Design and Development of a Low-Cost Multipurpose Arduino CNC plotter for Industrial Applications

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Abstract. CNC machines, or computer numerical control machines, are among the most popular devices utilized in modern businesses. A lot of labor-intensive tasks that require daily repetition were replaced by CNC machines; nonetheless, as time passes, the quantity and quality of the products produced by the machines remain constant. The goal of this project is to create an inexpensive, multifunctional CNC machine with an Arduino platform that can plot data depending on a provided image or text. This CNC plotter can also perform other operations like the engraving, laser cutting, PCB board soldering and 2D/3D operations. The prototype was built with the hardware components, microcontrollers and suitable software's are used. Quantitative analysis reveals that commercially available plotters exhibit superior accuracy, achieving precision levels in the range of 0.1 mm to 0.01 mm (aprx), while Arduino-based CNC plotters achieve accuracy levels ranging from 0.1 mm to 0.5 mm (aprx) . Despite this difference, solutions can still provide satisfactory results for hobbyist or educational purposes with proper calibration and tuning. Two types of images which are the input image and the import image have been tested, one with a normal JPG image and other with CAD file format. The trial experiment of the Arduino based CNC plotter was tested with all the power supply and microcontrollers connections was done. The test trial was done and found to be made some changes regarding the current input as the noise level of the lead screw keeps increasing. In the future these works are led by the error occurring in the prototype and thus making it multiple tool CNC plotters.

Keywords: CNC plotter, Microcontroller, Arduino, Engraving and PCB soldering..

1 Introduction

A 2D plotter, also known as a 2D plotting machine or XY plotter, is a device used to create two-dimensional drawings, diagrams, and graphs on paper or other flat surfaces. It consists of a movable pen or marker that can be precisely controlled in both the horizontal

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(X-axis) and vertical (Y-axis) directions. 2D plotters are commonly used in various applications, including engineering, architecture, design, and art. It is a computer-controlled device designed to create precise two-dimensional drawings, designs, and patterns on various materials, such as paper, wood, plastic, fabric, and more. This can be particularly used to print number on number board especially for two wheelers and four wheelers. It can plot graphs, charts, or diagrams onto paper or other suitable surfaces. The key feature that sets a 2D CNC plotter apart from a traditional 2D plotter is its ability to automate and control the motion of a cutting tool or a pen with high precision. The versatility of an Arduino-based CNC plotter allows for customization according to specific needs, enabling users to experiment with various materials and designs. An Arduino-based CNC plotter is a versatile and cost-effective device that combines the power of Arduino microcontroller technology with precision mechanical components to create an automated drawing and plotting machine [4]. This innovative system allows users to convert digital designs into tangible artwork, intricate patterns, or precise diagrams with ease. Whether you're an artist, engineer, or hobbyist, an Arduino-based CNC plotter offers a user-friendly and customizable platform for a wide range of applications. The core of the CNC (Computer Numerical Control) plotter is the Arduino microcontroller, which serves as the brain of the system, controlling the movements of the plotter's motors and ensuring precise positioning of the pen or other drawing tool. This flexibility allows you to create drawings, paintings, and designs of varying complexities with great accuracy, while also offering the possibility to explore more advanced applications like laser engraving, PCB milling, or even 3D printing. Arduino-based 2D plotters typically consist of a framework, two motors (often stepper motors) that control the position of the drawing tool in both the X and Y directions, and an Arduino microcontroller that interprets commands and translates them into motor movements. Users can interact with the plotter by sending it commands through a computer or other input devices, enabling a seamless transition from digital to physical art or designs [6] [7]. This technology offers an accessible and educational platform for learning about programming, electronics, and mechanics, making it a popular choice for makers and students interested in exploring the intersection of creativity and technology.

