Experimental Study using a Low Cost and Versatile 3-Axis CNC Router with Bluetooth Connectivity

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ABSTRACT

The increase in the rapid growth of technology significantly increased the usage and utilization of CNC machines but are expensive. This paper discusses the design aspects and machinability study of Aluminium 5052 using a low cost CNC router cum engraver which is capable of 3-axis simultaneous interpolated operation with less complexity. The added Bluetooth feature makes the machine more user friendly to operate using a smartphone apart from the USB connection. 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. After the fabrication experimental trails were conducted to test the machining performance by varying the machining parameters. Taguchi L_9 orthogonal array design of experiment was adopted to carry out the experimental study. Grey Relational Analysis was used to optimise the machining parameters of spindle speed, feed rate and depth of cut with multi-performance characteristics of Surface roughness (Ra and Rz) and Material Removal Rate (MRR).

Key words - CNC Router, Milling, Grey Relational Analysis, Surface Roughness, Material Removal Rate.

1. INTRODUCTION

CNC is an acronym for Computer Numerical Control where the machining operations are automated with the help of a computer with ultra-precision and less human caused errors. The machine gets the input from a file created using computer-aided design (CAD) and computer-aided manufacturing (CAM) programs. This file is later interpreted to extract the commands needed to operate a particular machine via a post processor, and then loaded into the CNC machines for production. Even though concept of CNC based machines was developed in mid-20th century and has undergone many developments, the cost is an important factor that remains unchanged [1]. Due to the high cost of these machines many are not able to own one even though they need to do some useful machining operations. Low cost CNC machines are ideal for giving training to the students particularly in the field of Engineering because the cost and maintenance of the machine is low. As the use of smartphones are increasing day by day, interfacing the machine with smartphones using blue-tooth connectivity makes it more user friendly. The smaller size make it portable and the components can easily be disassembled or assembled. The size, space

and energy needed for the machine is also reduced. It now requires only less material and components to make the machine, hence bringing down the cost greatly. For a CNC Router an end mill attached to the spindle cuts the material. The machine spindle can be replaced with a laser engraver, plasma cutter, water jet cutter drag knife or hot wire for a variety of applications making it more versatile. Also the probing feature helps the machine to set the zero for z axis automatically with a touch plate.

2. LITERATURE REVIEW

CNC machines come with multiple axis, but generally for a router the minimum number of axis is three they are X, Y, and Z. Stepper motors or servo motors are used for precise motion and the power transmission is usually using Ball screws which are expensive. The working requirements of a router is larger which means requirement of longer ball screws. A good alternative for this is to use belt for power transmission for X and Y axes as they are cheap and requires less maintenance. A microcontroller reads the program file, interprets it and later sends it to the machine. ArduinoUNO is best suited to be used as a microcontroller since it is open

source, cheap and readily available in the market. A Shield is inserted to the ArduinoUNO to connect the stepper drivers, limit switches and Emergency stop. Limit switches restrict the machine movement beyond the safe limit and an emergency stop is used to stop the machine in case of emergency.

Shapeoko is a project aiming to enable people to easily *assemble or scratch build an easy-to-use desktop CNC* machine [2]. The Shapeoko is a CNC router designed by Edward Ford where the gantry holding the milling tool moves, while the worktable is stationary. The machine uses NEMA 17 stepper motors for precise motion and ArduinoUNO as a microcontroller on its arrival. Belt drive is used for power transmission for the X and Y axes whereas leadscrew is used for Z axis. Dremel is used as a spindle for the machine.

Even though the machine has many advantages it is available outside India and importing it is the only way of owning one. Some of the electronics used are not easily accessible. The NEMA 17 motors does not offer sufficient torque in some situations and the plate thickness for the motor mounts is around 3mm which is very thin. The machine does not offer any Bluetooth connectivity feature.

