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DESIGN AND IMPLEMENTATION OF CNC ROUTER: A REVIEW

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ABSTRACT
The Computer Numeric Control (CNC) is a technology which tries to bridge the gap between the computers and the mechanical system. It provides an easy and effective way to control the action of mechanical system by generating, parsing and executing the program instructions and converting them to the electrical signals to control the actuators which are used to control different actions of the machine. This paper reviews the sequence of works that have been carried out by different researchers on design, analysis, implementation and construction of a computer numerical controlled mechanical systems. The main goal of this paper is to allow the future researchers to provide a passage into the work to improve the performance, accuracy, efficiency and the design of CNC machine.

***Keywords:** CNC, Digital Chopper, Drilling Machine,MCU,CAM, FPGA, UART, 3D Linear Interpolation, HM CFRP, ANOVA.*

I INTRODUCTION
The Computer Numeric Control (CNC) is a technology that uses microcomputers to generate, parse and execute the sequential controls, that describes the actuators behaviour. Apart from drilling, turning and milling the application of CNC machine can be seen in welding cutting, electronics components insertion and robots. The development in the CNC technology is a continuous process, there have been many improvements in this technology, but it still needs further refinement since it still misses many important production parameters such as optimization and low cost. The numerical control machine was invented around 19th century. It includes three main steps that is receiving data and accordingly control actions. A machine control unit(MCU) is responsible to decide the parameters such as feed rate, spindle speed, depth of cut, and tool path. A CNC machine has three axis X, Yand Z axis. X and Y axis are responsible for providing the tool, direction of motion (tool path) and Z axis is responsible to describe the depth of cut and height of the work piece. On research field, it is intended to investigate: (i) power efficiency (ii) process efficiency (iii) process optimization (iv) simulation on computer integrated manufacturing (CIM) (v) development of supervisory systems with real time three-dimensional animation (vi) application of artificial intelligence to estimate parameters like tool life cycle etc. The machine is based on the removal of material of a workpiece. Nowadays there are machines with six or more axes with more degree of freedom.

II LITERATURE REVIEW

Paulo Augusto Sherring da Rocha Junior et al. [1]studied a design of CNC prototype machine with three cartesian axis with 600mm of length both X and Y axis and 100mm of length Z axis. Three stepper motors with holding torque of 10 kgf-cm, 8W of power per phase, 1.8° step angle and positioning precision higher than 95% were used to control the motion of spindle in X, Y and Z axis. As end effector, a universal DC machine with nominal speed of 35000 rpm was used. The software to control and load the program into the machine was designed in the LabVIEW integrated development environment (IDE). The transfer of instructions from the software to the machine was by using Universal Serial Bus (USB) based on a PIC18F2550 microcontroller. The simulation in MATLAB showed the good results of voltage regulation using digital chopper. On the basis of above statements, they concluded that the machine works well with wood, acrylic, copper clad, and even with fluctuating power supply.

Gautam Jodh et al. [2] discussed the design of computer numeric control drilling machine.Moving gantry type design of the machine was chosen. For frame structure steel angles were used to provide enough rigidity to the machine. Calculations were made considering different parameters to find out power requirements of the machine. For X, Y and Z axis drive, precision stepper motors were selected. The prebuilt open source software CMM was used to provide input to the machine. From the calculations and results, they concluded that machine had enough rigidity to work well even with mild steel.

Pratik Bhambhatt et al. [3]studied the base structure of CNC machine. Theyconsidered different types of table structures and machines such as X-Y tables, a cantilevered, moving gantry, moving table etc. They based their analysis considering the moving gantry type CNC machine. The analysis of base structure by applying different constraints was done using ANSYS. The results of analysis revealed that the minimum and maximum stresses on the base structure was about 8027.45 N/m^2 and 4.50689e+007 N/m^2 respectively. On the basis of these results they concluded that the machine can be used under harsh loading condition without altering its performance.

M. Bhavani et al. [4] designed, implemented and constructed the mini CNC machine for PCB drawing and drilling, wood engraving and glass cutting.The GRBL firmware was used to interpret the G-code and converting it to electrical signals to control the actuators. The MCU used was Arduino Uno development board based on Atmega 328 microcontroller, which was responsible for controlling important parameters of the machine, like feed rate, depth of cut, and spindle speed etc. The GT2 timing belts were used instead of lead or ball screws to reduce the cost. The communication between the computer and the MCU was done using universal serial bus. The optimum price L293D motor driver (H-bridge) was used to drive the stepper motors. The PC software that was used to send the G-code to the machine was universal G-code sender which is a free CAM software. The authors conclude in their paper that machine has good adaptability to be used with most CAM softwares, and had enough rigidity to be used with copper clad with ease.