2 Literature Survey

The summary of the literature survey gives a detailed information of different methods used in CNC plotting also known as CNC pyrography. Many researchers develop a Cartesian based robots for pick and place operations and they detect the path planning using various algorithms [1]. Similar to CNC 2D plotters 3D printers and related machines are been developed. Some of the CNC plotters are nowadays mostly used for educational purposes than industrial usages. Industrial robots with six degrees of freedom (dof) are appealing substitutes for Computer Numerical Control (CNC) machine tools for cutting big parts due to their inexpensive cost, increased adaptability, and larger work volume. The 6 DOF axes robots are been used as in this project 3 DOF axes are used for pick and place operations. A 3R end-effector with a Cartesian manipulator is used for pruning apples from the gardens [8]. Nowadays a Multi-axis tool path optimization for 3D printing/ Additive manufacturing is used [10] [11]. Automatic tool changing robots able to perform painting with different paint brushes are developed by some researches. PLC (Programmable Logical Controller. In most of the CNC based plotters and 3D printers the closed loop feedback with non-linear optimal

control is used [12].A 3-DoF CNC machine with a brush, a paint mixer, and a syringe pump block for paint supplementation is shown by the robot. Their research focuses on acrylic painting in black and white, or monochrome.

3 Methodology

After the literature survey the methodology of the Arduino based CNC plotter is given below,

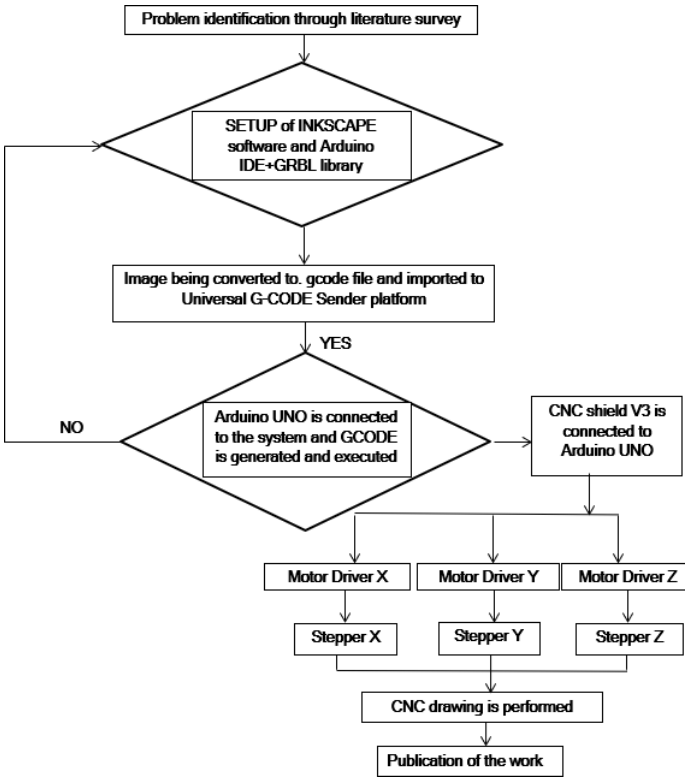

Fig.1. Methodology for CNC plotter.

4 Design and Components

Hardware Design

The hardware components consist of the power supply, where 12 V- 2A Adapter is connected to the CNC shield V3. The heart of the CNC plotter is usually an Arduino board. Popular

choices include Arduino Uno, Arduino Mega, or Arduino Nano. These boards provide the necessary processing power and I/O pins for controlling the motors and other peripherals. CNC shiel is connected with Arduino UNO board and A4988 motor driver. The motor driver is used for the stepper motor X, Y and Z. Stepper motors are commonly used in CNC applications due to their precise control and ability to move in discrete steps. Servo motors can also be used, especially for smaller-scale projects or where precise positioning is required.Stepper used here is NEMA 17 4.2kgcm which runs upto 3000 rpmand with 1.8degree step angle of holding torque and thus providing high torque. Arduino UNO is used a microcontroller as it used for low-cost automation.The A4988 driver has built-in translator for easy operationand its designed to operate bipolar stepper motor in full, half, quarter, eighth and sixteenth step modals with output capacity of 35V and +/- 2A. This also uses a GRBL CNC Control board where it is used for 2D/ 3D printing operations. This works on the basis of G-Code Reference Block Library (GRBL). The tool head holds the drawing or cutting implement, such as a pen, pencil, engraving bit, or cutting tool. It should be designed to securely hold the chosen implement and allow for precise control over its movement. Limit switches or endstops are used to define the boundaries of the CNC plotter's workspace and prevent the motors from moving beyond these limits. They are typically placed at the extremities of each axis.

