LOW COST COMPUTER NUMERIC CONTROLLER USING OPEN SOURCE SOFTWARE AND HARDWARE

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ABSTRACT: This paper presents a low cost serial communication based computer numeric controller (CNC) machine based on open source software and hardware. Computer numeric control (CNC) machine plays an important role in the field of automation. It reduces human involvement which eventually reduces rate of error, and increases processing speed resulting into an efficient system. In this research work universal serial bus (USB) based CNC controller has been designed and implemented using open source software (G-Code and GRBL) and hardware (Arduino and GRBL shield) which are easily available and cheaper as compared to commercially available controllers. We have also evaluated our economical machine and have found its performance comparable to the existing state-of-the-art expensive machines.

Keywords: G Serial Communication, CNC Controller, G-Code, Arduino, GRBL

1. INTRODUCTION

Requirements of today's industry are to produce large quantity and quality products with low production and installation cost having finishing and dimensional accuracy. These tasks can be easily completed by the machines which are controlled by computers to make work easier with ultra-precision and less human caused errors [1]. These are commonly known as CNC (Computer Numeric Control) Machines. By using CNC technology, machines are not restricted to manual control and products are produced with ultra-precision at fast rates.

The concept of CNC based machines was developed in mid 20^{th} century and now their development has got much matured as per industrial requirements, but is still very expensive [2]. The rate of this machine is 10 to 20 times higher than the manual machine which is just because of licensed software and hardware, cost.

Traditional CNC controllers are based on parallel communication protocol. To perform the required task, these controllers are required to be connected with the computer system having parallel port. However, such ports are now obsolete [3]. This research work proposes and implements a serial communication (USB) based CNC, which is totally designed using open source software and hardware tools. This software and hardware is easily available with less cost and provide accurate results as well. The accuracy and precision has been tested by making a CNC machine for PCB drilling.

The proposed low cost CNC machine is a low cost multi axis plotter based on open source hardware and software. It is a 3 Degree of Freedom (DOF) machine used to make multiple objects of different shapes. It uses the USB port to interface with the computer. The diagram of the design would be produced on the software such as Express PCB or AutoCAD. The image produced will then be converted into G-Code by using G-Code Converter Software which is free ware software. The G-Code will then be transferred to the Arduino which is the controller used for programming, via USB port. In order to drive the motors a motion controller is required for which we are using is GRBL Shield. This Shield is specially designed for Arduino UNO Board. Drill bit will be attached with the motors which will mill and drill according to the design that has been generated.

This paper is organized as follows: Section II presents the complete hardware description. Softwares required to drive hardware are presented in Section III. System implementation is discussed in Section IV and last section concludes the results.

2. Hardware

The main hardware part of the CNC machine is a Machine Control Unit (MCU). The MCU consists of a data processor and a motor control driver circuit. Data processing is performed using microcontrollers and an H-bridge circuit is used for driving motors [3]. A CNC driller requires four motors – three stepper motors for the precise movement in x, y and z coordinates, while the fourth one, a DC motor, for drilling [4]. Microcontroller processes the required data of the design model received from software and then transfers it to driving circuit which enable motors according to required task.

2.1. Microcontroller

The controller used in this machine is ArduinoUNO which contains ATmega328 microcontroller of AVR series, as shown in Fig.1. It has 14 digital input/output pins with support of 6 PWM pins and 6 analog input/output pins. It is open source hardware and software board, which can be programmed easily using basic instructions of C language and Arduino's built-in libraries. Arduino board is an electronic tool with lot of built-in and open source libraries and hardware expansion cards which are known as Arduino shields. These shields can be easily attached with Arduino board to provide advance functionalities like support of Voice Recognition, Internet Connectivity etc.

A GRBL Shield is attached to the ArduinoUNO board. It is a free source library which translates the required design into hardware driving signals using the processor of microcontroller. These signals are then used by GRBL shield to drive three stepper motors of CNC machine.

Fig. 1 Arduino UNO Board having Atmega328 Microcontroller

2.2. Motor Driving Circuit

Shield that controls the motion of CNC and is compatible with Arduino UNO is known as GRBL shield. It has three driving circuits to control stepper motor of x, y, and z axis as shown in Fig. 2. It supports arc and circle shapes with jerk control mechanism, so that the surface of the object remain smooth and are minimum chances of tool breakage.