Dr. Usha S. Mehta et al. [5] presented the design and implementation of a 3 axis Linear Interpolation Controller in a Xilinx Spartans 6 Field Programmable Gate Array (FPGA) to control a 3D linear motion of a computer numerical control (CNC) machine or robotic arm. It is implemented using Verilog HDL. The controller was based on linear interpolation algorithm which is based on the fact that any line in 3D space can be decomposed into three planes by dropping perpendiculars into each plane. This line is then equal to lines traced in any of two planes.Universal Asynchronous Receiver Transmitter (UART) is used for asynchronous serial data communication with the interpolation module. It is a generic UART supporting all baud rates. UART architecture is based on Recursive Running Sum Filter. Tap control module controls the entire linear interpolation process. It receives data like absolute/incremental addressing of 3D coordinates, displacement coefficients in X, Y and Z axes for the respective servo drives and feed rate of the machining process from the UART register interface. The authors concluded that the approximate precision of the algorithm was excellent and concurrent FPGA based hardware processing ensured the modulehave good real-time performance.

Aneeta Pinhiero et al. [6] has designed and constructed a low cost three axis mini CNC plotter using stepper motors, Arduino microcontroller and the motor control software. The DB9 serial communication port was used to transfer the data from computer to the CNC plotter and to control the motion of the stepper motors.The linear rails and linear ball bearings were used to construct the x, y, and z axis. The machine used the GRBL software to transfer G-Code to the machine control unit to control the actuators. They concluded that the cost of the machine is minimal and the size of the machine is small that it can be assembled and disassembled at any time according to the requirements.

Venkata Ajay Kumar. G et al. [7] studied the bed structure of the machine. They focused their analysis on the machine bed under static loads, then investigations were carried out to reduce the weight of the machine bed without deteriorating its structural rigidity. The 3D model of the bed was created by using commercial 3D modelling software CATIA V5 R20 and analyses were carried out using ANSYS. The analysis was carried out on three materials cast iron, stainless steel and High Modulus Carbon Fiber Reinforced Polymer Material (HM CFRP). Static analysis for comparison of the results obtained from the analysis under static load condition is given in table below.

Table 1. Comparison of the static structural analysis results

Material	Cast iron	Steel	HM CFRP
Total deformation (mm)	$3.9449x10^{-5}$	$2.652x10^{-5}$	$2.0453x10^{-5}$
Normal Stress(mpa)	0.040435	0.036949	0.040435
Normal Strain	$2.5335x10^{-7}$	$1.4113x10^{-7}$	$1.3193x10^{-7}$

On the basis of above mentioned results, they concluded that the total deformation and of HM CFRP composite machine bed was less than the deformation of both steel and cast iron This was due to its high young's modulus

than both steel and cast iron. Since stress is independent of material property, hence stress induced in all machine beds is approximately same.

Kulkarni Bharat P et al. [8]discussed and implemented a three axis CNC PCB drilling machine. Their implementation was based on the Atmega 328 microcontroller as MCU. They proposed the methodology and flow chart for the working of the machine which was given as.

