

Simulation and hardware implementation of low cost CNC mill prototype

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Abstract

Fabrication laboratories (fab labs) are small scale workshops offering digital manufacturing technology and electronics tools. But setting up a fab lab in an educational institution is expensive. In order to develop a less expensive fab lab in every educational institution, to convert a student project into a best product, low cost equipments are required. Computer Numerical Controlled (CNC) mill is one of the important machines in a fab lab. Milling itself is a machining process similar to both drilling and cutting, and able to achieve many of the operations performed by cutting and drilling machines. It is mandatorily to teach the technology in Polytechnic and engineering colleges. But the problem is to afford the same machines for education. This low cost CNC milling machine prototype will be a good alternative for expensive machines. Because of Open Source tools, this CNC mill can be developed at 5% of the cost of basic commercial product in the market. And also, each student can have their working experience with CNC machines individually. By this paper, a low-cost, three axis vertical CNC mill prototype is to develop using off-the-shelf components, stepper motors with drivers, Arduino open source microcontroller, and open source motor control software. The machine can be easily customized for modification and replication and provides students better access and insight into the operation and use of CNC mills. The suitability of proposed system can be demonstrated through simulation results using MATLAB/Simulink.

Keywords: CNC

1. Introduction

Fabrication laboratories (fab labs) are small scale workshops offering digital manufacturing technology and electronics tools. Fab labs continue a tradition of places for Do-It-Yourself (DIY) with technology for tinkering and inventing. But setting up a fab lab in an educational institution is expensive. In order to develop a less expensive fab lab in every educational institutions, to convert a student project into a best product ,low cost equipments are required.

Computer Numerical Controlled (CNC) mill is one of the important machines in a fab lab. As an initiative we are developing a low cost CNC mill prototype for educational purpose. Milling is a machining process similar to both drilling and cutting, and able to achieve many of the operations performed by cutting and drilling machines. Like drilling, milling uses a rotating cylindrical cutting tool. However, the cutter in a milling machine is able to move along multiple axes, and can create a variety of shapes, slots and holes. In addition, the work-piece is often moved across the milling tool in different directions.

CNC milling devices are the most widely used type of CNC machine. Typically, they are grouped by the number of axes on which they operate, which are labelled with various letters. X and Y designate horizontal movement of the work-piece (forward-and-back and

side-to-side on a flat plane). Z represents vertical, or up-and-down, movement. Most machines offer from 3 to 5 axes, providing performance along at least the X, Y and Z axes. CNC milling centres are ideal solutions to everything ranging from prototyping and short-run production of complex parts to the fabrication of unique precision components.

By converting instructions into actions the CNC machines control operating tools. The movement is triggered by entering alphanumerical codes into a CNC machine. Tools attached to the machine include laser cutters, routers and cutting tips. By upgrading with advances in computer technology the CNC principle has been used in machines since the 1940s.

When it comes to powering a CNC machine, the heart and soul of the machine relies in the motor. The CNC routers speed, accuracy, and precision all rely on the size and type of the motor. The two primary motor classes that are used with CNC machines are stepper motors and servo motors, each possessing its own advantages and disadvantages. Both types of motor have several variances from size to power. The stepper motors are preferred based on cost, versatility, life span & motor design.

2. Simulink model and results

2.1. Simulink model of stepper motor

The MATLAB/simulink is used for the simulation of the stepper motor driver for analyzing the performance of it in CNC mill prototype. Block diagram of stepper motor simulation model, made up of basic block: controller, driver and stepper motor is shown in Figure 1.

Simulink model is presented in the Figure.2. It consists of two parts: electrical and mechanical parts. The electrical part is represented by equivalent circuit and mechanical part is represented by state space model. The voltage per phase V_{ph} (v) and mechanical load torque T (Nm) are the input parameters to the simulink model. The current per phase I_{ph} (A), electromagnetic torque T_e (Nm), motor speed W (rad/s) and rotor position θ (degree) are the output parameters to the simulink model.[5].

Two H-bridge MOSFET PWM converters connected to a 24V DC voltage source are used to feed the motor phases. By comparing the measured currents with their references, two hysteresis based controllers generate the MOSFET drive signals which independently control the motor phase currents.