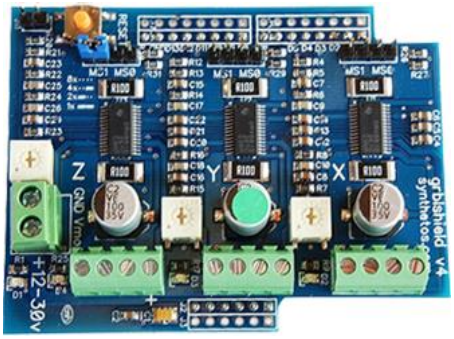

Fig. 2 GRBL Shield

2.3. Motors

Stepper motors are specifically used for this CNC machine. These motors are brushless DC motors which divide complete circular rotation into small but equal steps. By controlling these steps, accuracy of a CNC machine is increased as the input fed to the stepper motor is based on the step size. All the stepper motors used in this machine are bipolar. Equation (1) is used to calculate steps per inch.

$$\text{Leadscrew}\left(\frac{\text{Revolution}}{\text{Inch}}\right) * \left(\frac{1}{\text{Microstep}}\right) * \text{Motor}\left(\frac{\text{Step}}{\text{Revolutionch}}\right) = \left(\frac{\text{Step}}{\text{Inch}}\right) \quad (1)$$

3. Software

A number of software tools are required to perform operation on the required job. The design has to be passed in a sequence through different softwares – firstly, an image of a PCB with drilled holes as per requirement is prepared in a designing tool like AutoCAD/PCB express etc. This image is, then, converted into a G-code (GRBL understandable code) using any image to G-code convertor, easily available on internet. Finally, the G-code is transferred to and processed by GRBL library of Arduino. Details of these softwares are given below.

3.1. Image Designing Tools

There are multiple software tools used to make input design file of different formats (STL, DXF, BMP, etc.) which is later converted into required machine specific code i.e. G-Code. Softwares used to prepare these file are Proteus, Circuit Maker, ExpressPCB and AutoCAD [5]. By using any of the above mentioned softwares, a basic design/diagram is created which is fed to CNC for cutting and drilling.

3.2. G-code

G-Code is a programming language that converts the human understandable language into machine understandable format. It generates information in terms of x, y, z-coordinates which are sent to software of computer numeric controller for automation [6]. G-Code is a programing language which guides the CNC machine as to what, how and when to move tool (drilling, cutting etc) by instructing about the paths. Without G-Code, it is very difficult to program a machine having multiple tools. A CNC machine uses an image prepared in a designing tool to manufacture a product. Different softwares are available on the internet which is used to convert the image file into G-Code file. G-Code programs consolidate the picture into small sets of instructions called blocks. Numbers of instruction sets (blocks) depends upon the task complexity. The software used in this work is "All to G-Code converter". G-Code file generated by this software is easily readable in the notepad, providing the X, Y and Z coordinates.

```
X221.698364 Y-58.234215 Z0
X220.016769 Y-59.739368 Z10   } providing the exact values of x, y and z coordinates
X215.570007 Y-56.006035 Z0
```

```
G1 F1000                % It is the file name that has been transferred to the GRBL.
Z10                     % It moves the Z-axis motor to the specified point and the
                          tool is moved downward
X0.393701 Y0.393701     % Here the X and Y axis motors move simultaneously
                          to the specified point and with these movements the tool also
                          moves with it.
X0.393701 Y0.393701
X1753.412231 Y0.393701
X1753.412231 Y895.901245
X0.393701 Y895.901245
X0.393701 Y0.393701
X0 Y0                   % The motors move back to their initial positions
Z0
```

The G-code produced for the figure made in AutoCAD (Fig. 3) is as follows:

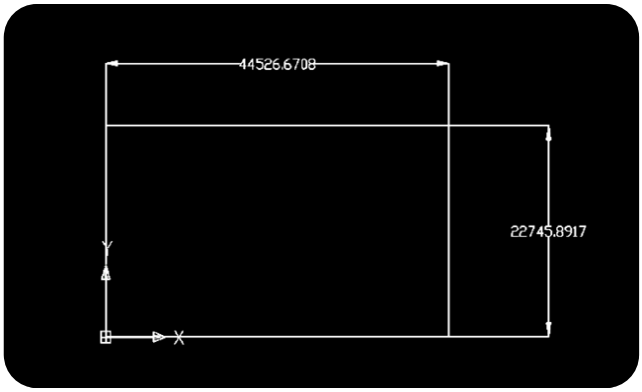

Fig. 3 Image created in AutoCAD

3.3. GRBL

In order to use G-Code into the CNC machine, a computer or a microcontroller is required which can generate the enable signals to drive motors in x, y and z directions according to prepared design. GRBL is open source library for AVR microcontrollers. This library is designed to control the numeric controller on the basis of received G-code. It interprets the G-code to control the motion of motors. It is an alternate for the parallel port based CNC machine with lower cost and higher efficiency [7].

GRBL is fully compatible with Arduino with controller Atmega168 and Atmega328. GRBL installed in Arduino board directly receives the G-code serially. GRBL software can be access using Serial Monitor screen of Arduino software. Different basic settings can be applied directly by issuing default commands of GRBL as shown in Fig. 4.

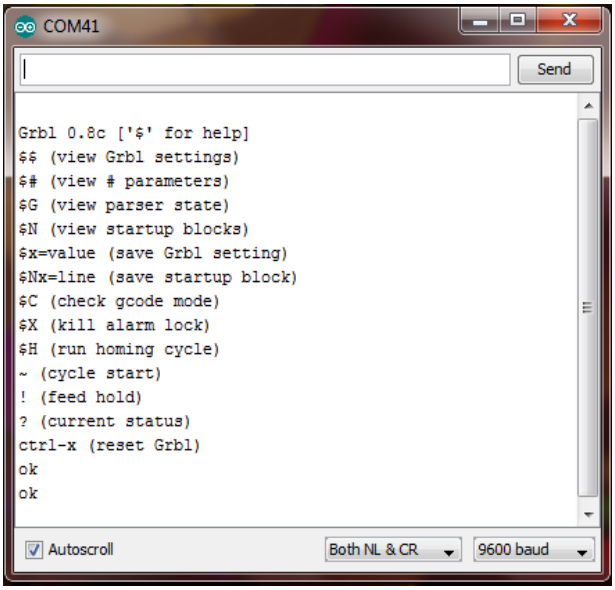

Fig. 4 Interface to Apply and View Settings of GRBL in Arduino

All the G-code instructions can be passed to Arduino using this Serial Monitor Screen as shown in Fig.5. GRBL provides support to draw complex shapes like circular, parabolic, helical, rectangular etc. GRBL is intelligent software which manages the acceleration by keeping 20 upcoming motions. So, it controls the velocity to make smooth cutting or drilling and avoids the jerk, otherwise tools can be damaged.

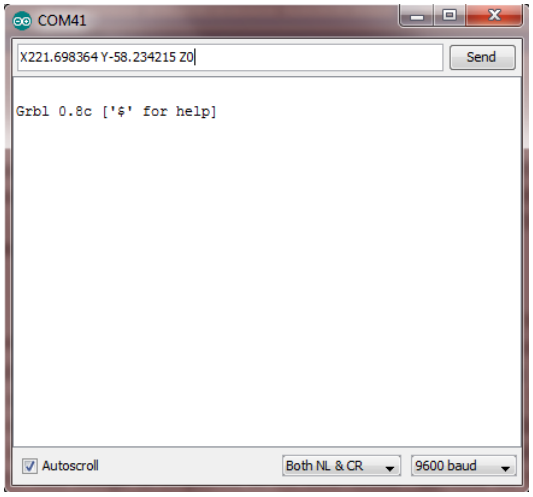

Fig. 5 G-code Instruction passed to Arduino using GRBL

3.4. Flow Chart

A flow chart of the implemented solution is presented in this subsection. The flow chart is shown in Fig. 6.