3. OBJECTIVE OF PAPER

Due to the drawbacks found on Shapeoko we aim to design and fabricate a low cost CNC router that can overcome the limitations of shapeoko. This is achieved by using higher torque stepper motors and easily accessible and low cost electronics. Nema 23 stepper motors offer greater amount of torque compared to Nema 17 and the use of thicker plates makes the machine more rigid. ArduinoUNO is an open source hardware which is used as a microcontroller to interpret the program file and the shield used is an easily available one. An advantage of open source hardware is that it is cheap and 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 are also available [3].The use of spindle with greater power than dremel can easily cut the materials with lesser time and using CAD/CAM programs which are familiar to the engineering students make the manufacturing process easier and also improves their designing and manufacturing skills. The Bluetooth connectivity feature really improves the user experience by interfacing the machine with a smartphone, the machine can be controlled with the

touch of our fingertips. Due to the compact design it is portable and easy to assemble/disassemble and the increased flexibility makes it suitable for a variety of applications. In this paper, the development of a Bluetooth enabled 3-axis CNC Router using Arduino-based control system is presented with following objectives:

- Lower cost
- Easy to operate
- Simple interface
- Greater Flexibility
- Low power consumption
- Bluetooth connectivity

4. FABRICATION

4.1 Structural Design – CAD Model

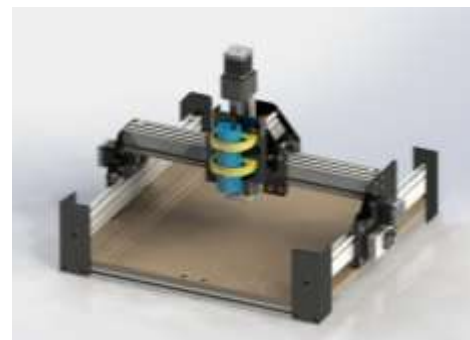The 3D solid model of the machine to be fabricated is given in Fig.1.

Fig. 1 3D Solid Model

4.2 Description of Components

4.2.1 Aluminium Extrusions

Clear anodised T slot aluminium extrusions are used for the framework of the machine as given in Fig.2. T slot nuts are inserted to the slot for tightening parts at suitable location. The ends are tapped to form the thread suitable for fasteners. 20*20 mm cross section extrusions are used for our application.

Fig. 2 Aluminium Extrusion

4.2.2 Aluminium Angles

Aluminium angles of 20mm height and width are used shown in Fig.3. They are bolted at the top and bottom of the extrusion for extra rigidity and it also serves as rail for the grooved bearings to roll over it.

Fig. 3 Aluminium angles

4.2.3 Aluminium Plates

Aluminium alloy 6061 plates of thickness 6mm are used for mounting for X and Y axis stepper motors. The image of the plates are shown in Fig.4

Fig. 4 Aluminium Plates

4.2.4 Bearings

Idler bearings shown in Fig.5 are used to tension the belts and to guide them towards the end of X and Y axis. Grooved bearings shown in Fig.6 are fixed to the X and Y axis plates and allows the motion of the machine along the 3 axis. The weight of the X and Y axis are supported by the grooved bearings.

Fig. 5 Idler Bearing

4.2.5 Leadscrew and Delrin

Lead screw of 10 mm diameter and 1.5 mm pitch is used for the Z axis power transmission. The nut for lead screw is made of delrin which has self-lubricating property which means less maintenance. The Z axis moves up and down by this mechanism of lead screw and nut shown in Fig. 7.

Fig. 6 Grooved Bearing

Fig. 7 Leadscrew and Delrin Nut

4.2.6 MDF

MDF (Medium-density fibre board) is used as the base of the machine for holding the job. Sufficient holes are provided to fix the job using nuts and bolts.

4.2.7 Pulley

Aluminium pulley of 20 teeth is fixed to the stepper motor shaft to transmit the power from the stepper motors to the belts

4.2.8 Belt

Belt used is GT2 of 2mm pitch. Belt is used for X and Y axis which is passed over the idler bearings to help the machine to the required location along X and Y directions.

4.2.9 Corner Brackets

They are fixed to the Z axis plate to support the hose clips which holds the spindle.

4.2.10 Linear Slides

They are used to keep the alignment of the Z axis correct during the up and down motion.

4.2.11 Power Supply

Power supply provides sufficient power for the electronics. Switch Mode Power Supply (SMPS) with 12V 25A is used for the electronics while 230V AC is used for the spindle power.

4.2.12 Microcontroller Board

ArduinoUNO is used as the motion control board. It uses Atmega 328 p chip. It is an open source microcontroller that is used for a variety of applications. The microcontroller is flashed with the GCODE interpreter firmware called GRBL which is later configured to the machine requirements in the software Universal Gcode Sender.

4.2.13 Stepper Motor

A stepper motor or stepping motor is a brushless DC electric motor that divides a full rotation into 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. NEMA 23 stepper motor with 10KG-Cm holding torque is used for driving the belts and leadscrew. Arduino provides the pulses for the stepper motor which is amplified by the stepper drivers.

