



## Design and Implementation of Computer Numerically Control - CNC- Plotter Machine

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### Abstract:

The increase in the number of accidents in the workshop and the problems caused by the production of complex parts by traditional processing, such as the lack of quality and the need for a lot of time for the production process and with the advancement of technology, all these request of CNC. machines in the industry are growing rapidly. Computer numerical control machining is a process used in manufacturing that involves the use of computers to control machine tools. without direct human assistance. CNC is a very broad term that includes a variety of types of machines, all of different sizes, shapes and functions. The CNC has found its applications mainly in lathes, drills, milling machines, etc. In this paper, a two-dimensional CNC machine designed and implemented in an efficient and low-cost hardware architecture is capable of drawing images/texts. Also, the idea of our project is to design and draw printed circuits based on a low-cost computer digital control system. The control mechanism of the designed machine is based on the use of Arduino UNO, Inkscape and Geode-Sender software. The result of this work is to help researchers and designers in plotting photos, figures, and texts, or any other drawings. Generally, the outcome of the paper is to help researchers and designers in the area of Computer Numerical Control machines.

**Keywords:** CNC Machine; Arduino; G Code Sender, Computer Numerical Control (CNC).

### 1. Introduction:

CNC machining is a process used in the manufacturing sector that involves the use of computerized machine tools. A computer program is created for an object and the machines

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are programmed with the CNC machining language (called G-code) which essentially controls all the features such as feed rate, coordination, position and speed. The computer can control precise positioning and speed with CNC machining. CNC machining is used in the production of metal and plastic parts. The work includes design and development of CNC tool control unit prototype model. In modern CNC systems, end-to-end component development is highly automated by using computer programs to build a file that is interpreted to issue the commands needed to operate CAD and aided manufacturing programs. (pronterface). [1]. In this paper, a low-cost 3-axis vertical CNC engraving machine will be developed. The Arduino open source microcontroller platform will be used to control motors and open source software will be used to run G-code and machine applications. The mini CNC drawing machine is defined as being based on Arduino controller and CNC shield. CNC is a digital control system for the processor. G codes are a planning sign. G codes are movements associated with a predetermined function. G codes are also used in the direction of the movement of the pen in the X, Y, Z direction [2]. Other writing tools such as pencils, sketches, pens, etc. can change pens. The objective is to create a mini CNC tracing machine capable of drawing difficult patterns on paper or writing surface. It is focused on reducing project costs and improves performance and agility. This has also helped many people who have many opportunities to write different things, where tracking can be done without physical work with this tool.

### **1.1 Methodology:**

Power is provided by an external power supply to the Arduino, a cable allows the data to be transferred to the Arduino board from a computer, two stepper motors in the X and Y axis will be used for precise movement and one stepper motor to lift the pen in the Z direction, L293D to feed the stepping motor with G-codes in sequence. The Arduino turns the G-code command into an electronic pulse and sends it to the stepper motor via IC L293D. The stepper motor moves left and right in the X direction, the stepper motor moves forward and backward in the Y direction, while the servo motor moves in the Z direction up and down. We can use this machine to draw many difficult patterns. The precision of this machine allows to obtain very high results, so in the industry we can use it to reduce the costs of printing models and maintain the level of precision. The G code is interfaced by the FTDI module to the ATMEGA 328 CNC-based controller, which turns the code into practical machine code, i.e. serial to USB converter. Therefore, it acts as a PC interface module for the controller. Also, this code is transmitted to the stepper motor by simple conductors that convert the code and move the stepper motor according to the instructions.

## 1.2 Flow Chart and Block Diagram:

Circuit block diagram of designed drawing machine consists of three axes to control namely X, Y and Z, where X and Y axes control the movement of the worktable while the Z axis controls the movement of the pen up or down. The PC program converts the text into G code and sends it sequentially to the microcontroller. Arduino starts to control the three motors based on the locations of the G code received with the correct synchronization of these three motor axes during printing as shown in figure (1).

