Low cost and open source software-based CNC router for machining contours

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Abstract: After the advance of NC technology to CNC technology there are attempts to bring openness in the control to bring modularity, flexibility and accuracy in the system to replace proprietary controllers. To experiment the same a portable open architecture-based CNC machine is developed for engraving application. Open source software’s are used to identify the contour, generate CNC g-code and microcontrollers to execute the motion control. The mechanical structure is developed to meet the requirement of low cost without sacrificing the accuracy. Besides the accuracy of the profile to be machined, feed rate is another criterion which should be achieved as it is intended in the program. The 3 axis CNC structure is developed and tested satisfactorily for the targeted performance.

1. INTRODUCTION

The proprietary CNC machines are closed for users. The user cannot do anything more than programming. The replacement of proprietary CNC controllers by the open architecture control of CNC technology will change the way of automation in the industry. It helps in integrating equipment and software’s from different manufacturers. An integration of low-cost electronics with high performance computers will reduce cost without compromising performance.

The variation in the levels of Open architecture control is given in the (Figure 1) As the architecture goes from low to high the number of processors reduced and PC does CAD, Interpolation and control.

![Figure 1. Variations of Open Architecture control [2]](image)

Kartz, Rueven et al. [1] have explained the available open architectural control technology by leading
research groups like OMAC, OSACA, JOP. The university of Michigan etc. & Globalization of OAC standards. Jorge Correa et al. [2] proposed hardware & software for interpolation based on open source electronics. They introduced unique finite state machine (FSM) algorithms in the architecture.

Ma Xiong-bo et al. [3] suggested object-oriented programming and use dynamic link library (DLL) on OMC based architecture [4] defined openness in three stages. Open protocols & communication interface of HMI, ability to replace proprietary controls for different purposes & topological structure of control equipment. Yoram Koren [5] has demonstrated the advantage of using a hardware interpolator with a pair of DDA software integrators. He is the foremost in the field of open CNC systems. Rong Shine Lin et al. [6] proposed a real-time interpolator based on reference word interpolator eliminated intermediate acceleration and deceleration steps to achieve constant feed rate. Biddut Bhattacharjee et al. [7] have used the classical Runge-Kutta method to determine tool positions over Taylor’s series expansion method and believed that it has reduced the complexity in computing for complex contours by NURBS. Korem.Y et.al [8] proposed a direct search method using reference pulse-circular method by which he could draw larger radii with less errors for the same computer word size. Radha Sarma et al. [9] have demonstrated good tolerances in 5-Axis machining by considering both position and contour errors in discretization and interpolation. Korem.Y.et al. [10] proposed a real-time interpolator for parametric curves by performing segmentation by the CNC system itself instead of CAD module and reduced the feed rate and contour errors.

Figure 2. Aluminium Extrusion

Figure 3. Linear guide rail and block

Figure 4. Ball screw and nut assembly

The main idea behind fabricating a low cost 3 axis CNC mill[11] is to establish method[12] of integrating the hardware and less costly open source software like Arduino microcontrollers. Due to this development time is drastically reduced as ready to use software’s, variety of low-cost interfaces such as microcontroller based shields (Arduino shields). In this work the development of a CNC mill using control with Arduino is designed to satisfy the requirements such as low cost, easy operation, and flexibility with easy interface and low power consumption.

2. DESIGN OF 3-AXIS CNC MILL

The basic elements of hardware and software and their specifications are described here

2.1. Structure design and configuration:

The basic structure is the most essential part of structure. The mechanical efficiency of the structure depends upon the dynamic response. Properly designed structure will be rigid and stiff which delivers better operation. The X, Y and Z axis move in the corresponding directions to and fro. So, considering the requirement and budget of the machine the travel length is decided. The travel length for X axis slide is 200mm Y axis slide is 200mm and for Z axis slide is 75mm. The structure is light and less
expensive which will be used for engraving on wood, plastic and soft metals.

2.1.1. Mechanical components:
Anodized Aluminum over the material such as steel, fiber plastics etc. For this prototype design, the aluminum profile of 40X40 cross section (Figure 2) is selected for the base structure of machine with corner brackets for keeping the extrusion enact with each linear guide rails and blocks: Linear Guide Rails and blocks in (Figure 3) are best suitable for steadiness and smooth travel of the slides, sturdy and stiffness of the axis to withstand the vibrations. Linear guide rails and blocks of size 10 are selected for this purpose.

Ball Screw and Nut Assembly: For both X&Y-axis to withstand load and thrust by cutting forces the ball screw and nut assembly in (Figure 4) of size 12mm is suitable.

Linear rail for Z-axis in(Figure 5)will be subjected to vertical forces to the axis. The steadiness and positioning accuracy of the rail is not as good as linear rails and blocks but considering the current requirement of Z-axis and budget, the rail makes a good deal as its cost effective and accurate.