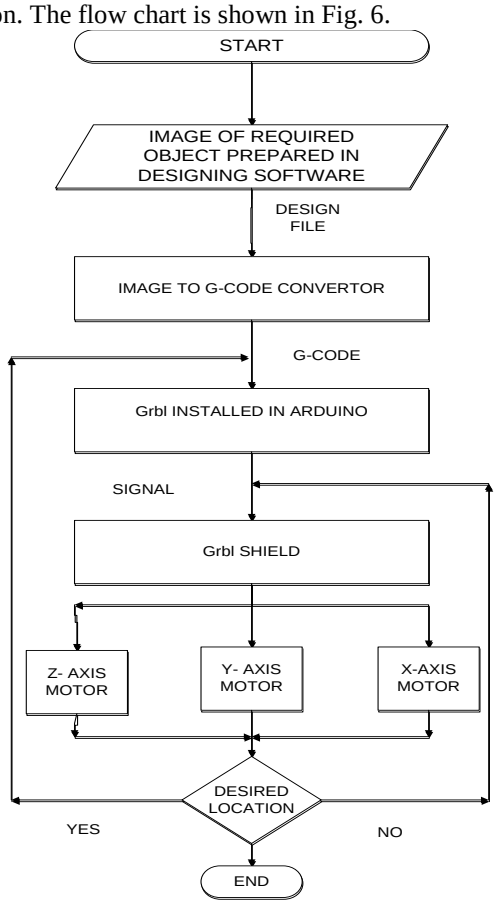

Fig. 6 Flow Chart of Implemented Software & Hardware Solution

4. Implementation

The complete hardware setup is assembled in three main steps:

i. Attachment of GRBL shield with Arduino.
ii. Stepper motors connections with GRBL shield
iii. Stepper motors installation in the mechanical structure.

This hardware setup is then connected to different softwares to provide final instructions, as discussed in the previous section. It is then installed and tested in two different machines.

Firstly, in milling machine which contain three bipolar stepper motors with heavy torque and a step size of 1.2^0, which means 300 steps per rotation, as shown in Fig. 7. Secondly, it is installed in a PCB drilling machine that contains three stepper motor and a high speed drilling machine, as shown in Fig. 8.