4.2.14 CNC Shield

A CNC shield is inserted to the Arduino microcontroller to make the wiring for limit switches, Emergency. Stop and connection of stepper drivers easy. It has compact size and it is compatible with the G-Code interpreter firmware called GRBL. It supports maximum of four stepper drivers to run four stepper motors. It can support a maximum of 36 volts and setting the micro stepping is easy with a shield.

4.2.15 Stepper Motor Driver Board

The stepper motor driver receives the step and direction signals from the microcontroller and converts them into rated high voltage electrical signals to run the stepper motor. The stepper drivers used are DRV8825 from Pololu. It features adjustable current limiting, over-current and over-temperature protection, and six micro step resolutions from full to 1/32 step. It operates from 8.2 V to 45 V and can deliver up to approximately 2.5 A per phase with a heat sink attached. The drivers are cooled using a dc fan as it can get hot during operation.

4.2.16 Limit Switch and Emergency Stop

Limit switch is a type of end stop mechanical switch positioned to trigger if the machine exceeds the safe limit and an emergency stop is used to stop the whole process in an emergency situation.

4.2.17 Bluetooth Module

HC-05 module is an easy to use Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup. This is configured using the Arduino IDE software and connected to the CNC shield using resistors to meet the voltage requirements.

4.2.18 Spindle

A spindle holds the end mill to cut the material to our requirements. A 350 W, 220 volts air cooled spindle is used that has maximum of 30,000 rotations per minute. A speed controller is used to vary the rpm of the spindle to our requirements.

5. STEPS IN FABRICATION

Fabrication work is carried away in various steps like Measuring, Marking, Cutting, Grinding, and Drilling. The aluminium plates are cut to the required dimensions for the x and y axis and sufficient holes for mounting stepper motor, bearings and limit switches were drilled. Idler bearings serves to guide the belt through the pulley in tension to the ends of each axis and grooved bearings roll over the rail. After gathering all metal parts and accessories required for assembling, the procedure of making the machine is listed below step by step.

1. The 20*20 mm aluminium extrusions were cut to the required length and tapped at the ends using 5mm tap for the fastners. The aluminium angles are bolted to the top and bottom of the extrusion. This forms a single rail.

2. For the Y axis two rails are kept at a distance of 750mm having a length of 1000mm.

3. For the X axis two rails are bolted to each other and forms a bridge between the y axis rails.

4. The Z axis is assembled next with stepper motor on top, leadscrew coupled to the motor shaft, delrin nut passed over through it and an end bearing keeps it aligned straight. The spindle mount plate is fixed to the delrin nut. The linear slides are fixed at the ends for

smooth up and down motion. Limit switch is fixed at the top and Grooved bearings are fixed at the back of the plate.

5. Next step is to mount the X axis stepper motor with pulley attached and idler bearings to one of the X axis plate (back plate) and the other X axis plate to the Z axis assembly. The two X axis plates are later joined together with a distance equal to the width of the X axis rail. The top grooved bearings are fixed to two x axis plates and is laid over the X axis rail and tightened using the bottom grooved bearings. So a total of 4 grooved bearings on one plate of X axis and remaining 4 on the other plate of the X axis makes the machine free to move right and left. The Limit switches are fixed at the bottom ends of one of the X axis plate.

6. The next step is to fix two plates at the ends of the X axis rail extrusions to form the Y axis plates. The two stepper motors with pulley and idler bearings are fixed to the two Y plates and similar to X axis assembly bearings are installed. The distance between two Y axis plate is 750 mm which is the width of the machine. The whole assembly including the Z axis, X and Y axis plates forms the gantry of the machine which is a single unit after assembly. Note that the two stepper motors of Y axis works in unison to move back and forth.

7. Next step is to lay the gantry over the Y axis rails such that the top grooved bearings lay exactly over it and move the machine back and forth for alignment. If so the bottom grooved bearings are installed at the bottom of the Y axis plates for tightening.

8. Next step is to move all the axis of the machine for checking the alignment. If it is free to move belts are installed for X and Y axis.

9. All the electronics are enclosed in a box and is fitted to one of the X axis plate. Emergency stop is also fixed to the same.