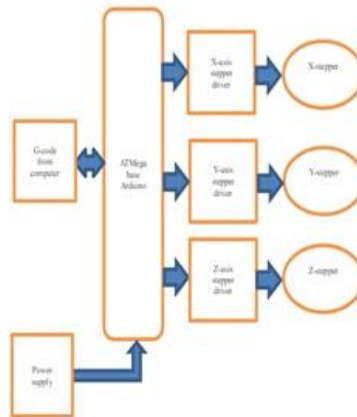


Figure (1) shows the basic block diagram of the CNC plotter machine

As shown in Figure (1) two stepper motors taken from an old two DVD/CD drive represent X and Y axes controls the motion of worktable and one servo motor represents Z axis to control the motion of pen up and down. The movement control for these three motors is done through microcontroller, the Arduino microcontroller is used in this work to control motors rotation. It has gained considerable attraction in the professional market. [5] The microcontroller used in the hardware implementation is Arduino Uno microcontroller. The microcontroller connected with a PC through USB serial port in order to receive the G-code from the PC. The Arduino here acts as the brain that controls the speed and directions of the stepper and servo motors. In the PC a C-language program is programmed to generate the control signals in the G-code and transmit these codes to the Arduino microcontroller through G-code interpreter via USB port. These command signals directly controls the motion and speed of the three motors in order to control the drawing tool. The stepper motors can rotate clockwise or counter-clockwise direction with discrete steps. The appropriate voltages sequence that energizing the motor coils is responsible about motor direction of rotation. The Arduino microcontroller generates these voltages sequence and drives the stepper motors with it through drive circuit. The drive circuits receive voltage signals from Arduino ports and

these signals controls the speed and direction of motors rotations. The stepper motors consider the heart of CNC plotter because the size and type of motor speed and accuracy depend on it [6]. Servo motor tiny and light weight DC motor, it can rotate 90 degrees in each direction, in order to rotate the servo motor 90 degree at 1.5 ms (about 5V) pulse is applied to its control pin from a total period of 20 ms [7]. The servo motor is used to lift the pen up or down on the paper, because the current of the servo motor is too small and the Arduino port can hold this small current, there is no need for a drive circuit. This motor has three legs (VCC, GND, and Control) the microcontroller sends an ON/OFF switch signal to the control pin of the servo motor in order to start or stop motor rotation. The computer (PC) is connected to the Arduino-based circuit via the USB serial port. Two L293 motor drive ICs [8] connect the two stepper motors to Arduino at pins 2,3,4,5,8,9,10,11, because the current limitation of the Arduino output port pin is about 40 mA, while the stepper motor takes more than 150 mA. The drawing current of the stepper motor varied around this typical value when the motor rotate at low or high step speed. The control pin of the servo motor received the pulse signal from pin 6 (PWM) of the Arduino Uno microcontroller.

## **2. Software and Coding:**

### **2.1 Arduino IDE:**

The Arduino IDE logo in figure (2) is abbreviation for Integrated Development Environment. Arduino uses its own programming language that resembles C-language. In the Arduino microcontroller a program called Bootloader has been entered which functions as an intermediary between the Arduino compiler and the microcontroller. Arduino IDE is made from JAVA programming language, also the Arduino IDE comes with a C / C ++ library that is usually called Wiring which makes input and output operations easier. This Arduino IDE was developed from processing software which was overhauled into an Arduino IDE specifically for programming with Arduino.



Figure (2) Arduino Software (IDE)

## **2.2 Inkscape 0.48.5:**

Through this software we can convert any image into G code extension file Inkscape is a free and open source vector graphics editor that can be used to create or edit vector graphics such as illustrations, line diagrams, art, graphics, complex logos and frames. Inkscape's primary vector graphics are Scalable Vector Graphics (SVG), but many other formats can be imported and exported. The generated shapes can be further manipulated with transformations, such as movement, rotation, scale and tilt. Through this software, we can set the size of the image, for example 4cm x 4cm, then create its borders and save it in the G code extension. After creating the G code for the image, upload it to the processing software that produces our output.

### **2.2.1 Create a G-code file with Inkscape:**

The CNC plotter in our project will work on an area of 20cm x 20cm. So we chose the properties of the Inkscape document 40cm x 40cm (width x height), which is four times the working area of the plotter, because the plotter can only draw in the first quadrant. So, initially, we keep the axis at the end closer to the motors, which are considered the origin, to easily modify the design as shown in figure (3).

