

Experimental Implementation of CNC Based Plotting Machine

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ABSTRACT

Computer Numerical Control (CNC) technology provides an effective approach for automating machine movement with improved precision, repeatability, and reduced human intervention. This paper presents the design and experimental implementation of a low-cost CNC-based plotting machine capable of reproducing drawings, patterns, text, and images from computer-generated instructions. The proposed system employs an Arduino Uno as the main controller, 28BYJ-48 stepper motors for X- and Y-axis movement, ULN2003 motor-driver circuits, and an MG90S servo motor for controlling the vertical movement of the plotting pen. Inkscape is employed to convert the required drawing into G-code, while the Universal G-code Sender/GRBL environment transfers the generated commands to the controller. The Arduino processes these instructions and produces the required motor-control signals for coordinated plotting. Experimental implementation demonstrates that the developed prototype can reproduce programmed designs with satisfactory accuracy while maintaining simple construction, portability, low power consumption, and low implementation cost. The proposed system is therefore suitable for educational laboratories, small-scale drawing applications, PCB-layout plotting, and as a platform for further CNC automation development.

Keywords— Computer Numerical Control (CNC), Arduino Uno, G-code, Stepper Motor, Servo Motor, Inkscape, GRBL, CNC Plotter.

INTRODUCTION

Computer Numerical Control (CNC) is an automated control technique in which machine tools are operated according to numerical instructions generated and processed by a computer. CNC technology has become an important part of modern manufacturing because of its capability to improve productivity, flexibility, dimensional accuracy, and repeatability. Instead of manually controlling the position of a tool, CNC systems translate programmed instructions into electrical signals that operate motors and other actuating mechanisms. The movement of the plotting or machining tool can consequently be controlled accurately along predefined coordinate axes.

A CNC plotting machine is a comparatively simple application of CNC technology in which a pen or similar tool is moved over a working surface according to predefined coordinates. The required image or drawing is converted into machine-readable G-code and supplied to the controller. The controller interprets these instructions and operates the corresponding motors to obtain movement along the X and Y directions, while the vertical Z-axis mechanism raises or lowers the plotting pen. The project focuses on developing a mini CNC plotter capable of drawing complex designs using G-code while employing economical and easily available hardware components.

The proposed CNC plotter integrates an Arduino Uno, stepper motors, motor drivers, a servo motor, and software tools such as Arduino IDE, Inkscape, and Universal G-code Sender. This configuration provides an inexpensive platform for understanding CNC operation and implementing automated plotting. The system is intended to minimize manual effort while providing an effective solution for educational, prototyping, and small-scale plotting applications.

LITERATURE SURVEY

Nanfara, Uccello, and Murphy [1] discussed the fundamentals of CNC programming and presented CNC simulation as an effective method for learning, testing, and modifying machining programs. Their work demonstrated how CNC programs can either be transferred to an actual machine or evaluated using simulation software. Karthick *et al.* [2] investigated the design and control of an Automatic Tool Change (ATC) system for CNC machines with emphasis on reducing tool-changing time. Their approach considered mathematical methods for determining shorter tool-travel paths, rotary encoder-based position identification, and tool-change database integration for automated machining operations.

Saifee and Mehta [6] presented the design and implementation of an FPGA-based G-code-compatible CNC controller. Their study demonstrated the importance of G-code-based motion control for achieving consistent multi-axis operation and reducing errors associated with conventional manual machining. The work highlighted the use of interpolation instructions, tool commands, feed-rate instructions, spindle-speed commands, and machine-control codes in CNC systems. Previous investigations also indicate that suitable structural materials and effective tool-management strategies are important for achieving economical and reliable CNC operation. These studies establish the technological foundation for developing a compact and low-cost CNC plotting system using microcontroller-based motion control.

PROBLEM STATEMENT

Conventional plotting mechanisms face difficulties in maintaining accurate axis movement when mechanical or basic control techniques are employed. Manual plotting is also time-consuming and is susceptible to human errors, particularly when complex shapes and repetitive patterns are required. Therefore, there is a need for a low-cost, reliable, and user-friendly plotting system capable of accurately reproducing computer-generated drawings. The proposed work addresses this requirement by integrating CNC technology, G-code processing, a microcontroller, stepper motors, and software tools into an automated plotting machine.

OBJECTIVES

The main objectives of the proposed work are:

1. To design and experimentally implement a low-cost CNC-based plotting machine capable of accurately drawing computer-generated shapes, patterns, text, and images using G-code instructions.
2. To develop an Arduino-based motion-control system for coordinated X-Y axis movement and Z-axis pen control using stepper motors, motor drivers, and a servo motor.

PROPOSED SYSTEM

The proposed system is an Arduino-based CNC plotting machine designed to convert a digital image or drawing into physical pen movement. Initially, the required design is prepared using Inkscape and converted into G-code. The generated G-code contains coordinate and movement information corresponding to the required drawing. Universal G-code Sender/GRBL is then used to transfer these instructions to the Arduino controller.