STEP and DIRECTION control signals are generated using signal builder block. Those signals are used to control the movement of motor. Value of 1 and 0 of STEP signal enables the rotation of motor and stops the rotation of motor respectively. Value of '1' of DIRECTION signal enables the rotation of motor in one direction and '0' reverses the rotation of motor respectively [5].

H bridge consists of four MOSFET transistors are used to made the converter bridge 'A' and 'B'. The output of bridge supply the motor windings with required excitation current and motor movement is enabled. The 24v is used to supply the bridges.

2.2 Simulation results

The simulation execution time is defined to be 60 s according to the signals from signal builder. At no-load condition stepper motor is run for the first simulation [5]. Simulation results at no load is presented in the Figure 5. From simulation results we can conclude that for 0.1s motor is rotating in one direction, stops in a period from 0.1 s to 0.15 s. For 0.05 s motor rotating in opposite direction and again it stops for 0.1s.

From Figure 5 it is concluded that motor has a speed of 200 rad/s and motor moved from 0 to 38 degrees. Before it starts from 0.155 s to move in opposite direction it remains in that position for 0.05 s. It stops for a time of 0.205 s on position 18 degree. Simulation results at 0.1 Nm is presented in the Figure 6. Simulation results at 0.4 Nm is presented in the Figure 7.

