

Fabrication of Low Cost 3-Axis Cnc Router

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ABSTRACT : Increase in the rapid growth of Technology significantly increased the usage and utilization of CNC systems in industries but at considerable expensive. The idea on fabrication of low cost CNC Router came forward to reduce the cost and complexity in CNC systems. This paper discusses the development of a low cost CNC router which is capable of 3-axis simultaneous interpolated operation. The lower cost is achieved by incorporating the features of a standard PC interface with micro-controller based CNC system in an Arduino based embedded system. The system also features an offline G-Code parser and then interpreted on the micro-controller from a USB. Improved procedures are employed in the system to reduce the computational overheads in controlling a 3-axis CNC machine, while avoiding any loss in overall system performance.

I. INTRODUCTION:

In modern CNC systems, end-to-end component design is highly automated using computer-aided design (CAD) and computer-aided manufacturing (CAM) programs. The programs produce a computer file that is interpreted to extract the commands needed to operate a particular machine via a post processor, and then loaded into the CNC machines for production. Since any particular component might require the use of a number of different tools – drills, saws, etc., modern machines often combine multiple tools into a single "cell". In other installations, a number of different machines are used with an external controller and human or robotic operators that move the component from machine to machine. In either case, the series of steps needed to produce any part is highly automated and produces a part that closely matches the original CAD design. With the on-going development of technology and economy, new industrial requirements such as high precision, good quality, high production rates and low production costs are increasingly demanded. Most of such requirements, including dimensional accuracy, conformance to tolerances of finished products and production rate can be met with better machine tools. With the help of CNC technology, machine tools today are not limited to human capabilities and are able to make ultra-precision products down to nano scales in a much faster manner. The traditional design philosophy of machine tools is multifunctionality and highest precision possible. However, with the dramatic increase of industry varieties and the growing demand of miniature products, these general purpose machine tools are not efficient, either in terms of machine time or cost, in manufacturing products with special sizes and precision requirements. There are several advantages of using small machines to produce small sized objects. With a smaller machine size, space is saved. The energy required to operate the machine is reduced as well. It now requires less material and components to make the machine, hence bringing down the cost greatly. The weight of moving component also comes down so that during operation, the vibration and noise, as well as pollution to the environment, are markedly reduced. As the machine becomes denser and lighter, it becomes more portable. The layout of the manufacturing plant can be more flexible. The productivity and manufacturing speed also increases due to possible faster operation.

II. LITERATURE REVIEW:

several authors have studied the development of such machines on a smaller, low-cost scale. Yung C. Shin, Henry Chin, Michael J. Brink, Studied the Characterization of CNC machining centers, | Journal of Manufacturing Systems, 1991. Heisel. M Kumar, V Puttige, worked on low cost automation for CNC machining center and published paper at IJMET, Vol. 3. I. Pahole, L. Rataj, M. Ficko, S. Klancnik, S. Brezovnik, M. Brezovnik, and J. Balic, did research on the "Construction and evaluation of low-cost table CNC milling machine", 2009. V.K. Pabolu and K.N.H. Srinivas, made a design of Low Cost CNC and published a journal on "Design and implementation of a three dimensional CNC machine", 2010. T. Andrei and I. Nae, did the workout on "Practical applications performed by a stepper motor CNC router", 2010. P.A. Sherring da Rocha Jr., R.D.S. Souza, and M. Emilia de Lima Tostes, "Prototype CNC machine design", 2012. X. Xu, Y. Li, J. Sun, and S. Wang, "Research and development of open CNC system based on PC and motion controller", 2012. A LOW-COST BUILD-YOUR-OWN THREE AXIS CNC MILL PROTOTYPE,

Sundar Pandian and 2S. Raj Pandian 2013. Open source GCODE interpreter code GRBL controller Firmware Code By Ben is the inspiration for working on the low cost production system. The GRBL team implemented user friendly innovation on interpreting the CNC GCODEs using arduino based microcontroller system.