Fig.2. Hardware components for plotter (NEMA 17 stepper motor, A4988 motor driver, Arduino UNO board, GRBL CNC control board and CNC shield V3)

Software Design

The Software used is Arduino IDE+ GRBL, Inkscape Software and Universal Gcode Sender software. The Arduino IDE software is open source which allow user to download the software through the IDE official website. The setup of Arduino UNO is simple. Once finished downloading and install in the computer/ laptop,the Arduino UNO microcontroller can be connected using the USB cable to power it. Once external library file, GRBL required add on the Arduino Integrated Developent Environment (IDE) software before uploading the code to the microcontroller. The GRBL library file contains the coding to function the CNC machine which is open source file that be able to download from Github website. Next is the Inkscape software, this software is free open source software that allows user to draw some projects without any change of license fee for using the software. Here, Inkscape has been used to convert some industrial drawing from this software and exported image into a G-code file format. Universal G-code sender works on a GRBL firmware used for CNC based off 2D plotting operations. The G-code file saved with the Inkscape software is now imported to UGS software and connected with Arduino UNO. The file is saved and exported to G-code using the Universal G-code sender software. These are the above three software being used for the plotting, engraving or cutting operations.

Fig.3. Software used for CNC plotter (Arduino IDE, Inkscape and Universal G-code Sender)

Mechanical Design

The mechanical design consists of the CAD design of the CNC plotter. Each component can either be designed in 3D modeling software like the SolidWorks or Parametric Corporation Technology (PTC) Creo software's. Here 2020 and 2040 Aluminium profiles are used for the mechanical construction. They are in light weight and used for 3D printer or plotters constructions. The other requirements including the M5 sliding nut, fasteners, Idler pulley and GT2 belt pulley set.

Fig.4. Mechanical components (2020 Aluminium profile, M5 sliding nut, Idler pulley and V wheel set)

5 Experimental Setup

The experimental setup consists of the software integrated with the hardware. Integrating the Arduino with GRBL library and powering the Arduino board. The image is imported to Inkscape software and the some of the G-code extensions like adding orientation points and path to g-code where the file directory and name of the image is stored and now converted to a g-code file format. The image converted to G-code in the Inkscape software is now imported to UGS software and then Arduino UNO board is been connected and powered. The G-code is executed line by line. Now the file is stored in a g-code format.

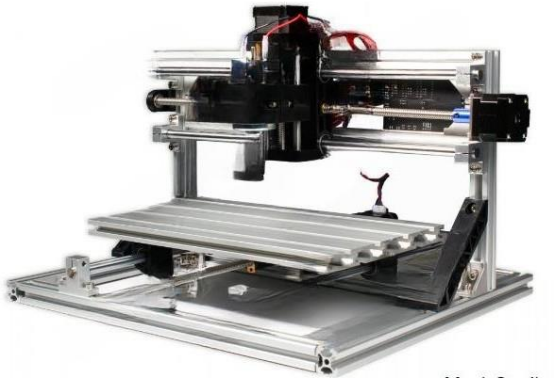

Fig.5. Prototype of the Arduino based CNC plotter

Current State

1. The prototype is now connected to the Arduino UNO which is connected the laptop system.

2. The Arduino is connected to the CNC shield with the motor driver for the stepper motor X, Y and Z. The workplace for the CNC plotter can be adjusted in the UGS software.
3. The Step size and Feed rate was given the UGS software.
4. Here the step size was given as 1 mm and feed rate was given as 1000 mm.
5. Now the trial was made to run and found that the noise level is high and the stepper motor input current has to be checked as it has high noise level.
6. Mechanical Inaccuracies, Software Bugs or Limitations, Overheating, Structural Rigidity are some of the external errors that were found.