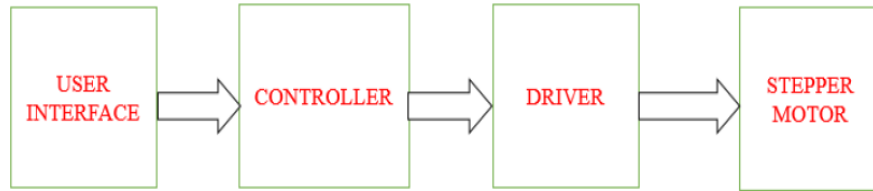


Figure 1. Block diagram of stepper motor simulation model

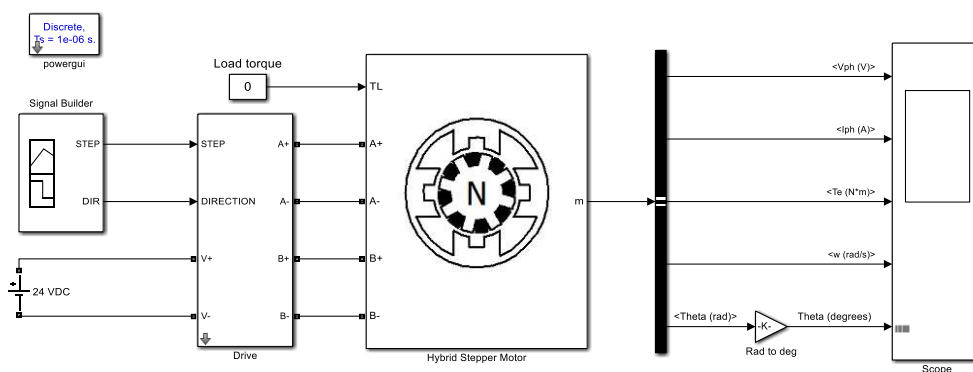


Figure 2. Simulink model of stepper motor

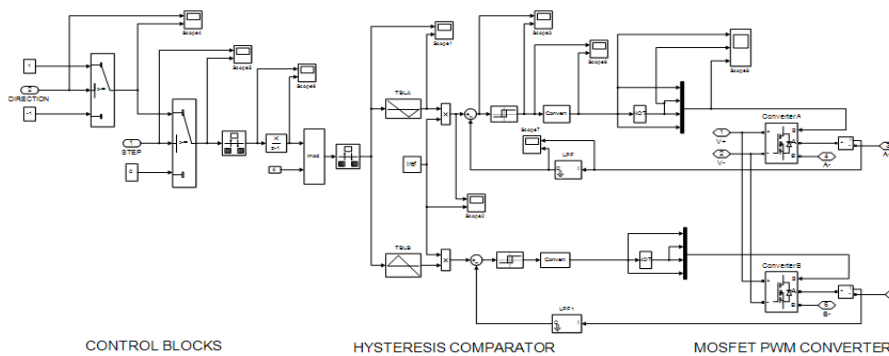


Figure 3. Simulink model of control unit

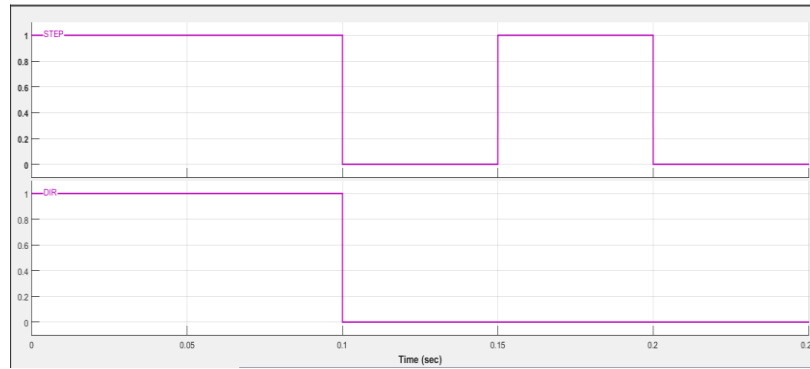


Figure 4. Output signal from signal builder

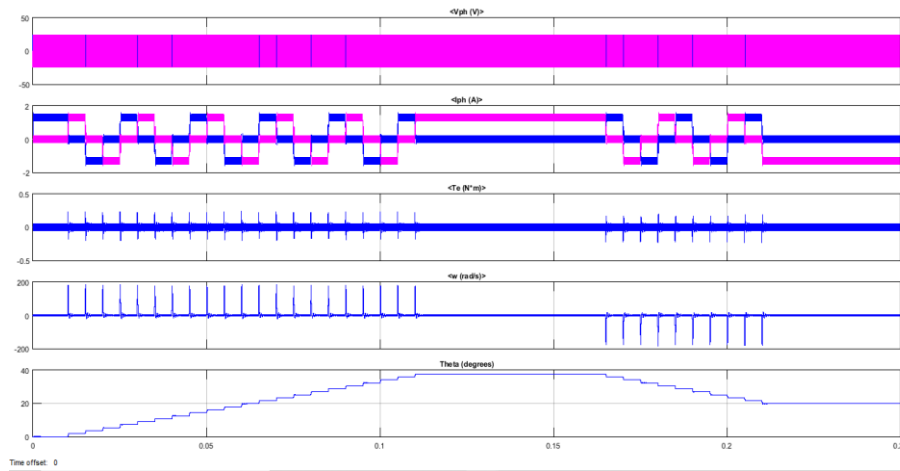


Figure 5. Stepper motor transient performance characteristics at no load

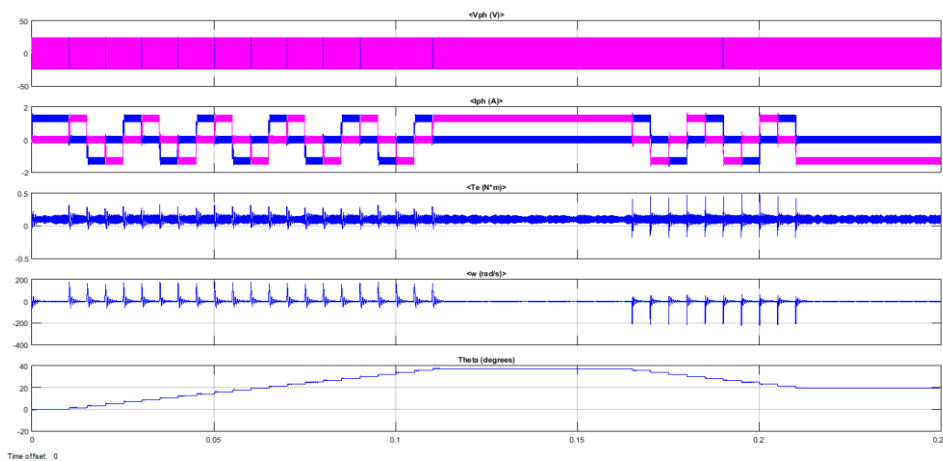


Figure 6. Stepper motor transient performance characteristics for load 0.1 Nm

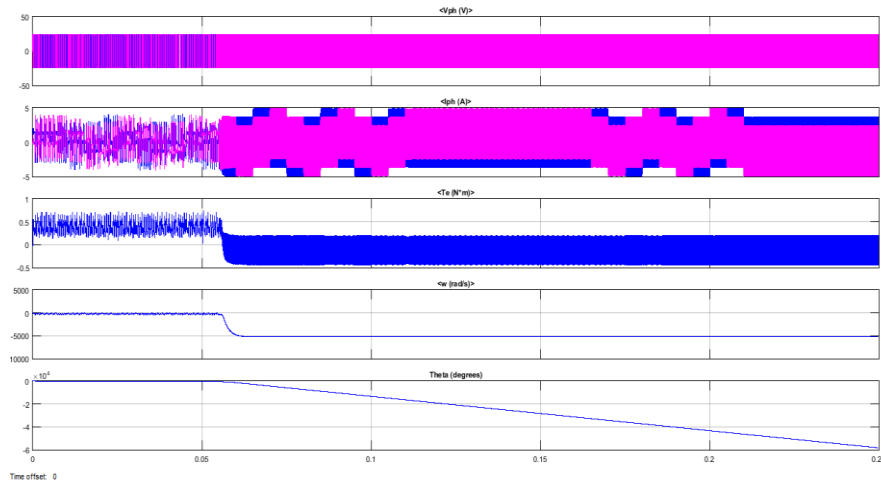


Figure 7. Stepper motor transient performance characteristics for load 0.4 Nm

3. CNC mill prototype

The CNC Mill prototype consists of mechanical structure, electronic structure and an Arduino based control structure. The detailed block diagram of CNC mill prototype is shown in the Figure 8.

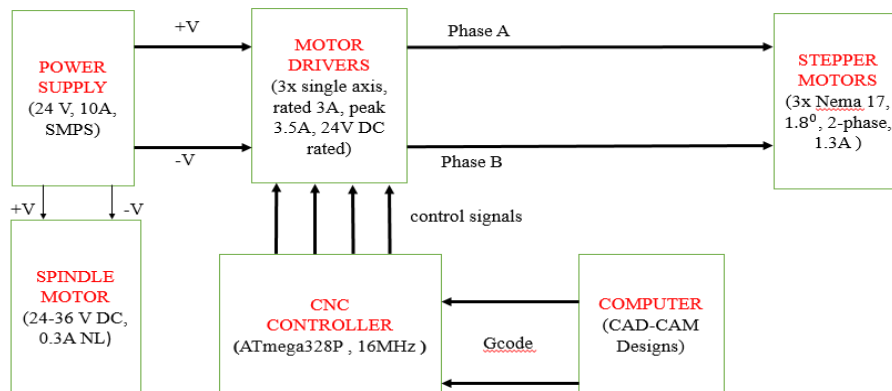


Figure 8. Detailed block diagram of the CNC Mill prototype

3.1. Electronic structure

The Electronic system of the CNC Mill prototype is accomplished by the components shown in the TABLE 1.

The single axis TB6560 stepper motor driver is used in our system. To the + 24V pin and the GND pin of motor driver the DC power supply is connected. The pin A+ and A- of motor driver is connected to the A+ and A- terminals of phase winding A of the stepper motor. Similarly phase winding B is also connected to the motor driver. The step pulse pin and direction pin of Arduino board are connected to the CLK+ and CW+ pins of stepper motor driver respectively. To GND pin of Arduino board the CLK- and CW- pins are connected.

For controlling the running current from 0.3 A up to 3A, the switches SW1 to SW3 in connection with dip switch S1 are used. To control the stop current switch S2 is used (ON: 20%, OFF: 50%), To set the excitation mode (from whole to 1/16 steps) S3 and S4 are used, and to control the decay setting S5 and S6 are used. With a USB connector, the Arduino

board is interfaced to the PC and therefore the CNC machine can also be controlled from a laptop PC. Thus the machine become the portable.

Six limit switches have been installed, two for each axis using the digital input pins on the Arduino, to avoid the axis of motors going out of safe operating range. For the work pieces on the work table a clamping mechanism is also installed.