III. OBJECTIVE OF PAPER:

The idea behind fabrication of low cost CNC router is to full fill the demand of CNC routers from small scale to large scale industries with optimized low cost. A major new development in computer technology is the availability of low-cost open source hardware, such as the Arduino microcontroller. An advantage of open source hardware is that a wide variety of ready-to-use software is available for them on the Web, therefore the prototyping and development times are drastically reduced. Moreover, a wide range of low-cost interfaces, sensors, and accessories such as Arduino shields are also available.. However, for the development of low-cost educational models of CNC machines, such tools may be quite adequate from the viewpoint of machine control. In this paper, the development of a prototype 3-axis CNC Router using Arduino-based control system is presented with following specifications:

- Low cost
- Easily operable
- Easy interface
- Flexible
- Low power consumption

IV. EXPERIMENTAL SETUP:

Machine structure is the “backbone” of the machine tool. It integrates all machine components into a complete system. The machine structure is crucial to the performance of the machine tools since it is directly affecting the static and dynamic stiffness, as well as the damping response of the machine tool. A carefully designed structure can provide high stiffness, result in higher operation bandwidth and more precise operation. A small-scale machine tool generally requires even higher stiffness than the ordinary large-scale machine tool since it is usually operated at higher speeds. Granty style closed frame structure is chosen for our experimental setup which provides a strong ridged structure loop, symmetry, and good thermal stability, which provides better stiffness than the open frame structures generally used for easy access to the work zone, with the same order-of-magnitude in size. Closed frame structures typically are used in precision machines such. Therefore it is much easier to move the tool with respect to a fixed work piece. This structure consumes less material, hence is very less expensive to build. Most machines designed for cutting flat steel plate use a gantry design because it is an easy way to move cutting tools in an Z-X coordinate system. The rail system that the gantry rides on forms one axis, usually the Z-axis. The gantry bridge itself forms the other axis, usually the Y-axis. By motorizing each axis and coordinating the motion of the two axes simultaneously, you can move a torch in any pattern necessary to cut shapes out of steel plate. Thus, a gantry design lends itself to CNC shape cutting, which primarily uses an Z-X coordinate system for programming parts. A gantry cutting machine will ride on some sort of rail system in the Z-axis, either floor mounted, pedestal mounted, or sometimes integrated onto the side of a table. The rails are designed to provide accurate motion for the machine, and are strong enough to support the weight of the entire machine and all of the equipment mounted to it. Depending on the size of the machine, these rails can be as simple as a small strip of metal, or as complex as a recirculating ball bearing linear rail system, or as large as a railroad train rail. A gantry cutting machine will also have some sort of guiding system in the X-axis too, which is mounted to the bridge structure itself. The X-axis guiding system will usually be smaller than the Z-axis rails, because they only have to carry the weight of a small carriage and cutting tool, not the entire gantry. Gantry machines may have one tool carriage or many tool carriages. Some times the tool carriages will each have their own drive motor that moves them in the X-axis, and some times there will be only one motor that drives the X-axis, and all of the tool carriages will be connected together by a steel band, tie rod, wire rope, or similar mechanical device.

4.1 STRUCTURAL DESIGN – CAD MODEL

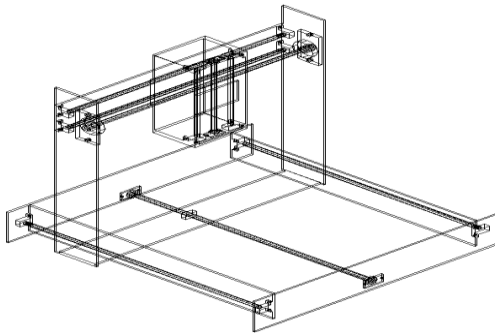


Fig.1., 3D WIREFRAME MODEL

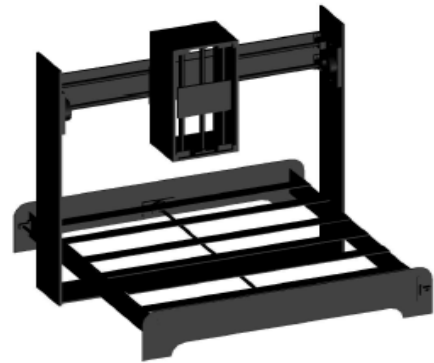


Fig.2., 3D SOLID MODEL

4.2 DESCRIPTION OF COMPONENTS:

4.2.1 BALL/ LEAD SCREWS

A ball screw is a mechanical linear actuator that translates rotational motion to linear motion with little friction. A threaded shaft provides a helical raceway for ball bearings which act as a precision screw. As well as being able to apply or withstand high thrust loads, they can do so with minimum internal friction.