Fig. 7 Proposed Setup Installed in Milling Machine

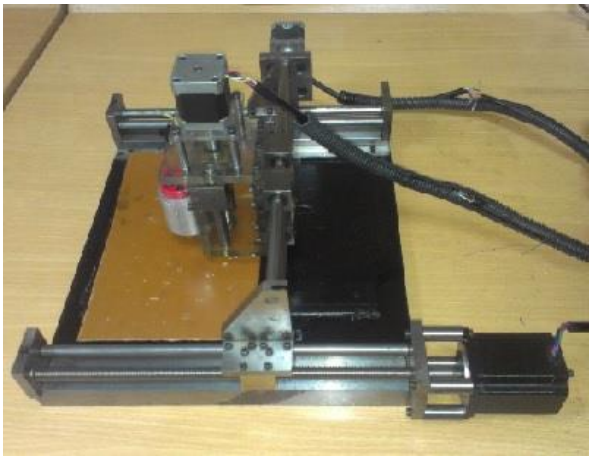

Fig. 8 Proposed Setup Installed in PCB Drilling Machine

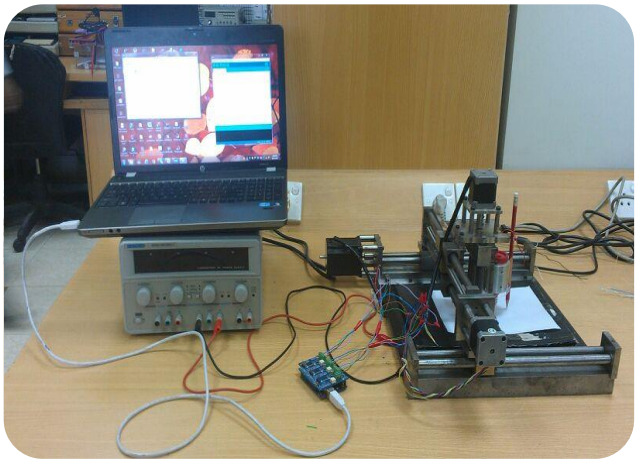

Fig. 9: Complete Project Display

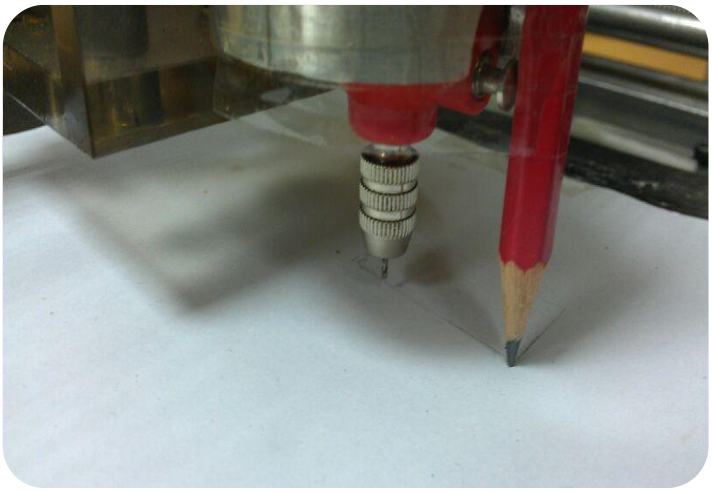

Fig. 10: Side View of Imaging on Sheet

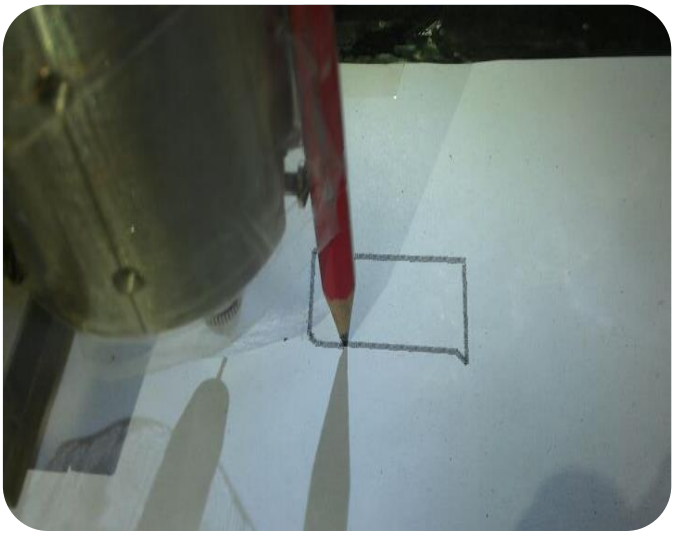

Fig. 11: Front view of imaging on sheet

5. Comparison of Low Cost Multi-Axis Plotter with other CNC Machines

Sr. #	Low Cost Multi axis Plotter	Price	Currency	Source Website
1	GRBL Shield	78	Dollars	www.synthetos.com
2	Arduino Shield	27.68	Dollars	http://store.arduino.cc/index.php
3	Dc Supply	37	Dollars	
4	3 Stepper Motors	11.06(each)	Dollars	http://www.omc-stepperonline.com/stepper-motors-unipolar-stepper-motors-c-1_26.html
5	Structure of Machine	358.68	Dollars	

Total cost = $534.54

Sr .#	Other CNC Machines	Price	Currency	Source website
1	Cast Iron 3 Axis Milling Machine	600	Dollars	https://www.flickr.com/photos/60552763@N00/475947347/
	Bolton Tools 3 Axis Mini CNC Milling Machine Mill Drill M4A1.5 HP	5899	Dollars	http://www.ebay.com/itm/Bolton-Tools-3-AXIS-Mini-CNC-Milling-Machine-Mill-Drill-M4A1-5-HP-/380466742482
	Engraving Cutting G code CNC Cutting Plotter	6300	Dollars	http://www.alibaba.com/product-detail/engraving-cutting-G-code-cnc-cutting_1669060658.html

6. CONCLUSION

The figures of the results shown above prove that the proposed machine has successfully accomplished the task. This proposed machine is easy to implement, inexpensive and comparable to the commercially available machines. Since such CNC machines are not manufactured in Pakistan, the industries here need to import them from other countries which drastically increases the overall cost of the machines. The main purpose of this project was to take an initiative to manufacture such machines in Pakistan and to provide a cost effective solution to the industries importing the machines. Thus, this project has been successful in providing such a solution, together with the latest technology based on serial ports of the laptops.

The overall cost of the plotter is below $600, which is quite cheap enough compared to the costs of similar machines having a starting price range of $5000-6000. If this work is continued, one can easily convert this machine in a multi-tasking machine by just changing the drill bits of the machine. This machine can best meet the broad range of application and needs of the industries in Pakistan.

7. REFERENCES

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