The work area of the CNC plotter is displayed with the text written in the default area. Text is selected with the cursor, then select "object to path" from the drop-down window to save the G-code format of the selected text. To generate G code for an image, the file must have a transparent background. The image must be dragged into the selected area, then select the trace bitmap from the drop-down window to create a transparent image.



Figure (3) Conversion of transparent image to G-code

Scans are selected as 8 and edge detection is selected to create a black and white image. After adding this transparent image to the default area, we used the path object command to create the G-code file of the selected image with the steps described above.

### 2.3 Processing:

Render is open-source software used for electronic drawings. The GTCRL machining program is used to send the G code file from the user interface to the CNC plotter. Figure (2.4) shows the user interface of the processing software 3.5.4 after running the GTCRL program. The Arduino Uno port is selected by pressing the P button on the keyboard, so the "G" button is used to load our desired G-code file. The CNC machine will immediately start drawing the selected G-code file as shown in the figure (4).



Figure (4) Uploading G-code file

### 2.4 Coding:

Arduino Uno can be programmed using Arduino software. Select Uno Arduino from the tool and then configure it with the microcontroller used. The ATmega 328 in the Arduino Uno has

a bootloader that allows you to download new programs without using an external hardware programmer. It communicates with C language protocols. The system can use the Atmel FLIP software (Windows) or DFU programmer (Mac OS X and Linux) to load the new firmware. You can also use an ISP header with an external scheduler. CNC plotter uses Brenham's line algorithm to plot. Below is a part of this algorithm.

### ***2.5 Software:***

A number of software tools are needed to perform the operation on the required work. The design must be transmitted in a sequence through different programs. First, an image of a PCB with drilled holes according to the requirements is prepared in a design tool like AutoCAD / PCB Express etc. This image is then converted to a G code (GRBL-comprehensible code) using any readily available image to G-code converter on the Internet. Finally, the G code is downloaded and processed from the Arduino GRBL library. The details of this program are given below.

### ***2.6 Image design tools:***

There is many software tools used to create an input design file of various formats (STL, DXF, BMP, etc.) which is then converted to the specific code of the required machine, for example. Code G The software used to prepare this file are Proteus, Circuit Maker, Express PCB and AutoCAD [9]. Using any of the programs mentioned above, a basic design/scheme is created and passed to the CNC for cutting and drilling.

#### ***2.6.1 G-code:***

G-code is a programming language that converts a human-readable language into a machine-readable format. It generates information in terms of x, y, z coordinates that are sent to the computer's digital control software for automation [10]. G-code is a programming language that tells the CNC machine what, how and when to move the tools (drilling, cutting, etc.) by indicating the paths. Without G-code, it is very difficult to program a machine with many tools. A CNC machine uses an image prepared in a design tool to make a product.

#### ***2.6.2 GRBL:***

To use G-code in the CNC machine, a computer or microcontroller is needed to generate the activation signals to drive the motors in the x, y, and z directions according to the prepared model. GRBL is an open source library for AVR microcontrollers. This library is designed to control the digital controller based on the received G code. Interprets the G code to control the movement of the motors. It is an alternative to the parallel port CNC machine with lower cost and higher efficiency. [11]

All G code instructions can be transmitted to Arduino using this serial monitor. GRBL allows you to draw complex shapes such as circular, parabolic, spiral, rectangular, etc. GRBL is a smart software that manages acceleration by keeping 20 moves ahead. Thus, control the speed to obtain a smooth cut or perforation and avoid creaking, otherwise the tool may be damaged.

### **3. Hardware Implementation:**

#### ***3.1 Stepper Motor:***

Stepper motor is a motor that is used as a drive or player. The working principle of a stepper motor is similar to a DC motor, equally stacked with a DC voltage to obtain a magnetic field. When a DC motor has a fixed magnet on the stator, the stepper motor has a fixed magnet on the rotor. The stepper motor is expressed by specification: "how many phases", "how many degrees per step", "how many volt supply voltages for each winding" and "how many amperes / milliamp currents are needed for each winding".