- A: Steel ball
- B: Screw shaft
- C: Ball nut
- D: Seal (both sides of ball nut)
- E: Recirculation parts (return tube, etc.)

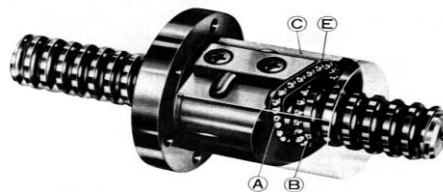


Fig.3., BALL/LEAD SCREW

4.2.2 BALL BEARINGS

A **ball bearing** is a type of rolling-element bearing that uses balls to maintain the separation between the bearing races. The purpose of a ball bearing is to reduce rotational friction and support radial and axial loads.



Fig.4., BALL BEARING

4.2.3 LINEAR RODS

Linear rods are rigid strong Mild Steel shafts which are used to carry the load without affecting the motion and supports linear movement. Linear rods with linear bearing assembly are used to carry the loads and supports the structures in linear motions the total load of the structure is taken away by the linear rod bearing assembly and therefore the load on ball screw is reduced and causes precise smooth linear motion.

4.2.4 LINEAR BALL BEARINGS

A linear bearing is to provide free motion in linear direction. The load is carried away by the linear bearing and reduces friction slides over linear rods. A linear-motion bearing or linear slide is a bearing designed to provide free motion in one direction. There are many different types of linear motion bearings. A rolling-element bearing is generally composed of a sleeve-like outer ring and several rows of balls retained by cages. The cages were originally machined from solid metal and were quickly replaced by stampings. It features smooth motion, low friction, high rigidity and long life. They are economical, and easy to maintain and replace.

4.2.5 SHAFT END SUPPORT Shaft supports are used to support linear rods /shafts rigidly without slip. Shaft support blocks are used for end or intermittent support where loads are light and slight shaft deflection is not a concern.



Fig.5., LINEAR RAIL ASSEMBLY(Linear Rods, Linear Bearings, End Shafts)

4.2.6 SHAFT COUPLINGS

A Shaft Coupling is a device used to connect two shafts together at their ends for the purpose of transmitting power. Couplings do not normally allow disconnection of shafts during operation, however there are torque limiting couplings which can slip or disconnect when some torque limit is exceeded. The primary purpose of couplings is to join two pieces of rotating equipment



N Fig.6., SHAFT

V. COUPLER.

POWER SUPPLY

48V 2.5A SMPS(Switch Mode Power Supply) adapters are used for stepper motors mounted in X and Z directions.24V 2.5A SMPS(Switch Mode Power Supply) adapter is used for stepper motor mounted in Y direction.12V 1A SMPS(Switch Mode Power Supply) adapter is used to drive the microcontroller board

MICROCONTROLLER BOARD

Atmega 328 p Arduino Development board is used as the motion control board. Atmega 328 p is a 16 bit 24 pin ARM Architecture microcontroller. The microcontroller is flashed with the GCODE interpreter firmware written in optimized 'C' language .Motion control is carried away through output pins connected to the stepper motor drives according to the firmware code in microcontroller. Inputs like RESET, FEED HOLD, CYCLE START/RESUME and axis Limits are given to the Inputs of microcontroller

STEPPER MOTOR

A **stepper motor** is a brushless, synchronous electric motor that converts digital pulses into mechanical shaft rotation in a number of equal steps.The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor (an open-loop controller).A NEMA 23 stepper motor is a stepper motor with a 2.3 x 2.3 inch size is chosen to drive the motion of the axes.NEMA 23 stepper motors are high torque about 19KG-Cm holding torque .NEMA 23 stepper motors have 1.8 degree step angle with 2.5A rated current

The speed of rotation is directly proportional to the pulse frequency. The higher the output voltage from the driver, the higher the level of torque drive.