6. METHODOLOGY

The machine works with the help of the mechanical system, electronics system and the program file creation is using CAD/CAM software. First step is to create a program file using a CAD/CAM software. There is also another option of manually writing the program file. The Bluetooth module is connected to the microcontroller to interface with smartphone and the USB connection can be used to connect with PC or laptop. The shield is inserted on top of the arduino and above it stepper drivers are mounted which amplifies the signal from the microcontroller and gives it to the stepper motors for each axis. The connections for the touch plate and limit switches for each axis goes to the arduino. The flow chart given in Fig.8 explains the whole process.

7. MECHANICAL SYSTEM

Machine structure is the "backbone" of the machine tool since it integrates all machine components into a complete system. The movement for the X and Y axis can be made by either the table of the machine holding the job moving or by making the tool for cutting move with the table fixed called gantry type. The gantry type consumes less material, hence is very less expensive to build. The belt driven motion for the X and Y axis makes the machine move faster and lubrication free. Moreover the machine can be moved by pushing along X and Y axis which cannot be done for ballscrews. Backlash is a common phenomenon that happens for a leadscrew driven mechanism. For the Z axis the backlash is reduced by loading the delrin nut with springs that presses it towards the leadscrew. The aluminium extrusions and angles used are anodised to resist corrosion.

Fig. 8 Flow chart

8. ELECTRONICS SYSTEM

Electronics system is the brain of the machine to interpret the data from the program file and converting it to the required number of pulses to drive the motor. The power to the electronics come from the SMPS and the ArduinoUNO microcontroller interprets the data from a USB or Bluetooth, Stepper drivers amplifies the pulses to run the stepper motor. The data is interpreted by the arduino with the help of a firmware called GRBL flashed into the arduino and later configured. Shield is inserted to the arduino and stepper drivers are inserted to the shield.

8.1 GRBL

It is a G-Code interpreter written for the arduino platform in C programming language. GRBL is intelligent to manage 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 [4]. The Baud rate for the serial port for 0.9j version is 115200. The G-code and has been tested with the output of several CAM tools without any problems. Arcs, circles and helical motion, as well as other basic functional g-code commands are also supported. The firmware is configured using software UniversalGcodeSender in which we set the travel for each axis, velocity, acceleration required, Steps per mm and setting the hard and soft limits.

8.2 Arduino, CNC Shield & Driver Assembly

The connection of ArduinoUNO, CNC shield and stepper drivers are shown in Fig.9. ArduinoUNO is at the bottom and the CNC shield is inserted above it and finally the stepper drivers are inserted into the shield at the top. The stepper motors, limit switches, emergency stop etc. are inserted to the shield on the pins provided. A microstepping of 1/8 is set by shortening M0 and M1 pins on the shield .It is done to reduce the vibration of stepper motors.
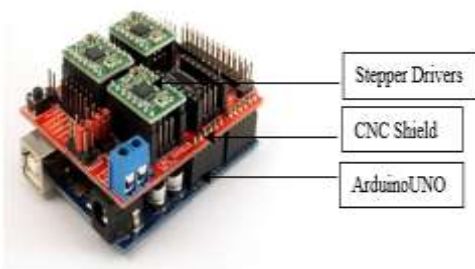

Fig. 9 Electronics Assembly

8.3 Touchplate

A touch plate is used for the probing operation which is a feature to automatically set the zero for the Z axis. An alligator clip is attached to the tool bit which is connected to the Arduino pin A5 and the wire from the touchplate is connected to Arduino ground. Once the probing cycle is loaded the machine moves down until the bit touches the touchplate and retracts back knowing the surface of the job.

8.4 Bluetooth

For incorporating the Bluetooth connectivity feature HC-05 Bluetooth module is used. The required sketch for configuring the Bluetooth is imported into the arduino IDE and the Bluetooth module is configured using the ArduinoUNO microcontroller. The baud rate should be changed to 115200 which will be 9600 by default. RX, TX, GND and VCC pins of the bluetooth module should be connected to TX, RX, GND and VCC pins of the shield respectively with 1k or 2k resistors as shown in Fig.10. After it is connected to the shield it can be paired with the smartphone using android applications which will be discussed later.
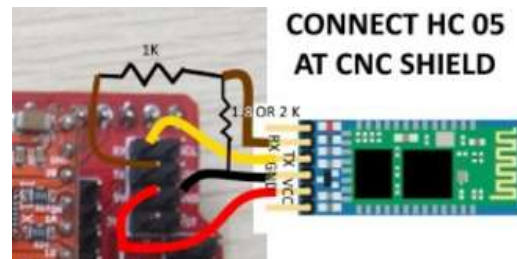

Fig. 10 Connecting Bluetooth to shield

9. SOFTWARES

9.1 CAD Software

A CAD (Computer-aided Design) software is used to design the part to be machined. PTC Creo, Dassault Solidworks, Autodesk Inventor, Auto CAD, E-Machine shop are some examples of CAD packages. The designed part should be saved to a format that is acceptable to the CAM software.