The stepper motor does not respond to the clock signal and has several turns where the windings must be fed (voltage) first in a certain order in order to rotate. Reversing the sequence of voltage assignments will cause the rotation of the stepper motor to reverse direction. If the control signal is not sent according to the command, the stepper motors will not rotate properly; it may only vibrate and not move. To control the stepper motor, it is used a circuit of drivers that handle current and voltage requirements.

#### **3.2 Servo Motor:**

Servo motor shows in figure (5,a) is device or actuator (motor) designed with a closed loop feedback control system (servo), so that it can be set-up or adjusted to determine and ensure the angle position. Servo motor is controlled by providing pulse width modulation (PWM) signals via control cables of the motor output shaft. There are basically 2 types of servomotor: AC and DC servomotor [6]. Servo motor is a type of motor that has three cables. Each issued as a power supply, ground, and control.

The control cable is used to determine the motor to rotate the rotor to a certain position. Normally, the rotor only rotates up to 200 °. However, some rotors are capable of rotating by 360 °. Servo motors is commonly used to move a robotic arm or rotate an analogue measuring instrument, or as additional accessories for the Arduino project.

Usually, the servo motor is equipped with three red, orange and brown cables.

- a. Red cable is connected to 5 volt power supply.
- b. Orange cable is connected to digital pin which supports PWM.
- c. Brown cable is connected to ground.



(a) (b)  
Figure (5) a) Servo motor, b) Servo motor component

The width of provided control signals pulse will determine the angular position of the rotation of the servo motor shaft. The servo motor component can be seen in figure (5,b).

For example, the pulse width with a time of 1.5 ms (milli seconds) will rotate the servo motor shaft to a 90° angle position. If the pulse is shorter than 1.5 ms, it will rotate toward position 0° or left (counterclockwise), whereas if the pulse given is longer than 1.5 ms, the servo axis of the motor will rotate toward the position 180° or to the right (clockwise), the servo motor block diagram can be seen in figure (6).

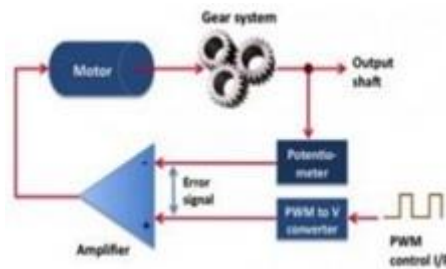


Figure (6) .Servo motor Diagram block

### 3.3 Arduino Uno R3:

Arduino is an open-source platform for easy-to-use hardware and software-based electronics. The Arduino boards shown in Figure (7) can read the light input from a sensor, press a button, send a message and turn it into an output switch in a generator, turn on an LED, and publish something on the Internet.



Figure (7) Arduino UNO board

By sending a set of instructions to the board's microcontroller, we can tell the board what to do. Arduino UNO is a microcontroller board; it contains everything needed to support it tracker [9]. Thus, using a script, control the location of motors.

### 3.3.1 Microcontroller:

The controller used in this machine is an Arduino UNO that contains an AT mega 328 AVR series microcontroller as shown in Figure13. It has 14 pin digital I/O with support for 6 pin PWM and 6 pin analog I/O. It is an open-source hardware and software board that can be easily programmed using basic C language instructions and Arduino's built-in libraries. The Arduino board is an electronic tool with many built-in and open-source libraries and hardware expansion boards that are known as Arduino shields. A GRBL shield is attached to the Arduino UNO board. It is an open-source library that translates the required design into hardware control signals using the microcontroller processor. These signals are then used by the GRBL shield to drive three stepper motors of the CNC machine.

### 3.4 L293D motor control shield:

L293D is a monolithic integrated, high voltage, high current, 4-channel driver. Basically this means using this chip you can drive DC motors with power supplier up to 36 Volts, and the chip can supply a maximum current of 600mA per channel. L293D chip is also known as a type of H-Bridge. The H-Bridge is typically an electrical circuit that enables a voltage to be applied across a load in either direction to an output, e.g. motor, as seen in figure (8).