STEPPER MOTOR DRIVER BOARD

The stepper motor driver receives step and direction signals from the microcontroller and converts them into rated high voltage electrical signals to run the step motor. RMCS-1102 is a micro-stepping drive designed for smooth and quiet operation. It is chosen to drive the NEMA 23 stepper motor. RMCS-1102 achieves micro-stepping using a synchronous PWM output drive. RMCS-1102 receives PULSE/STEP, DIRECTION inputs from the microcontroller and generates high-rated PWM output signals to the stepper motor.

LIMIT SWITCHES

A Limit Switch is the simplest type of end stop, a simple mechanical switch positioned to trigger when an axis reaches the end of its motion. Limit switches are used to protect the stepper motor and circuit by shutting the motors by triggering the switch when the axis reaches its end.

The signal pin from limit switches are connected to the microcontroller board to sense the axes ends.

FABRICATION WORK:

Fabrication work is carried away in various steps like Measuring and Marking, Gas cutting, Welding, Grinding, Drilling, Fitting of mechanical parts ready for assembly directly.

After gathering all metal parts and accessories required for assembling, the procedure of making the machine is listed below step by step.

- [1] Start from the base. Install four walls of Y axis.
- [2] Install main support for Z axis, Install Z axis chamber,
- [3] Assemble and fix Z axis leadscrew and slides, Install Z axis motor.
- [4] Build XY axis, start from table at the top, Install screw nut connector underneath the table.
- [5] Install and fix leadscrews.
- [6] Install cross roller guide of X axis, Install two motors and complete XY.
- [7] Complete machine limit switches.



A: Stepper Motor Mounted To Z-AXIS

B: X-Axis Lead Screw Assembly

C: Stepper Motor Mounted To X-Axis

D: Y-Axis Lead Screw Assembly

Fig 7., FABRICATED MODEL OF CNC ROUTER

VI. METHODOLOGY:

This system can be divided into three modules. As shown in figure 8, the mechanical system gets necessary control signals from the electronics system, which ultimately results in the desired actuation of motors. The electronics system gets a command or a set of commands from the software system and generates controls for the mechanical system.

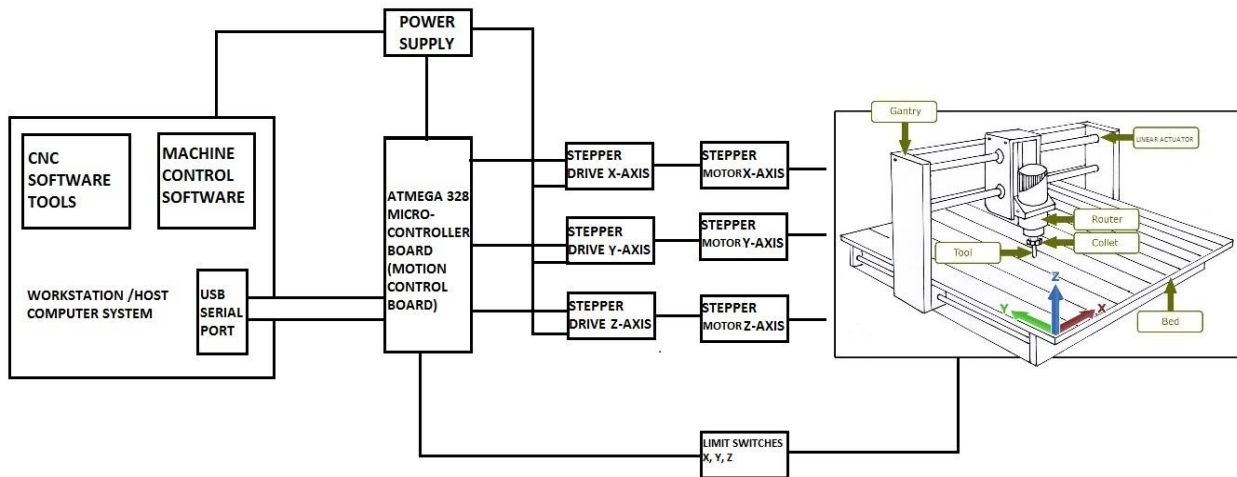


Fig 8., BLOCK DIAGRAM OF OVERALL PROCESS

The working methodology of system is well explained in the above fig 8., the detail explanation is given by dividing the system into three modules.