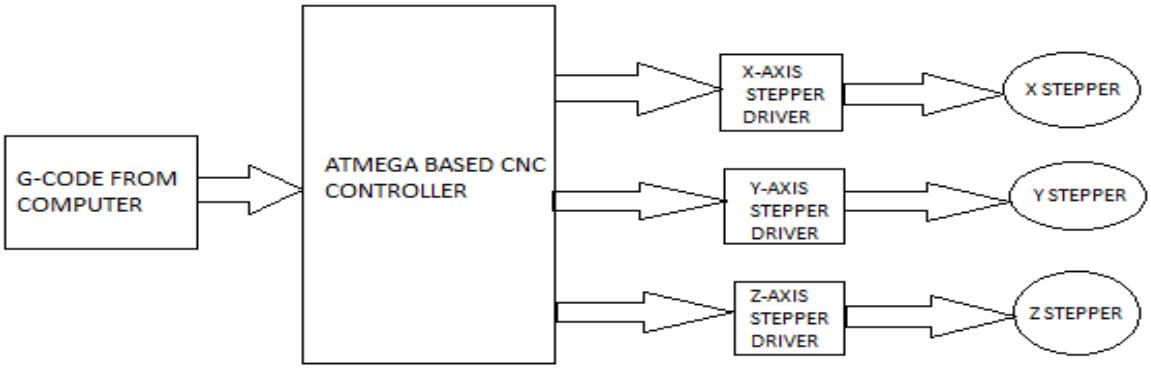


Figure 1. Block diagram of proposed methodology

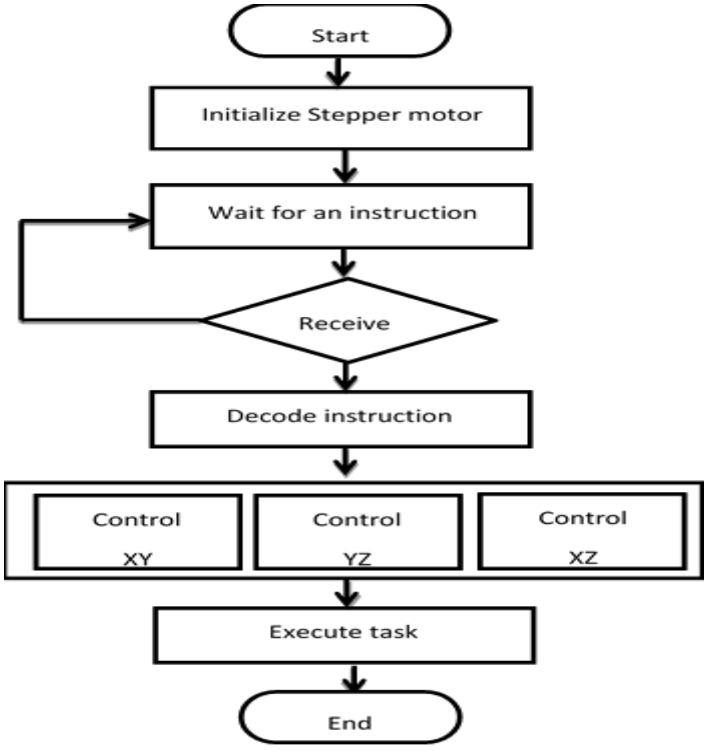


Figure 2. Flow chart of System

On the basis of proposed methodology and flow chart, they selected FTDI driver for communication between

the computer and the machine. Easy driver was used to control and regulate the stepper motors. The software used for generating and sending G-code to the machine were Eagle, FlatCamSoftware and Universal G-code Sender respectively.

The B. V. Subrahmanyam et al. [9] have made their paper on the static and dynamic analysis of machine tool structure. In this paper, they studied about static and dynamic behaviour of three various types of machine tool structure i.e. milling machine, shaping machine, lathe machine. To perform an analysis on machines they used ANSYS which is Finite Element Analysis software. For analysis of machine structure, they fixed the base of machine and the load taken as the weight of machine itself. In static analysis, they found out equivalent stresses and stresses in X, Y, Z direction, also they found the deformation of machines due to its self-weight. From static analysis, they conclude that the equivalent stress generated in the lathe machine structure was higher than other machine structures also they state that the deformation along X-direction was high for all machines. For dynamic analysis, they used modal analysis method to determine the vibrational characteristics of machine. They used six natural frequencies modes for each machine for finding the deformations. For milling machine, the maximum deformation was 0.079172mm occurred at 17.711Hz, for shaping machine 0.117925mm deformation occurred at 32.247Hz and for lathe machine 0.254419mm deformation takes place at 20.662Hz. From these results, they conclude that as the natural frequencies increases the deformation also increases.

The C. C. Hong et al. [10] worked on five axis turning-milling complex CNC machine. This paper provided details about computer aided engineering (CAE) for heavy industries. They performed research analysis with CAE software on secondary and primary shaft system and machinery bed. They used commercial computer software SOLIDWORKS 2014 simulation software. In this study, the analysis done without considering inertia force, damping force and impact force. They completed work with mathematical model in matrix form as

$[M] \{u\} = \{f\}$

Where;

M = material stiffness constant,

u = displacement vector

f = external load factor

They analysed machinery bed structure by applying 36 boundary conditions. They provided different meshing size for analysis and found maximum displacement values for machinery bed. From this paper, it is clear that external load value below 10MPa is safe. They conducted two types of analysis, a) with gravity force, b) with gravity force & external load.They succeeded to reduce weight of CNC machine and ensures enough endurance limit to resist external load.

Pahole et al. [11]proposed a low-cost design and evaluation of CNC machine. The working dimensions were 180x140x250 mm. The static rigidity and positional accuracy of the machine are experimentally measured, and the commercial Mach3 machine control software was used with a parallel port-equipped personal computer.