Table 1. Electronic components required for CNC mill prototype

<i>Components</i>	<i>Specifications</i>
Powe supply	24 V, 10A, SMPS
Motor driver	single axis, rated 3A, peak 3.5A, 24V DC rated
Stepper motor	Nema 17, 1.8°, 2-phase, 1.3A
Spindle motor	24-36 V DC, 12000 rpm, 0.3A NL
Microcontroller	ATmega328P , 16MHz

3.2. Mechanical structure

The three stepper motors for the three axes (X, Y and Z), the frame parts, the lead screws, guide rods and related accessories form the mechanical system. The body of the machine is made up of high density PVC boards. It has a mobile bed and a fixed gantry.



Figure 9. Y axis assembly exploded



Figure 10. Y axis assembly



Figure 11. X axis assembly with column



Figure 12. Z axis assembly

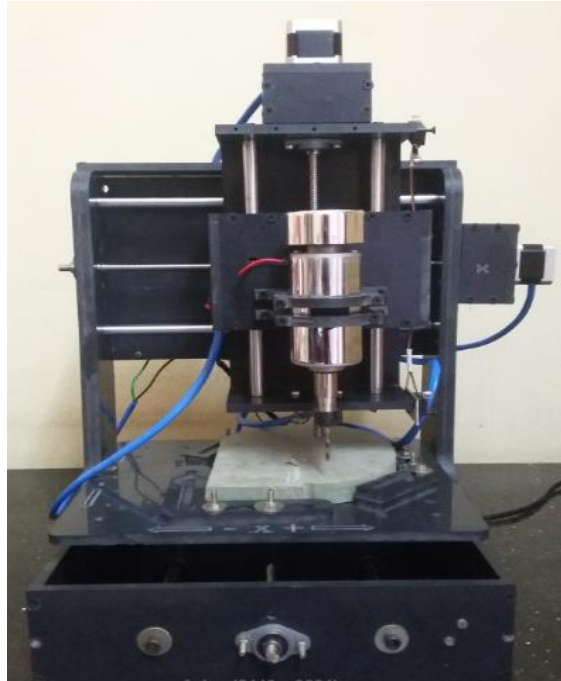


Figure 13. Complete assembly

3.3. Arduino based control structure

The TABLE 2 show the specifications of Arduino control board used in the CNC Mill prototype.

Table 2. Specifications of Arduino control board

Parameters	Specifications
Operating voltage	5 V
Input voltage	7-12 V
Digital I/O pins	14 (6 provide PWM output)
Analog Input pins	6
DC current per I/O pin	40 mA
Clock speed	16 MHz
PC connection	USB
Operating voltage	5 V

4. CNC mill prototype control software

The CNC machining process is shown in the Fig.14.

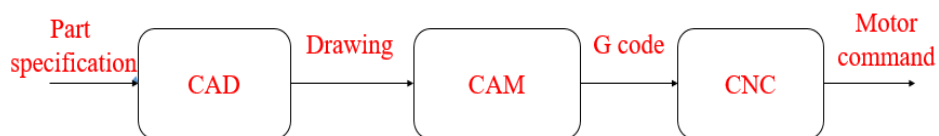


Figure 14. CNC machining process

4.1. CAD software

To create, modify and optimize 3D and 2D designs of product and parts, Computer Aided Designing (CAD) software used. A product's shape, dimension, model type, material etc. can be explained by a CAD file. CAD modelling software used here is AutoDesk Fusion 360. It is a professional 3D CAD program software, used for developing 3D modelling, process planning, testing, 3D printing and CAM. The CAD model needs to be converted to G-Code file for machining.