VII. MECHANICAL SYSTEM:

The mechanical system which is assembled in such a way that the 3-axis movement is achieved by using the linear rails assembled with linear bearings. Stepper motors are mounted to the each axis which is source of motion acted according to the control signal generated from the electronics circuit. Each stepper motor is coupled through the shaft couplers to each of the Lead/Ball screw of each axis which is responsible for converting the rotational motion of the stepper motor to linear motion. The linear motion of each axis is carried away smoothly by the linear rail assembly connected to the each axis which is capable of load carriers and allow linear motion in each axis. The controlled motion in each axis is achieved directly by by controlling the rotation of the stepper motor. The speed of the motion in each axis can also be controlled by direct control of the speed of the stepper motor by giving required control signals. Thus the tool path of the spindle fixed to the end effector is controlled in each axis for smooth carving or cutting action of work piece.

VIII. ELECTRONICS SYSTEM:

Electronics system is responsible for generating control signal to the stepper motors which guides the motion of tool path in each direction or axis. Electronics system is comprises of

- [1] Powersupply
- [2] Microcontroller board and
- [3] Stepper motor driver board

Power supply:

power supply is heart of the CNC system which converts the AC voltage to DC voltage and supplies required voltages to the corresponding devices. Microcontroller board recieves 12v supply where as the stepper motor board recieves 48v.

Microcontroller board:

Atmega 328p Arduino based microcontroller development board is chosen here to control the the motion of the the system. It acts as brain of the CNC system which recieves the commands from the software system from computer connected through the USB serial port. Arduino development board is flashed with the GCODE interperetor code which was written in the C language, which is responsible to generate the control signal for corresponding command signal from the computer system to the stepper motors which directly controls the motion of the tool path. The commands from computer or software system is received and convert them to the actual electronic signals to the Stepper Motor Driver Board.

Stepper Motor Driver Board:

RMCS-1102 is micro-stepping drive designed for smooth and quiet operation is chosen to drive the NEMA 23 stepper motor. Stepper motor Driver Board recieves the control signal form the micrcontroller board

to the terminals PULSE and DIR which generates the corresponding digital pulse signals for 4 Lead stepper motor to control the rotation of the motor.

Electronics Circuit Wiring:

The wiring of the various components of electronics system is represented in the Fig., shown below. The microcontroller board is connected to the computer system through the USB serial port. The Stepper Motor Driver board terminals PULSE and DIR of each Board is connected to the microcontroller terminals from 2 to 7 pins (2 terminals for each axis stepper motor driver) respectively. Terminals A+,A-,B+ and B- of Stepper Motor Driver Board are connected to the 4 lead stepper motor directly. Power supply is provided for all the components of electronics system.