9.2 CAM Software

A CAM (Computer Aided Manufacturing) software handle the intermediate step of translating CAD files into a machine-friendly format used by the microcontroller board that is the G-Code file. Some of

the commonly used CAM software are Vectric Aspire, V Carve Pro, Estlcam, Artcam, Meshcam, Mastercam etc.

9.3 CNC Control Software (GCode- Sender)

Universal Gcode Sender is used to send the G-code files to the Arduino. Gcode Sender will take a G-code program in file and send it line by-line to the Arduino. This software is used when the machine is connected through a Usb cable. The advantage of this software is that it is open source one and it is very simple to use.

9.4 Bluetooth Applications

Android applications are used to control the machine with a smartphone using the Bluetooth. Two android applications used are listed below.

9.4.1 PANMANEECNC

This application is used for moving the machine along each axis and supports the probing feature. Due to the bug in the application there are issues for file transfer using this application. Emergency stop, Pause, Spindle ON/OFF, Feed override are some of the features of this application.

9.4.2 CNC Bluetooth Commander

This application is used for sending the G-Code file to the machine using Bluetooth without any issues. Pause, emergency stop and reset are there in this application.

10. EXPERIMENT

To test the machine performance an experiment was conducted. The aim is to machine 9 slots by varying the feed rates, depth of cut and spindle speed and to measure the surface roughness and calculate material removal rates. The optimum machining parameters were found out using Grey relational analysis. Machining operations were done on aluminium alloy 5052 of 4mm thickness. The tool used was HSS $1/4^{th}$ inch diameter parallel shank end mill from Addison. Kerosene oil was used as coolant/lubricant. The feed rates were in the range 100 - 300 mm/min, depth of cut 0.1 - 0.3 mm, spindle speed 20,000 - 30,000 rpm. The plunge rate was 150 mm/min for the whole process. The instrument used for measuring surface roughness is Mahr federal pocket surf. Taguchi L9 orthogonal array design of experiment was adopted to carry out the experimental study with the machining parameters spindle speed, feed and depth of cut. In recent years, the Taguchi method has become a powerful tool for improving productivity during research and development so that high quality products can be produced quickly and at low cost [5].

10.1 Procedure

- o The design for the slots of 21mm length and 6.35mm breadth were created and the program file for machining was created in Aspire software.

- o The job was fixed on the machine and the machine was connected to the smartphone via Bluetooth.

- o The Zero position was set and the Program file was imported to CNC Bluetooth commander application.

- o The program was sent wirelessly and time to machine each slots were noted.

- o After the machining operations the machine was switched off and the job was taken.

10.2 Grey Relational Analysis

Grey relational analysis is an optimisation method to find out the optimum machining parameters. In the case when experiments are ambiguous or when the experimental method cannot be carried out exactly, grey analysis helps to compensate for the shortcomings in statistical regression [6]. It converts multi-objective optimisation to single objective optimisation. The grey theory makes use of relatively small data sets and does not demand strict compliance to certain statistical laws, such as simple or linear relationships among the observables [7].

10.3 Steps

10.3.1 Normalisation

In grey relational analysis, the data pre-processing is the first step performed to normalize the random grey data with different measurement units to transform them to dimensionless parameters [8, 9]. There are two equations for normalisation. One for defect type factors Equation (1) (lower the better) and the other for benefit type factors Equation (2) (higher the better). Data pre-processing is a means of transferring the original sequence to a comparable sequence [10].

$$x *_i (k) = \frac{x_{i\,max}(k) - x_i(k)}{x_{i\,max}(k) - x_{i\,min}(k)} \quad \cdots\cdots (1)$$

$x *_i (k) = \frac{x_i(k) - x_{i\,min}(k)}{x_{i\,max}(k) - x_{i\,min}(k)}$ ...... (2)

Where $x_i(k)$ and $x *_i (k)$ are the observed data and normalised data respectively, for i^{th} experiment using k^{th} response and $x_{i\,max}(k)$ and $x_{i\,min}(k)$ are the largest and smallest values of $x_i(k)$ in the kth response. Here the equation (1) is used for surface roughness as lower value of surface roughness indicates better finish and Equation (2) is used for MRR as the higher value of MRR indicates better performance.