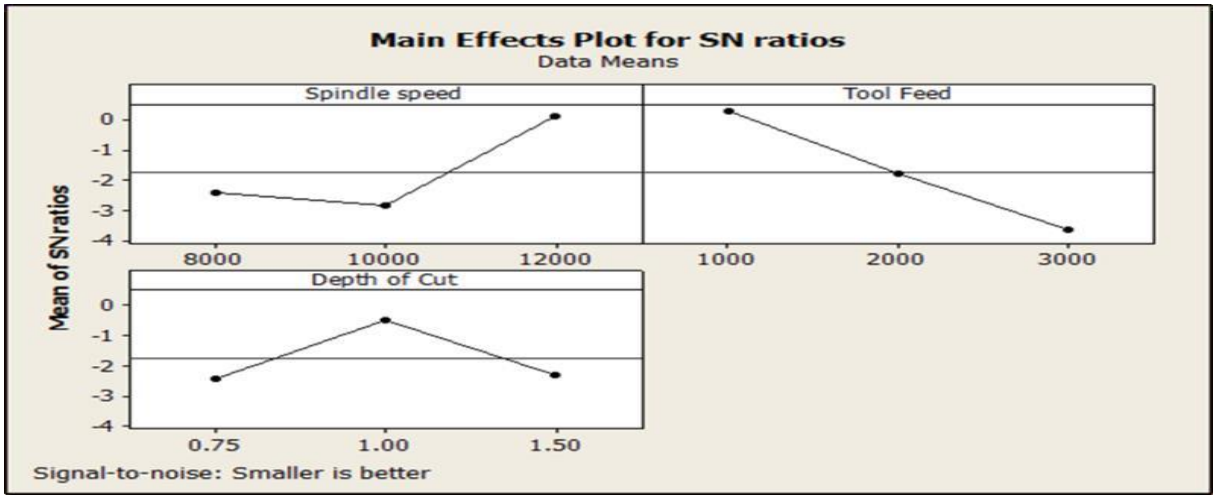
They concluded that the overall dimensions of the machine were as expected and use of open source hardware and software in the machine ensured the low cost of the machine.

Dhruv H. Patel et al. [12]studied the influence of various machining parameters like tool speed(rpm), tool feed(mm/min), and depth of cut(mm). Experiments were conducted on composite material of Acrylic resin and Aluminium Trihydrate with three levels and three factors to optimize process parameter and surface roughness. An L9(3*3) Taguchi standard orthogonal array was chosen for design of experiments. The output characteristic and surface finish were analysed by software Minitab 16 and analysis of variance for means (ANOVA) with signal to noise ratio graph were plotted as.

Table 2. Analysis of variance for means

Sources	DF	Seq SS	Adj SS	Adj MS	F Value	P Value
Spindle speed	2	03208	0.3208	0.1604	10.45	0.087
Tool speed	2	0.4762	0.4762	0.2381	15.52	0.061
Depth of Cut	2	0.1828	0.1828	0.0914	5.96	0.144
Error	2	0.0306	0.0306	0.0153		
Total	8	1.0106				

Fig 3. Main effect plot for S/N ratio



On the basis of above results they concluded that ANOVA showed the percentage contribution of feed rate was maximum and from S-N ratio, it could be seen that optimal value of surface finish was obtained at first level of tool feed, third level of spindle speed and second level of depth of cut.

R. Ginting et al. [13] discussed the design and testing of complex 3-axis CNC machine. Theydesigned and perform following tests on the machine (a) Cutting system test (b) Engraving system test (c) Marking system test (d) Accuracy test (e) Depth measurement (f) Speed test. Based on these tests they concluded that the CNC machine could be used for cutting, engraving, and marking on wood to form 2D or 3D objects with 98.5% carving and 100% depth accuracy.

Venkata Krishna Pabolu et al. [14] has discussed the mechanical, electrical, and software subsystems of the three-dimensional computerized numerical control machines. Stepper motors, linear rails and gearing arrangement were used in the mechanical system, low cost 8-bit Atmel 89C51 microcontroller and ULN 2803 stepper motor driver comprised the electronics system, the C# .net platform 3.5 and Keil compiler were used as software subsystem. They concluded that the use of all the open source software and low-cost hardware optimized the cost of the machine.