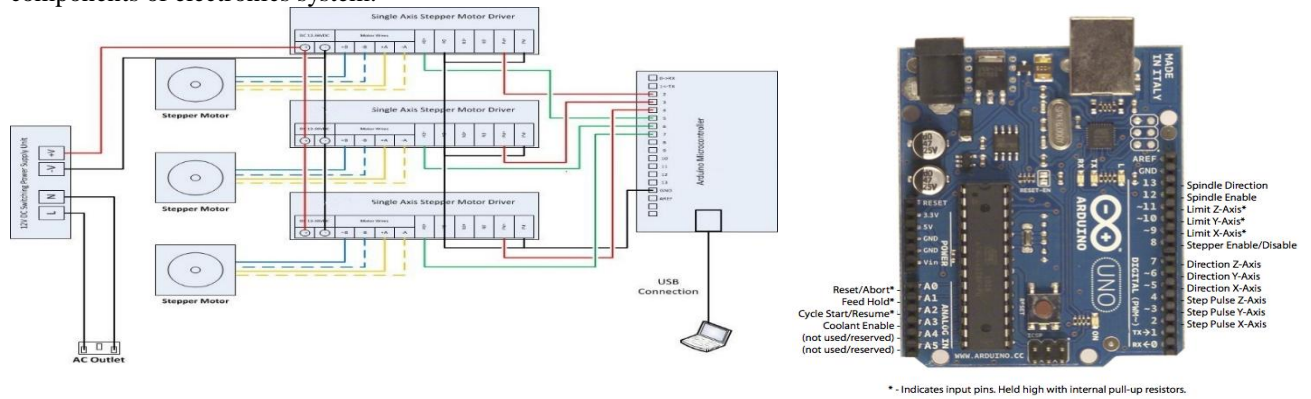


Fig 9., ELECTRONICS CIRCUIT WIRING Fig 10., MICROCONTROLLER PIN CONFIGURATION

To avoid the axis motors going out of safe operating range, six limit switches have been installed two for each axis. An emergency stop button manual operation has also been used for the machine.

SOFTWARE AND CODING SYSTEM:

The tool chain of CNC-based manufacturing is represented in the fig11. The part to be machined is designed in a computer-aided design (CAD) software, whose output is a drawing in one of many acceptable formats most preferable format is .stl format. This drawing is then fed to the computer-aided manufacturing (CAM) software, whose output is the machine

readable code used for numerical control of the machine. Since implementation of the G code is machine dependent, it is necessary to test out different choices for an open source G code interpreter for the Arduino, so that the correct motions are obtained for the machine axes through the stepper motor driver. We have used grbl, an open source G-code interpreter or milling controller for the Arduino development board.

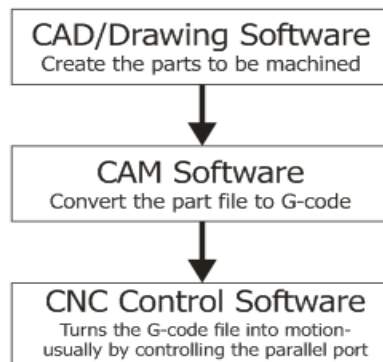


Fig 11., SOFTWARE TOOL CHAIN

CAD SOFTWARE: Computer-aided design (CAD) is the use of computer systems to assist in the creation, modification, analysis, or optimization of a design 3D parts for CNC cutting. CAD tools in the truest sense are designed to allow you to easily change and manipulate parts based on parameters. The most widely used interchangeable mesh file format is .STL files are important because, they are used by CAM tools to generate

Gcode.OpenSCAD, FreeCAD, HeeksCAD PTC Creo (formerly PTC Pro/Engineer), Dassault Solidworks, Autodesk Inventor, Auto CAD are some examples of CAD packages.

CAM SOFTWARE:Computer Aided Manufacturing, or CAM, tools handle the intermediate step of translating CAD files into a machine-friendly format used by the Microcontroller board. CAM software needs an .STL file format from CAD software to generate machine friendly GCODE. Some example packages are like CAD/CAM, G-Simple, FreeMill, Dolphin CAD/CAM, CamBam, Vizion (ArtCam), OneCNC, VirtualGibbs, MasterCAM , BOBCAD-CAM, MeshCAM, VisualMill, TurboCADCAM, DeskCNC, SheetCAM, OneCNC, SprutCam, EdgeCAM, ArtCAM etc.

CNC CONTROL SOFTWARE (GCODE Sender): Gcode Sender is used to send the G-code files to an integrated hardware interpreter(Atmega 328).Gcode Sender will take a G-code program in file and send it line-by-line to the Atmega 328 microcontroller. The Gcodes will send over the serial ports through USB communication between the computer and microcontroller.Grbl Controller is software that is designed to send GCode to CNC machines is , such as 3D milling machines. It isn't super smart, it just needs to give the user a nice way to get commands down to whatever controller they are using.

