen plotter is a simplified version of a CNC machine that converts digital designs into physical drawings through coordinated movements along the X, Y, and Z axes. The plotting process is controlled by G-code commands generated from computer-aided design (CAD) software. [2-3]

Despite recent advances, low-cost Arduino-based plotters still exhibit significant technical limitations that hinder their overall performance. A key shortcoming in current research lies in limited motion precision and poor coordination among the three axes, which restricts accuracy in complex operations. Furthermore, many current designs are constrained by small workspaces and reduced structural stability, limiting their practical scalability. These mechanical deficiencies are compounded by insufficient integration between software and hardware platforms, highlighting a clear need for a more synchronized, robust, and scalable low-cost plotting system. [4-5]

This work presents several significant contributions to the design and implementation of accessible CNC hardware. First, it introduces a fully functional, low-cost three-axis CNC plotter built on an integrated hardware architecture comprising an Arduino Uno board, a CNC shield, and dedicated stepper motor drivers. To streamline the workflow, the system incorporates an automated process that converts graphic designs directly into G-code using Inkscape, enabling seamless coordination between software and hardware. In operation, the plotter achieves precise motion control on the X and Y axes, as well as reliable pen-lifting functionality on the Z axis. Together, these features offer a practical and highly cost-effective solution specifically designed for educational demonstrations and rapid prototyping applications. [6-8]

II. METHODOLOGY

Various researchers have studied the implementation of affordable CNC systems based on open-source hardware platforms. Arduino-based CNC machines have gained popularity due to their low cost and ease of programming. Existing CNC plotters typically use stepper motors and G-code interpreters for motion control. Research has demonstrated the feasibility of successfully implementing small-scale CNC systems for drawing, engraving, and educational purposes. However, many available systems suffer from limitations such as low drawing precision, mechanical instability, and limited scalability. Studies on CNC plotters based on recycled CD-ROM mechanisms have shown promising results for cost-effective manufacturing. Nevertheless, these systems often exhibit issues related to vibration and limited working areas.This work addresses these limitations through robust three-axis architecture, combined with efficient G-code management and enhanced motion control.

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The hardware and software architecture of the proposed CNC plotter relies on a modular, integrated design to achieve precise motion control. At the core of the hardware setup is an Arduino Uno controller connected to a CNC shield and A4988 stepper motor drivers; these control two stepper motors for movement along the X and Y axes and a servo motor that manages the pen-lifting motion along the Z-axis. The entire electronic assembly is mounted on a rigid mechanical structure that ensures physical stability during operation. Regarding software, Inkscape is used to create vector graphics and generate G-code, which is then transferred to the hardware via a Processing-based GCTRL interface.

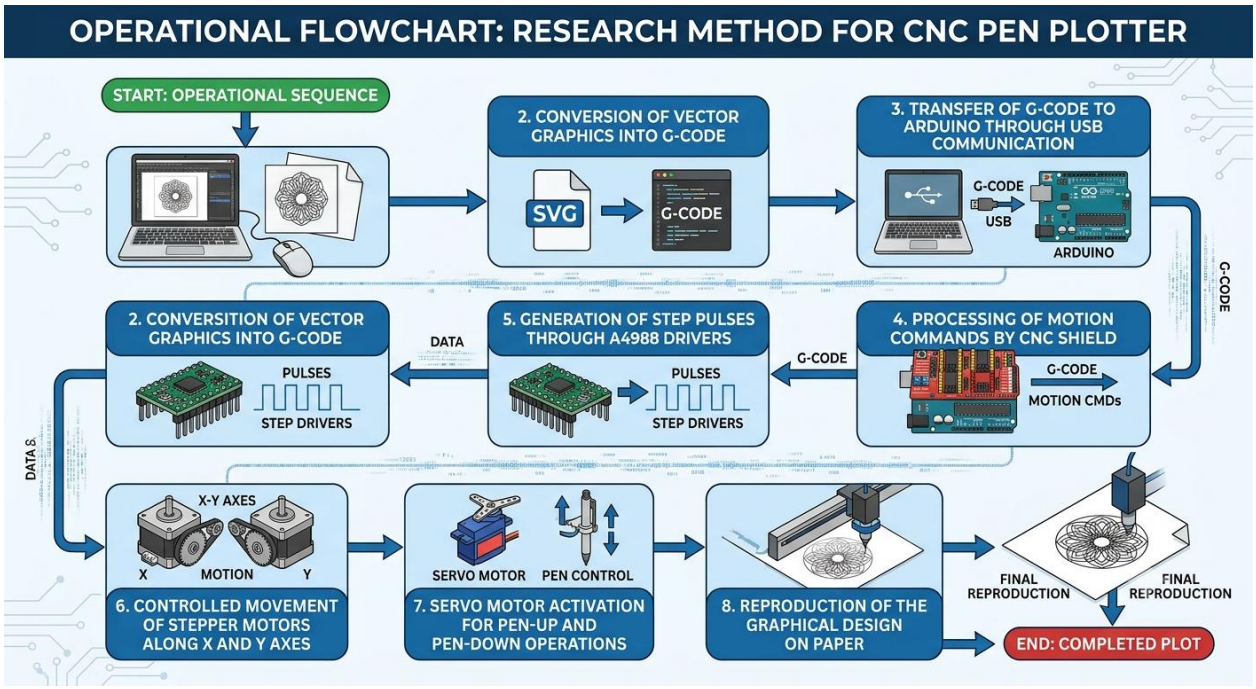


Figure 1 :- Operational Flow

The angular displacement of the stepper motor is expressed as:

$$\theta = n \times \alpha$$

Where:

θ = Angular displacement (degrees)
n = Number of input pulses
α = Step angle

The linear displacement of the lead screw mechanism is:

$$L = N \times P$$

Where:

L = Linear displacement (mm)
N = Number of screw revolutions
P = Lead screw pitch (mm/rev)

The positioning error is determined by:

$$[E = |X_a - X_m|]$$

where:

(X_a) = Actual position
(X_m) = Measured position

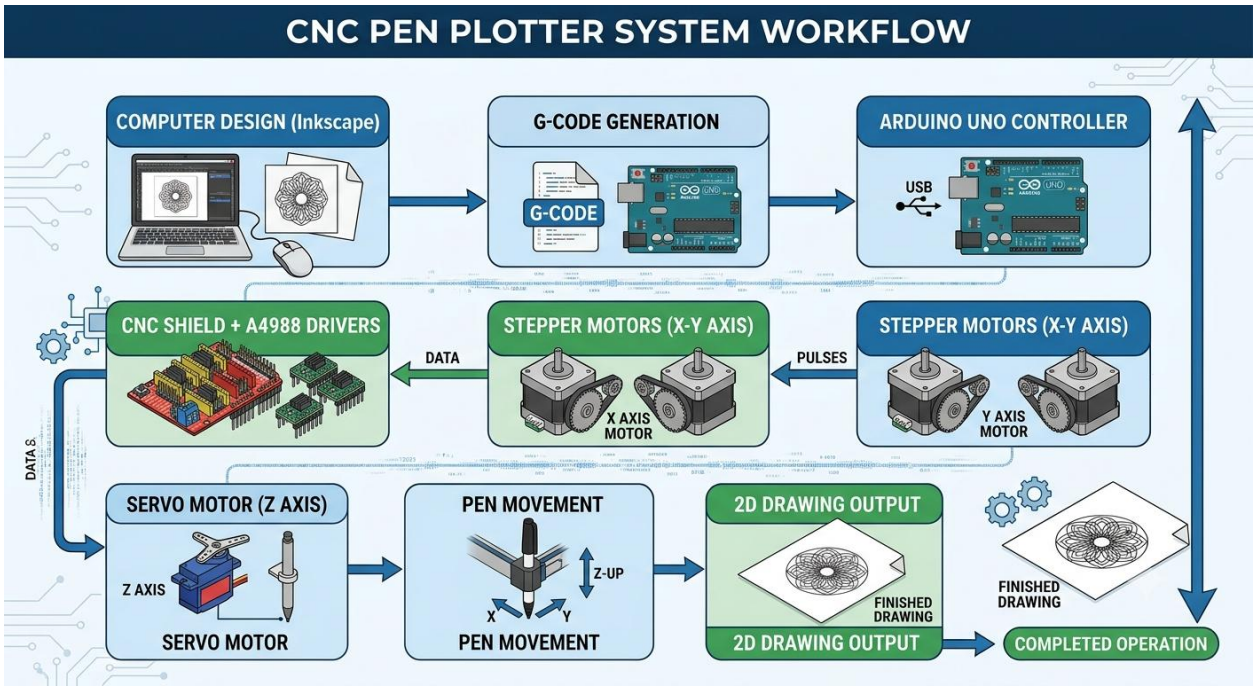


Figure 2 :- Operation of CNC Pen Plotter

III. RESULT AND ANALYSIS

The developed CNC pen plotter successfully performed various drawing operations, including plotting text, geometric shapes, and graphic illustrations.
Experimental evaluation of the system demonstrated consistent operational performance across key indicators. The platform exhibited high motion accuracy through precise path tracking and repeatable drawing operations, supported by reliable G-code interpretation. Furthermore, the system maintained stable plotting performance while operating with low power consumption, demonstrating its efficiency for practical and cost-effective applications.

Feature	Conventional CNC	Proposed Plotter
Initial Cost	High	Very Low
Maintenance	Complex	Simple
Operator Skill	High	Moderate
Educational Use	Limited	Excellent
Portability	Low	High
Drawing Capability	High	Moderate

Table 2:- Comparative Tabular Result

Experimental results demonstrate that the developed system offers a practical balance between performance and cost. The use of open-source hardware significantly reduces implementation costs, while the drawing precision is sufficient for educational and prototyping purposes.

Although slight vibrations were observed in the Z-axis mechanism, the overall drawing quality was satisfactory. Future structural improvements could further enhance precision and stability.

IV. CONCLUSION

This research presented the design and implementation of a low-cost, Arduino-based CNC plotter capable of generating accurate two-dimensional drawings through the automated execution of G-code. The integration of an Arduino Uno, a CNC shield, stepper motor drivers, and a servo motor for pen actuation enabled reliable and reproducible plotting operations. Experimental evaluation demonstrated satisfactory accuracy, low manufacturing costs, and ease of use. Compared to conventional CNC systems, the proposed solution offers significant economic advantages while maintaining sufficient functional performance for educational, research, and prototyping environments. Future developments could include wireless

communication, image processing integration, larger work areas, and laser engraving capabilities.

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