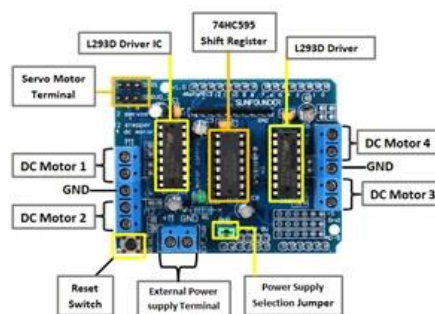


Figure (8) Dafruit Motor Shield

### 3.4.2 Electronics System and Wiring:

This section will cover the electronic components and wiring required to design and build our CNC drawing machine, so the main electronic components required are an Arduino UNO R3, CNC V3 Shield with A4988 Driver Module with Heatsink for Arduino, Stepper Motors, DC Power Supply, Pen Holder, Cables and USB Serial to Adapter. Here are some of the electronic components required for the wiring system as shown in figure (9).

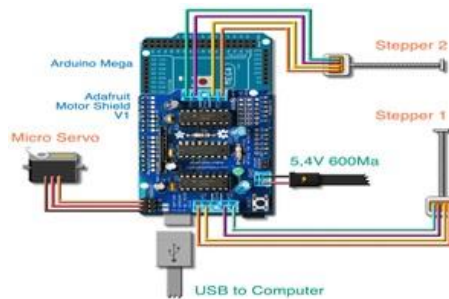


Figure (9) Electronics System And Wiring

### 3.4.3 Arduino Uno Microcontroller Circuit:

This circuit is the main control of all operating processes of Computer Numerically Controlled tools. This circuit will receive input from the program that we will create and then forward it to the output that will run the tool. Motor Driver Circuit Figure (10) is a circuit of motor drivers that works to run the motor stepper and motor servo.

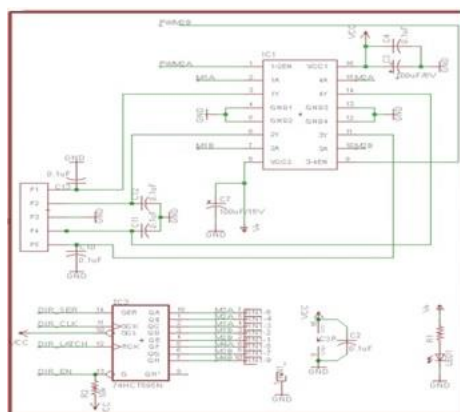


Figure (10) motor control shield

## 4. Solid works Design:

For any machine, mechanical design is the basic or essential need only after that any electrical elements can be covered upon it. Since this topic also includes actions like manufacturing, assembling and fixing up. It focusses on the available materials. As mentioned before using DVD drives can also be used. But for the area of 400mm\*400mm, the design will be like as shown in figure (11)

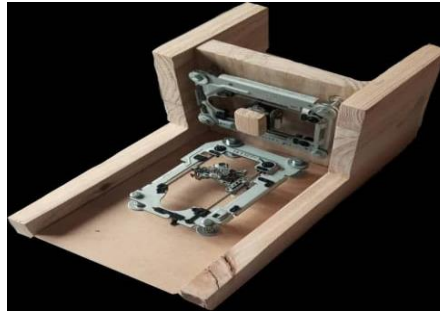


Figure (11) Solid Works Design

The design procedure will be concerned in the following parts:

1. The system frame.
2. The system servomechanism.

#### ***4.1. The System Frame:***

The frame of the machine is made from Wood material and consists of two parts as shown in figure (12).

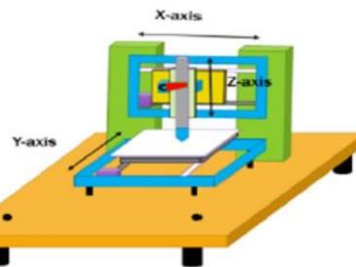


Figure (12) The machine frame

1. Vertical base.
2. Horizontal base.

Dimension of the frame parts will be chosen with respect to the suggested system servomechanism.