10.3.2 Determination of Grey Relation Coefficient

The next step is to determine the grey relation coefficient $\zeta_i(k)$ from Equation (3)

$\zeta_i(k) = \frac{\Delta min + \varsigma \Delta max}{\Delta i(k) + \varsigma \Delta max}$ ...... (3)

$X_0(k)$ denotes reference sequence

$X_j(k)$ denotes the comparability sequence

$\varsigma \,\epsilon\, [0,1]$ is the distinguishing factor, 0.5 is widely accepted

$\Delta i = |x_0(k) - x_j(k)| =$ difference in absolute value between $x_0(k)$ and $x_j(k)$

$\Delta min = \min(\forall j \in i) \min(\forall k) \; |x_0(k) - x_j(k)| =$ smallest value of Δi

$\Delta max = \max(\forall j \in i) \max(\forall k) \; |x_0(k) - x_j(k)| =$ largest value of Δi

10.3.3 CALCULATION OF GREY RELATION GRADE

The grey relation grade is calculated as

$\gamma_i = \frac{1}{m} \sum_{k=1}^{n} w * \zeta i(k)$ ...... (4)

Table 1 Experimental Observations and Normalisation

Sl. No	INPUT PARAMETERS			OUTPUT RESPONSES			DATA PRE-PROCESSING		
	Spindle Speed (rpm)	Feed Rate (mm)	Depth of Cut (mm)	MRR (mm^3/min)	Surface Roughness (Ra) (µm)	Surface Roughness (Rz) (µm)	MRR (mm^3/min)	Surface Roughness (Ra) (µm)	Surface Roughness (Rz) (µm)
1	20000	100	0.3	126.32	1.915	8.9	0.26154467	0.24180327	0.41666666
2	20000	200	0.2	165.04	2.21	11.9	0.38178938	0	0
3	20000	300	0.1	121.35	1.59	8.2	0.24611036	0.50819672	0.51388888
4	25000	100	0.2	84.2	1.05	5.6	0.13074128	0.95081967	0.875
5	25000	200	0.1	82.52	1.58	9.05	0.12552405	0.51639344	0.39583333
6	25000	300	0.3	364.11	1.815	10.15	1	0.32377049	0.24305555
7	**30000**	**100**	**0.1**	**42.1**	**0.99**	**4.7**	0	1	1
8	30000	200	0.3	247.6	1.78	8.85	0.63817893	0.35245901	0.42361111
9	30000	300	0.2	242.7	1.505	7.5	0.62296202	0.57786885	0.61111111

Here n is the number of responses, γ_i is the grey relational grade, m is the number of run and w is the weight factor. For this experiment all responses have equal weightage. Based on the grey relational grade calculated rank is given. Highest value of GRG is ranked 1 and the lowest value of GRG is ranked 9. Optimum value of process parameters is obtained in rank 1. In other words, regardless of category of the performance characteristics, a greater grey relational grade value corresponds to better performance [11].

Table 3 Response Table

Parameter	Level 1	Level 2	Level 3	Delta	Rank
Spindle Speed	0.420	0.580	0.609	0.189	2
Feed	0.630	0.435	0.545	0.195	1
Depth	0.563	0.540	0.507	0.056	3
Mean of GRGs = 0.537					

Table 2 Weighted grey relational grade and rank

GREY RELATIONAL COEFFICIENT			WEIGHTED GREY RELATIONAL GRADE	RANK
MRR (mm^3/min)	Surface Roughness (Ra) (μm)	Surface Roughness (Rz) (μm)		
0.404	0.397	0.462	0.421	8
0.447	0.333	0.333	0.371	9
0.399	0.504	0.507	0.470	6
0.365	0.910	0.800	0.692	2
0.364	0.508	0.453	0.442	7
1.000	0.425	0.398	0.608	3
0.333	1.000	1.000	**0.778**	**1**
0.580	0.436	0.465	0.493	5
0.570	0.542	0.563	0.558	4

10.4 Results and Discussion

In this study GRA is used to optimise the multiple performance characteristics such as MRR and surface roughness. Rank 1 is obtained corresponding to GRG value 0.778. Table 3 summarises the mean of GRG for each level of the machining parameters and the total mean. Feed is having the most significant effect from the observations. Fig.11 is the worked job.