Future Work

1. The Gcode is to be saved in SD card in a TEXT format and to be given to the Arduino in the SD library in Arduino IDE. Adding shielding to sensitive electronic components, using better quality wiring, or implementing filtering circuits can help reduce electrical noise and improve the stability of the system.
2. The noise in the prototype has to be completely avoided by modifying the current input to the motor driver which connects the stepper motor. Future iterations may involve upgrading to higher-quality linear motion components, optimizing belt tensioning mechanisms, or implementing anti-backlash features to minimize mechanical inaccuracies.
3. As it can be used for multiple tools can be attached to the plotter. The simulation is to be made using the MATLAB software and the optimizing path planning to find the acceleration and deceleration of profiles and real time error to enhance the speed and precision of the plotter. Continuously updating and refining the firmware and control software can help address bugs and improve the performance and features of the CNC plotter. Additionally, implementing user-friendly interfaces and adding features like automatic calibration can enhance usability.
4. To implement a closed loop control system to provide feedback about the actual position and development of advanced motion control algorithm like Proportional-Integral-Derivative controller (PID) can be used.

6 Result and Discussion

An Arduino-based CNC plotter built from scratch can be relatively inexpensive, with costs primarily associated with components such as Arduino boards, stepper motors, linear motion systems, and other electronic and mechanical parts. Inaccuracies or backlash can be introduced by mechanical components such belts, pulleys, or linear motion systems, which can result in inaccurate movement.Some of the errors in the Arduino based CNC plotter are some of the Mechanical errorrs, Electrical errors and Software related issues are as follows, In order to

reduce mechanical errors, future modifications can include switching to better linear motion components, improving belt tensioning systems, or adding anti-backlash features. The CNC plotter may experience irregular movement or signal interference due to electrical noise from motors or other components interfering with its operation. Improved wiring, filtering circuits, and the addition of shielding to delicate electronic components can all aid in lowering electrical noise and enhancing system stability. The CNC plotter's frame or construction might not be rigid enough, which could cause vibrations or movement errors. Overall stability and precision can be increased by adding more supports to the frame, utilizing harder materials, or making design modifications that increase rigidity. The sorts and sizes of projects that can be conducted may be restricted due to the work area's limitations in size. The CNC plotter can be made more capable of handling larger tasks by adding a mechanism for workpiece repositioning or by designing a larger or modular workspace. Improving the ventilation and cooling of components, selecting components with higher power ratings, or implementing thermal monitoring and protection mechanisms can help prevent overheating issues. The total cost of building a basic Arduino-based CNC plotter may range from Rs. 7000 to Rs. 15,000 INR, depending on the quality of components, size of the workspace, and desired capabilities. Additional costs may include tools, materials for constructing the frame, and optional components such as endstops, cooling fans, or different types of cutting or engraving tools. The drawing speed of the CNC machine has been increasing accordingly to the user feedback. Some of the hardware components have been designed and printed using 3D printer to cut down the building cost. The quantitative findings highlight the superior accuracy of commercially available plotters compared to low-cost Arduino-based CNC plotters for drawing on paper. While commercial options offer precision levels as fine as 0.01 mm, solutions achieve accuracy levels ranging from 0.1 mm to 0.5 mm. These results underscore the importance of considering specific requirements, budget constraints, and acceptable levels of accuracy when choosing between commercial and solutions for plotting applications.

7 Conclusion

In conclusion, the objectives of this project have been achieved. An Arduino based CNC drawing machine which able to move along x-axis and y-axis was built. The cost for building the CNC drawing machine is lower compare to the industries. The CNC drawing machine built was successfully communicated with the software to carry out given task. The gcode file image that created from the Inkscape software was successfully transferred to CNC machine for drawing. The import images and the input images were successfully converted to the gcode file and been drawn by the CNC machine. The drawn images scale is exactly same with its original import images and input images. Two users have been invited to use the CNC machine. Continuously updating and refining the firmware and control software can help address bugs and improve the performance and features of the CNC plotter. Additionally, implementing user-friendly interfaces and adding features like automatic calibration can enhance usability. Exploring cost-effective alternatives for components, optimizing the design for simplicity and affordability, or leveraging open-source hardware and software can help make the CNC plotter more accessible. Both users were satisfied with the results drawn by the CNC drawing machine.

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