#### ***4.2 The system servomechanism:***

The mechanism of the system consists of three control axes:

1. X-Axis (movement left / right of pen guide).
2. Y-axis (toward/upward movement of driver plate).
3. Z axis (pen guide movement up/down).

The X and Y axis servo motors are built by the DVD driver module which consists of a screw stepper motor (rotary to linear motion axis converter).

Z-axis servomechanism differs from XY-axes. Z-axis uses 180° Servomotor that moves the pen up and down, a spring used to hold the pen down to sketch and move smoothly as shown in figure (13).

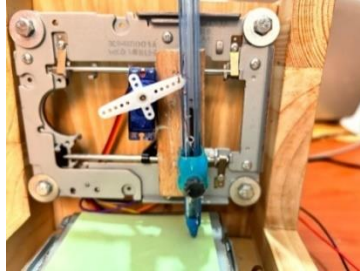


Figure (13) pen up and down mechanism

## **5. Results:**

### ***5.1 The complete and concise procedure of the CNC plotter machine:***

The process of CNC tracing machine starts with Inkscape software. We need to upload the JPG file of any image that we need to be drawn by the machine or we can write something in the document section that needs to be drawn by the machine. The Inkscape software will convert the image or write in G-code. Then another software for processing the face of the printer must be opened on the computer and run the code to transfer the G-code to the Arduino. Here Arduino should always be connected to the computer during operation. The Arduino will receive the G code, convert it into an electronic signal pulse and send it to the motor control IC.

### ***5.2 Results of Measurement and testing:***

Testing the tool is an important stage in tool making because at this stage, we will determine whether or not the tool is made according to its intended use as a drawing machine on the acrylic board. Measurement and testing were carried out in the designed circuit in the previous chapter, taking into consideration the measurement point (T). The next step is to analyze the test results to identify the advantages and disadvantages of the created tool

#### ***5.2.1 The purposes of tool measurement are:***

1. Studying the incoming and outgoing voltages at each test point.
2. Observing and verifying whether the designed tool has been created according to the plan.
3. Collecting data to compare theoretical analysis with practical results.
4. Determining if there are any errors in the circuit through measurement.

#### ***5.2.2 Measurement Test:***

Before measuring at the test point, we prepared a multimeter measuring instrument that can measure the amount of obtained voltage. The measurement and analysis steps are as follows:

1. The circuit power and connect it to a 15-volt voltage source are turned on.
2. The multimeter in the VDC state to measure the voltage is set up.

3. We calibrated the multimeter before use to obtain accurate results.
4. We identified the test point for each circuit.
5. Input point to the positive pole on the multimeter and ground to the negative pole are connected on the multimeter.
6. The measurement results from each test point are recorded.

### 5.2.3 Measurement Results:

#### A. Measurement Result of X Axis motor stepper circuit:

In this tool, there is a motor driver circuit that distributes electrical energy as needed for stepper motor movement, based on information or commands given by the microcontroller. What we need to test this time is the voltage that enters the stepper motor when the stepper motor is under load. Figure (14) shows the sequence of the stepper motor driver for the x-axis, which is driven by an acrylic drive from top to bottom.

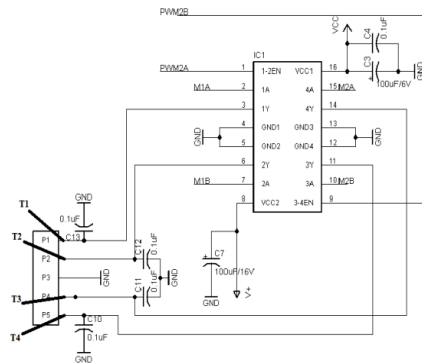


Figure (14) Motor Driver Stepper X Axis Circuit

From the circuit there are 4 test points; table (1) is the result of measurement.

Table (1) Results of Stepper Motor for X Axis measurement

Motor Stepper Voltage (T1)	Motor Stepper Voltage (T2)	Motor Stepper Voltage (T3)	Motor Stepper Voltage (T4)
7,2 v	0 v	0 v	0 v
0 v	2 v	0 v	0 v
0 v	0 v	2,8 v	0 v
0 v	0 v	0 v	2,8 v

#### B. The measurement result of Y Axis motor stepper

Figure (15) is Figure of motor driver stepper circuit for Y axis that is Pen drive from right to left or vice versa.