From Fig.12 we obtain the maximum MRR corresponding to spindle speed 30,000 rpm, feed rate 300mm/min and depth of cut of 0.3mm.

From Fig.13 we obtain the minimum Ra corresponding to spindle speed 30,000 rpm, feed rate 100mm/min and depth of cut of 0.1mm.

From Fig.14 we obtain the minimum Rz corresponding to spindle speed 30,000 rpm, feed rate 100mm/min and depth of cut of 0.1mm.

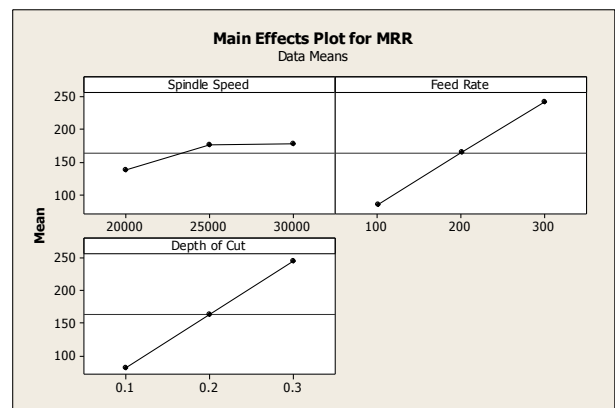*Fig. 11 Worked Job*

10.4.1 Main Effect Plots
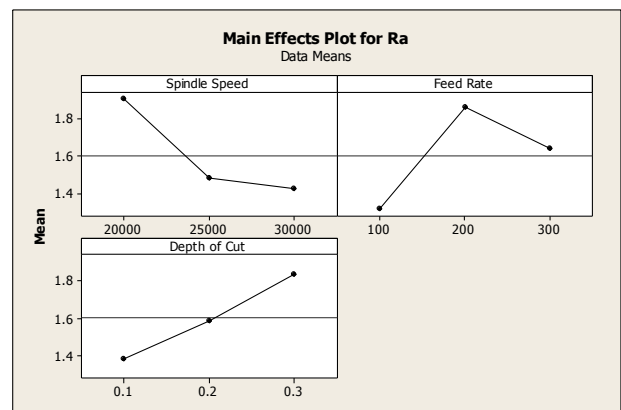

Fig. 12 Main effect plot for MRR

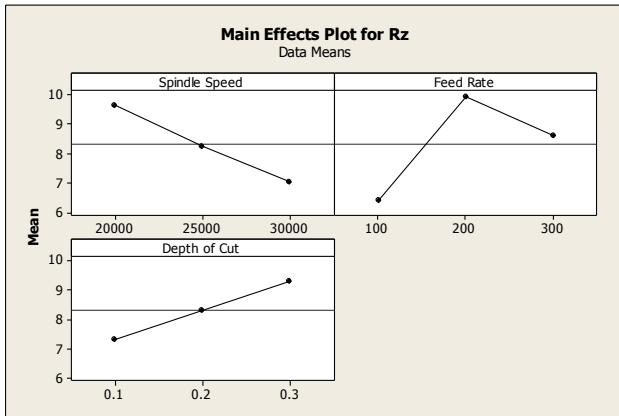*Fig. 13 Main effect plot for Ra*

Fig. 14 Main effect plot for Rz

11. CONCLUSION

The machine was fabricated successfully and during testing it worked well with the Bluetooth as well as with the USB connection. Most of the commonly available CAD/CAM softwares were supported and the machine proved to do 2-D as well as 3-D operations on the job. The Fabrication of this CNC Router with Bluetooth connectivity was cheaper than many commercially available CNC routers that lacks Bluetooth connectivity.

For the experiment L_9 orthogonal array design of experiments was adopted to study the influence of machining parameters on material removal rate and surface roughness in slot machining of 5052 aluminium alloy. The machining parameters were optimised using Grey relational analysis and the optimum feed rate was 100 mm/min at 0.1 mm depth of cut at spindle speed 30000 rpm. A confirmatory test was conducted to validate the calculated results.

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