G. R. Ramesh Kumar et al. [15] designed, fabricated and tested the CNC Laser Cutter. A laser cutter was incorporated instead of a spindle in a typical three axis CNC machine. The electrical signals to the laser cutter were controlled by the designed software. The software Inkscape was used for creating and designing an image to be converted into G-Code file which is used to run into the GRBL. The mechanical axis accuracy and repeatability results are shown below.

Table 3. x-axis repeated data

No. of repeats	Values
1st repeat	0.38 inch
2nd repeat	0.38 inch
3rd repeat	0.379 inch
4th repeat	0.38 inch
5th repeat	0.38 inch

Table 4. y-axis repeated data

No. of repeats	Values
1st repeat	0.3935 inch
2nd repeat	0.393 inch
3rd repeat	0.393 inch
4th repeat	0.393 inch
5th repeat	0.393 inch

Based on the above results they observed that the accuracy of x and y axis was promising with the precision.

Dr. B Jayachandriah et al. [16] fabricated a 3-axis CNC router based on the three machine subsystems. The mechanical system consisted of ball screws, ball bearings, linear roads, linear ball bearings, shaftsand shaft couplings. The electrical system comprised of power supply, stepper motors and microcontroller board. The free CAD software like FreeCAD were used to create the mechanical models to be fabricated on the machine. The CAM Software like G-Simple, Free mill etc. were used to generate G-code files to send to the machine controller using GCODE Sender software. The fabricated CNC router was tested to determine its accuracy and precision in different modes. The validation of the test results showed littleinaccuracy in alignment. Circular test also revealed thatincreasing feedrate will decrease machine accuracy and surface flatness.

Kajal J. Madekar et al. [17]discussed and designed the automatic mini CNC machine based on Atmega 328 microcontroller in an Arduino. For Serial communication between computer and machine controller, FTDI serial to USB converter FT232RL IC was used. The EasyDriver stepper motor driver was used to run the stepper motors according the control signals generated by microcontroller. On the basis of their study they concluded that their setup of hardware with combination of G-Code gives better accuracy and reduces work load.

The Shihao Liu et al. [18]studied and discussed the analysis of gantry machine centre. Their prime focus was on reducing the weight of the gantry structure. For getting the light weight structure of the column with increasing natural frequencies, the bionic design for the column structure was used. They made three types of bionic structure using CAD software and then imported to the ANSYS Software for analyses. They subjected the structure under different loading conditions. At the top of the column 6917N load was applied, on the middle of the column the load was 118216N. The result of analysis is given below.

Table 4. results of bionic structures

Bionic structures	A	B	C
Deformation reduced	15.05%	11.48%	16.38%
Mass reduced	3.96%	2.74%	1.32%
Maximum stress reduced	5.29%	10.22%	8.24%
Increased natural frequencies	5.78%	6.22%	6.32%
Manufacturability	Best	Good	Complicated

From the above results, they concluded that the type B is suitable bionic design for column structure because type B achieve light weight structure with reducing maximum stresses and increasing natural frequencies.

Migbar Assefa[19]dealt with the analysis of static and dynamic rigidity of the column of the CNC machine. The parameters used for the modelling of column structures were apertures,aspect ratio, and apertures size. They used the shell type structure for the purpose of analysis. The 3D model made in CAD software and then it was imported in the ANSYS analysis software. There it was subjected to different loading conditions. They

performed torsional analysis by applying 1560N load on the column for static study and bending analysis by applying the load of 1560N at the ends of the column. The above study revealed that the orientation of the apertures and aspect ratio does not affect the static and dynamic rigidity of the machine.

Rishikesh B. Kamthe et al. [20] worked on design, analysis and testing of the spindle of the CNC machine. Three methods were used for the analysis of the spindle. (i) Mathematical analysis (ii) Analysis in CAE software (iii) Experimental testing. They used the Macaulay's method for mathematical analysis. For CAE analysis theyused ANSYS software and Creo parametric for modelling a 3D model. From the results obtained using the analysis, they found that value of maximum deformation was $3.5711x10^{-5}$ and equivalent stress was 6.3875Mpa. From these results they found that the safe conditions for the operator were (i) noise level of 87.4dB (ii) temperature at 44.4^{o}C and (iii)speed 6174 rpm

III CONCLUSION

The literature study is mainly focussed on the machine stability, structural analysis in static and dynamic loading, machine control unit and software feasibility of the machine. The suggested work by the researchers has successfully got the result in reducing the weight of the machine, increase in natural frequencies, reduction in deformation and increase in software adaptability. This study will help the researchers in further improvement of the design and development of different parameters of the machine.

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