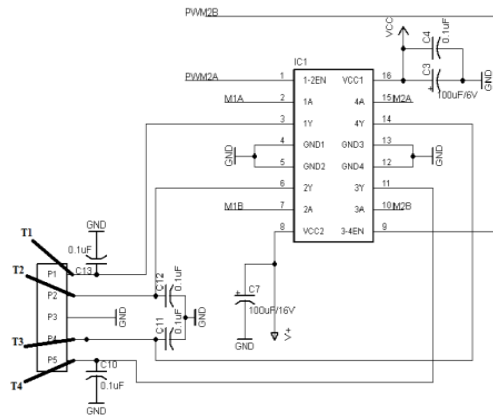


Figure (15) Y Axis motor stepper driver circuit

•From that circuit there are 4 test points. Table (2) is the measurement result

Table (2) Result of Stepper Motor for Y Axis measurement

Motor Stepper Voltage (T1)	Motor Stepper Voltage (T2)	Motor Stepper Voltage (T3)	Motor Stepper Voltage (T4)
4 v	0 v	0 v	0 v
0 v	6 v	0 v	0 v
0 v	0 v	4 v	0 v
0 v	0 v	0 v	0 v

**C. Measurement result of Z Axis motor servo circuit:**

Figure (16) is driver motor servo for Z axis that is pen driver from up to down or vice versa

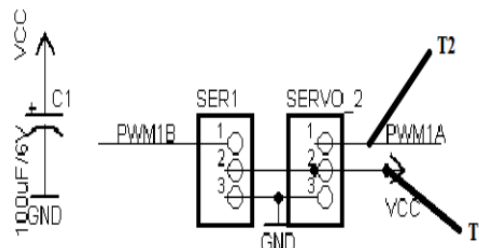


Figure (16) Motor Driver Servo Axis Z circuit

•From that current there are 2 testing points. Table (3) shows the measurement result.

Table (3) Measurement results of Motor Servo for Z Axis

Trial	Motor Servo voltage (T1) VCC
1	5 v
2	5 v
3	5 v
<b>Average</b>	<b>5 v</b>

**5.3 Program Testing Result:**

Text drawing creation is to generate G-code as computer commands machine part was done by using inkscape software. Stages that must be done are as follow:

1. Open Inkscape program , it will appear as Figure (17)

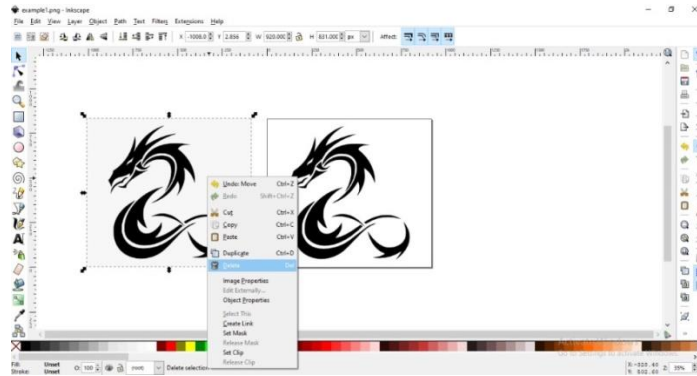


Figure (17) Interface Inkscape Program

2. By Pressing Shift + Ctrl + D to adjust the size of the layout, and change the default units and units to mm, then create the text and Select Path and click Object to Path or click Shift + Ctrl + C, this serves to determine the coordinates between X, Y and Z. Then Save and select title with G-code and G-code data creation process completed as Figure (18).