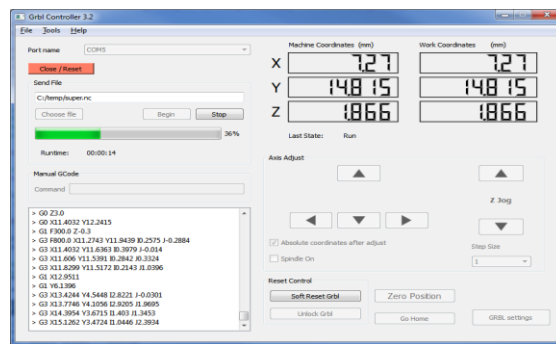


Fig 12., CNC CONTROL SOFTWARE WINDOW

GCODE FIRMWARE FOR MICROCONTROLLER:

Gcode firmware is the Brain of the machine which is responsible for tool path control.Gcode firmware is a program code written in optimized C language which interprets/compile the Gcodes.Gcode Firmware reads each line of the Gcode file received and generates the actual electronic signals to the motors and thus motion is controlled over the three axes.We have used grbl, an open source G-code interpreter or milling controller for the Arduino development board.Grbl is a no-compromise, high performance, low cost alternative to parallel-port-based motion control for CNC milling. It will run on a vanilla Arduino (Duemillanove/Uno) as long as it sports an Atmega 328. The controller is written in highly optimized C utilizing every clever feature of the AVR-chips to achieve precise timing and asynchronous operation. It is able to maintain up to 30kHz of stable, jitter free control pulses.It accepts standards-compliant G-code and has been tested with the output of several CAM tools with no problems. Arcs, circles and helical motion are fully supported, as well as, other basic functional g-code commands. Functions and variables are not currently supported, but may be included in future releases in a form of a pre-processor.

VALIDATION AND RESULTS:

The fabricated CNC Router is tested with different tests to determine its accuracy in different modes. The major tests are conducted i.e. surface flatness test, axes perpendicularity test and circular test. These tests can tell several geometric accuracies such as positioning, straightness, roll, pitch, yaw and perpendicularity by just machining a workpiece under certain tool path and feedrate. The dimension of created features on workpiece is then measured using CMM and the data are analyzed in MATLAB. The job is worked on different directions and analyzed using Cordinate Measuring Machine for surface flatness. The figures shows the surface of the cutting paths in different directions.



Fig 13 ., Surface Of cutting



Fig 14 ., Surface Of cutting



Fig15 ., Surface Of cutting

Path in X-Direction path in Z-Direction path in circular interpolation

Flatness test is measured by machining a flat surface on a workpiece. The flatness test gives the error in flat surfaces or whether there is tilting in the bed. Two different surfaces are created in two tool paths, one along X-axis and one along Y-axis, as shown in figures 16 and 17. Theoretically machining a surface in two directions won't affect the surface feature. Therefore, any differences among two surfaces can tell the existence of error in Z-axis.