The Arduino Uno acts as the central control unit and coordinates the movement of the plotting mechanism. Two 28BYJ-48 stepper motors provide precise motion along the X and Y axes through ULN2003 motor-driver circuits. An MG90S servo motor controls the upward and downward movement of the pen along the Z-axis. By coordinating these three movements, the system reproduces the programmed design on the plotting surface. The report identifies the main hardware as two 28BYJ-48 stepper motors, two ULN2003 drivers, one MG90S servo motor, and an Arduino Uno R3.

BLOCK DIAGRAM

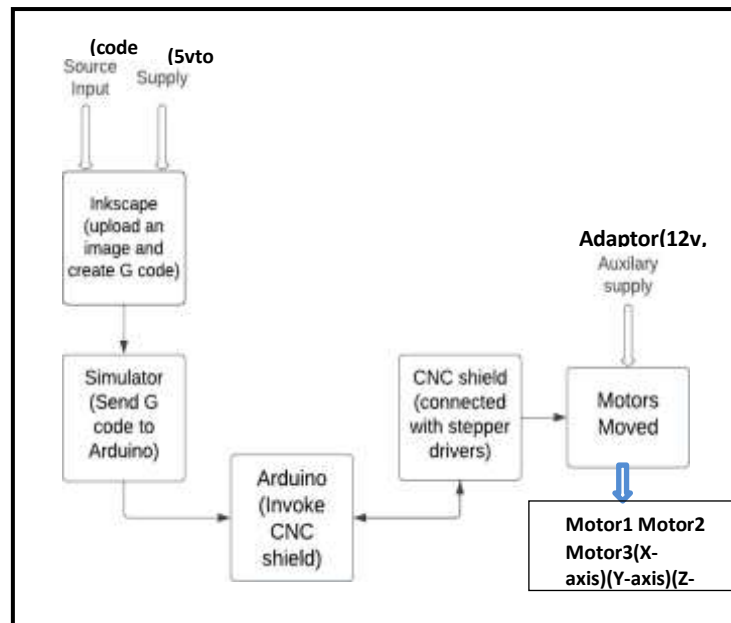


Fig 1:BlockDiagram of CNC Plotter

METHODOLOGY

The methodology begins with preparing the desired image, text, or drawing in the computer environment. Inkscape is used to process the graphical design and generate the corresponding G-code instructions. Before plotting, the design dimensions are adjusted according to the available working area of the CNC machine. The generated G-code is subsequently transferred through the Universal G-code Sender/GRBL interface to the Arduino Uno. The controller interprets the coordinate information and converts it into appropriate electrical control sequences for the motor drivers.

During operation, the Arduino controls two stepper motors responsible for movement along the X and Y axes. The ULN2003 driver circuits provide the required current-driving capability between the controller and stepper motors. The MG90S servo motor controls the plotting pen along the Z-axis through PWM signals, enabling the pen to be raised or lowered at the required positions.

Coordinated operation of these actuators allows the machine to trace the programmed trajectory. The report notes that G-code can first be checked in the GRBL environment to ensure that the coordinates remain within the machine's plotting limits before actual execution.

RESULTS AND DISCUSSION

Fig. 2 shows the successfully implemented experimental CNC plotter developed using the proposed hardware and software configuration. The Arduino coordinates the stepper and servo motors based on G-code processed through the GRBL controller, enabling the system to reproduce the desired pattern accurately..

The prototype provides controlled X-Y movement while the servo mechanism performs pen-up and pen-down operations. The report indicates that the uploaded diagram, graph, or design can be plotted accurately using the developed CNC machine. The implemented system is easy to control through a computer, portable, and comparatively

simple to assemble. The prototype uses a 40×40 cm board, while the effective plotting dimensions depend on the mechanical travel of the constructed system.

The experimental implementation also demonstrates the importance of properly scaling the G-code coordinates. Designs extending beyond the programmed X-Y limits cannot be completely plotted; therefore, the input image must be resized in Inkscape and verified in the GRBL environment before execution. This procedure helps achieve proper utilization of the available plotting area.



Fig 2 CNC plotter

CONCLUSION

A low-cost CNC-based plotting machine has been experimentally implemented using an Arduino Uno, stepper motors, ULN2003 drivers, a servo motor, and open-source software tools. The developed system converts digital images and drawings into G-code instructions and translates these instructions into coordinated mechanical movement for automated plotting. The prototype demonstrates the feasibility of obtaining controlled and repeatable plotting using economical and easily available components.

The developed machine consumes relatively low power, has simple construction, and can be transported without significant difficulty. The report further identifies its suitability for drawing PCB layouts, images, and text on solid surfaces and notes that the plotting tool can be replaced with other working heads for expanded applications. Therefore, the proposed system provides an effective educational and small-scale CNC platform while offering substantial scope for further improvements in accuracy, working area, mechanical strength, and multifunctional operation.

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