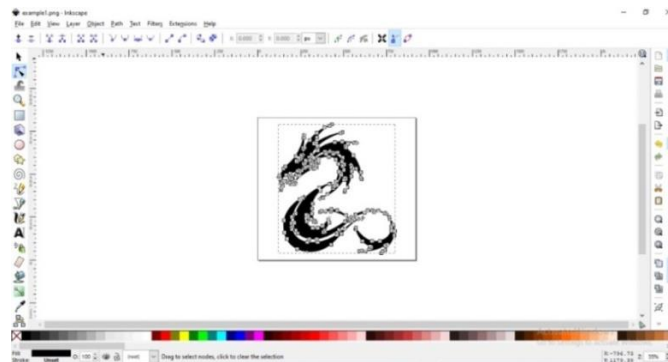


Figure (18) G-code data creation

3. Open pronterface program, then open created G-code project using Inkscape program, such as Figure (19) pronterface project which has been created in inkscape. It can be run then just send the data to the microcontroller using the processing program.

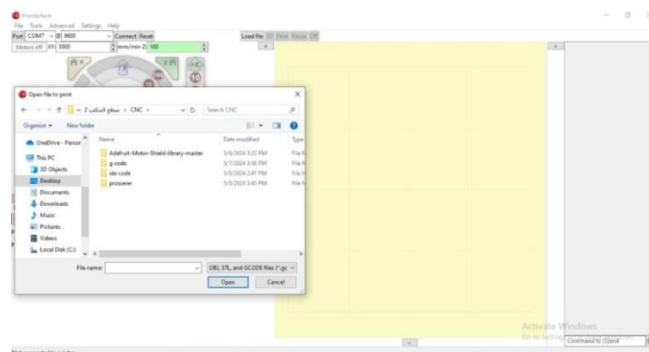


Figure (19) pronterface Project

4. Press load file then selects the g-code file, when you press print to operate the plotter CNC machine Figure (23).

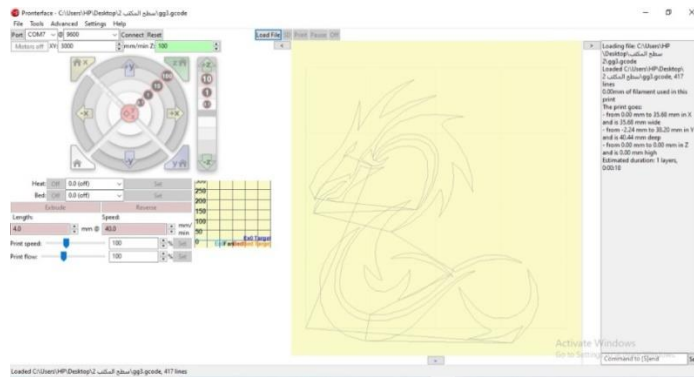


Figure (20) pronterface final step

### 5.4 The System Results

• After explained in the previous paragraph of making g-code from previous programs this is the result of run the code in the CNC machine in figures (21).

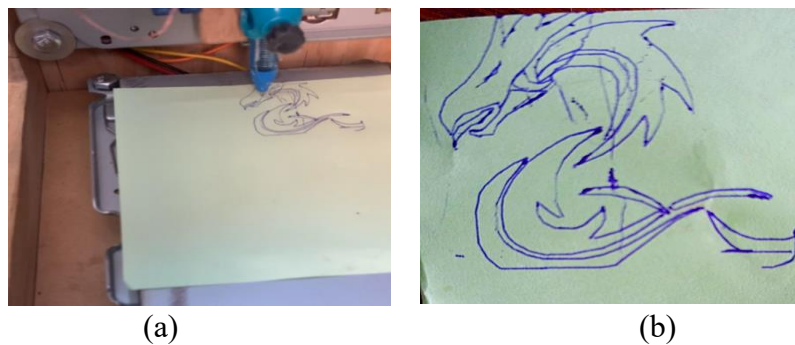


Figure (21) a) The tested picture, b) the resulting drawing

### 6. Conclusion:

The concept of a low-cost mini three-axis CNC plotter was introduced in this article. The new CNC machines are expensive, difficult to maintain and require highly skilled operators. These problems can be solved by this design. It is cheap and easy to manage and does not require highly trained operators. In a route that is not feasible with existing cars, it can be used for long hours. There are plans to extend this work for future development by using more power and precise motors and boards, more than that, metal tool can be used instead of the pen to be used as a lathe machine.

### 7. References:

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