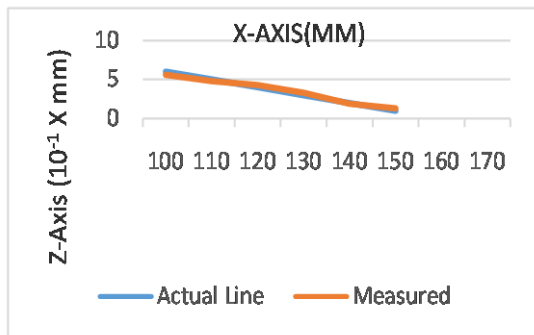


Fig 16 ., STRAIGHTNESS IN X-AXIS

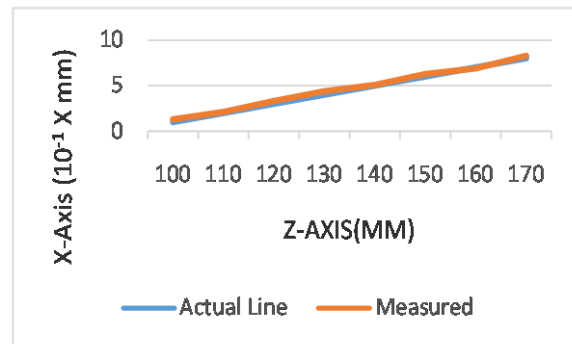


Fig17 ., STRAIGHTNESS IN Z-AXIS

The validation of test results shows that a little inaccuracy in alignment this is probably due to errors in assembling the machine. Due to the machine component inaccuracy and alignment issue during assembling, this prototype contains 0.28° tilting on X axis and -0.74° tilting on Y axis. Circular test also results that increasing feedrate will decrease machine accuracy and surface flatness. One of the jobs done on aluminum workpiece can be shown in figure 18. Finally the fabrication of the low cost 3-axis CNC machine considerably gives greater affordability in low budget with minimum accuracy errors. The greater cost optimization, easy interface, easy operable, high speed, less power consumption, easy programmable, increased flexibility for rapid prototyping is achieved.

CNC PROGRAM FOR JOB SHOWN IN FIG 18.

G21 G94	G01 X10 Y0	G01 Z-1 F80
M64	G01 X5 Y0	G01 X40 Y35
M65	G01 X15 Y0	G02 X35 Y40 R5
G91 G28 Z0	G00 Z5	G01 X-35 Y40
G91 G28 X0 Y0	G00 X20 Y25	G02 X-40 Y35 R5
G04 X1	G01 Z-1 F80	G01 X-40 Y-35
G21	G01 X30 Y25	G02 X-35 Y-40 R5
M62	G01 X25 Y25	G01 X35 Y-40
G21	G01 X25 Y0	G02 X40 Y-35 R5
G00 X-25 Y10	G00 Z5	G00 Z15
G01 Z-1 F80	G00 X-20 Y-30	G00 G28 X0 Y0
G01 X-25 Y5	G01 Z-1 F80	M05
G03 X-15 Y5 R5	G01 X-20 Y-5	G04 X5
G01 X-15 Y10	G01 X-15 Y-15	G21
G01 X-25 Y15	G01 X-10 Y-5	M63
G01 X-25 Y20	G01 X-10 Y-30	G04 X5
G02 X-15 Y20 R5	G00 Z5	
G01 X-15 Y15	G00 X5 Y-5	
G00 Z5	G01 Z-1 F80	
G00 X-10 Y25	G01 X0 Y-5	
G01 Z-1 F80	G03 X-5 Y-10 R5	
G01 X-10 Y0	G01 X-5 Y-25	
G00 Z5	G03 X0 Y-30 R5	
G00 X0 Y25	G01 X5 Y-30	
G01 Z-1 F80	G00 Z5	
G01 X-10 Y12.5	G00 X10 Y-5	
G01 X0 Y0	G01 Z-1 F80	
G00 Z5	G01 X20 Y-5	
G00 X5 Y25	G01 X15 Y-5	
G00 Z-1 F80	G01 X15 Y-30	
G01 X15 Y25	G00 Z5	
G01 X10 Y25	G00 X40 Y-35	



M65

Fig 18., WORKED JOB**IX. CONCLUSION:**

With the increasing demand for small scale high precision parts in various industries, the market for small scale machine tools has grown substantially. Using small machine tools to fabricate small scale parts can provide both flexibility and efficiency in manufacturing approaches and reduce capital cost, which is beneficial for small business owners. In this thesis, a small scale three axis CNC milling machine is designed and analyzed under very limited budget.

X. FUTURE WORK:

It is planned to scale up the prototype CNC machine in terms of size, use more powerful motors, strengthen the frame and worktable with materials like aluminum or cast iron, and augment the CNC control software with software for simulation ahead of actual run. For instructional purposes as well as for more precise operation, it is preferable to build CNC machines with DC or AC servomotors and encoder feedback using PC-based motion controllers. It is planned to implement the multi axis about 4 to 6 axis CNC router. The implementation of 3D printing (Rapidprototyping) technology to the same hardware abstract is ongoing plan for printing 3D models.

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