Nut and Lead screw: For Z-axis, the main focus is to provide the feed to get the depth of cut. Lead screw and nut assembly in (Figure 6)is accurate enough to provide the desired result at effective cost.

Pillow block bearing: The shaft of ball screw and lead shaft need to be supported at its ends and also giving the freedom of rotation. The thrust force and radial force are generated while movement of table on axis. These forces are to be absorbed and this can be done by using pillow block bearing as shown in (Figure 7). This bearing is used here for medium torque, medium load applications.

2.2. Electrical components
Stepper motors: CNC machine can only be powered using motors. Motors needs to generate the torque enough to offer the movement to table and withstand the cutting forces and also provide highly accurate positioning. These conditions are satisfied by Stepper motor which provides low speed torque which gives high accuracy at low cost. NEMA 23 18.9 kg-cm hybrid stepper motor selected for X-axis and Y-axis and NEMA 17 4.7 kg-cm for Z-axis as it provides instant response to start, stop and reverse.

Stepper motor drive: The driver TB6600 circuit works by sending pulses to the stepper motors which are compatible with Arduino microcontrollers.

Arduino Uno [13]: The motion control of the axis is done by Arduino uno controller board. it has 14 digital input/output pins of which6 analogue inputs,6 of them can be used as PWM outputs. It has a 16 MHz ceramic resonator, a USB connector, a power jack, ICSP header, and a reset button. It can be
easily connected to PC by USB cable or it can be powered with an AC-DC adapter or battery.

SMPS: The controller and other components of hardware is powered LUBI 12V 12A 145W Switch Mode Power Supply (SMPS) is an efficient in terms of power saving is selected with characteristics a slow ripple, noise with good short circuit and thermal protection.

2.3. Software
This prototype CNC incorporates various software in order to produce the output on machine. The various software includes Inkscape, MakerCAM, UGS which are open source software available for free and can be used by every personnel.

Inkscape: The free open source software is the one which convert any image through image processing by edge detection algorithm. Further it will convert this into Scalable Vector Graphics (SVG) format which can is input to MakerCAM software for g-code generation.

MakerCAM: A web-based Program which converts SVG format image for g-code generation which becomes input to CNC controllers.

Universal G-Code Sender (UGS): Arduino controller in conjunction with GRBL/TinyGetc could be interfaced with UGS G-code platform could implement motion control. UGS is a Java application runs on Java runtime environment.

3. INTERFACING
The software and hardware integrated in this work are Arduino IDE, Arduino control boards, Inkscape, MakerCAM, UGS platform.

After installing the software’s installed on operating system, the GRBL program is been copied to Arduino library and then uploaded to the Arduino UNO. The image or geometry to be engraved is imported to Inkscape and then converted to the bitmap image which will create the image by detecting edges and this image is saved in SVG format. This SVG format file is compatible for MakerCAM in which the interface identifies the edges and then the codes are generated automatically by feeding the required parameters. These codes are saved as G-codes for CNC machine and are then fed to UGS platform where control for the given geometric profile motion.

UGS will set the zero position for the engraving operation. Through serial communication g-code is transferred to controller. The command data is translated by microcontroller which are interfaced with the stepper motor drivers TB66000 and 3 NEMA 27 motor for all the three axes.
4. RESULTS & CONCLUSIONS

A 3 axis CNC router based on open architecture is designed and fabricated for engraving application as shown in the (Figure 8) and (Figure 9) in two different views. The circuitry interfacing with the driver and microcontroller is shown in (Figure 10). It is able to execute straight cuts as well as curved contours. Dimensional accuracy is achieved within a few microns’ deviation. The execution of complex contours accurately by maintaining intended feed is a challenge. The accuracy could only be achieved at a lesser feed rate than a straight cut. Feed rates are accurately achieved during straight cuts but with minor error during contour cuts. Feed rates up to 60 mm/min are comfortably achieved. The (Figure 12) indicate two dimensional open contours after edge detection by Inkscape and (Figure 11) shows the same contour achieved by router. The partial G-code obtained is shown in (Figure 11). Similarly (Figure 14) shows the closed loop executed by router. Since proprietary controllers are not used, the costs of fabrication and open electronic platforms are limited hence the machine can be produced at low cost.

Figure 11. Arbitrary curve executed by CNC

Figure 12. Planned arbitrary curve

G0 G54 G17 G21 G90 G94 M0 M5 M9 T0 F0. 50.
G21G91G1Z1F75
G90 G21
G21G91G1Z1F75
G90 G21
G21G91G1Z1F75
G90 G21

Figure 13. Sample g-code generated For open loop

Figure 14. Closed loop contour

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