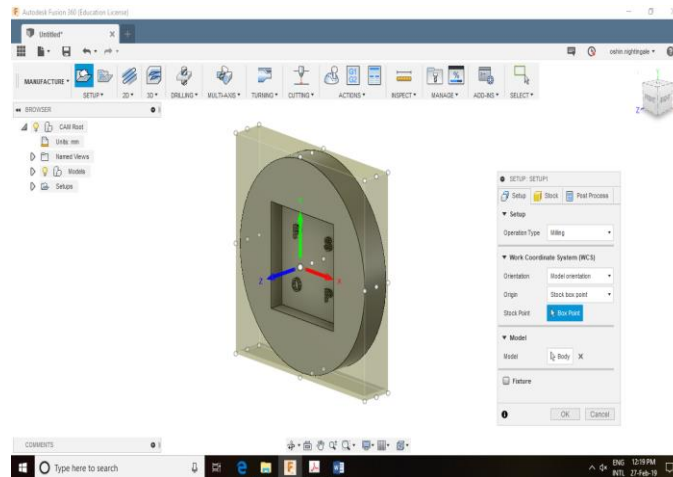


Figure 15. CAD model example in Fusion 360

4.2. CAM software

To generate machine tool path for CAD model, Computer Aided Manufacturing (CAM) used, alongside of CAD software. It generates code for controlling machine tool and geometric travel path. For machining the part, the toolpath file can be fed to CNC machine controller.

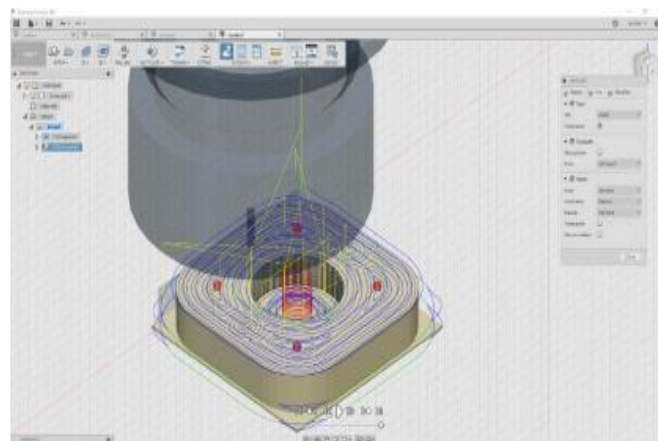


Figure 16. CAM Simulation

A program that converts G code to stepper motor control signals is included in the GRBL file, which is a pre-compiled hex file. From software, compiled Hex file cannot be loaded directly. So it requires another firmware called X loader to load hex file. After uploading the hex file, the controller will be converted to CNC controller, then G-code can be fed directly. Controlling Arduino requires another software to communicate serially to Arduino, to send signals to Arduino controller. For that Universal-G-Code-Sender is used, which is a cross platform developed in Java.

5. Hardware testing



Figure 17. Sample product in wax



Figure 18. Sample product in MDF

6. Comparison between shopBot desktop d2418 & CNC mill prototype

The comparison between an industrial standard milling machine, ShopBot Desktop D2418 and the CNC mill prototype developed by us is discussing here.

6.1 ShopBot Desktop D2418

ShopBot Desktop D2418 is an industrial standard CNC milling machine.

6.1.1 Specifications of ShopBot Desktop D2418

Model- ShopBot Desktop D2418

Cutting Volume- 24" x 18" x 3.5" (depth typically limited by cutter length) Resolution- 0.00025" / .00635mm (claimed)

Spindle- 1HP HSD Spindle, AT/MT1055-090 (Custom ShopBot part).

Motor Driver- Delta VFD007S11B Variable Frequency Drive

Collet Sizes- ER-20 with the following shank diameters- 1/8", 1/4", 3/8", 1/2" Dust Collection System- Festool CT36 HEPA Dust Extractor with in-line Oneida Ultimate Dust Deputy

Supported File Type - .sbp & .crv

Machinable Material – Wood, foams, plastic and Aluminium

6.1.2 Characteristics of ShopBot Desktop D2418

1. Capable of managing all machining needs
2. Suitable for automatic or interactive operation, cutting sharp edges, drilling holes, milling slots, etc.
3. Complicated machine setup
4. Highly expensive, it costs around 7 lakhs
5. Higher knowledge requirements for operators
6. High levels of efficiency and quality



Figure 19. ShopBot Desktop D2418

6.2 CNC mill prototype

The CNC Mill prototype is developed based on Zen CNC milling machine model. It is an open source model. It runs based on Arduino controller with 3 Stepper motor (for X and Z axis) and stepper driver. Motor speed and direction controlled using Arduino based control system.

6.2.1 Specifications of CNC mill prototype

Machine Strokes - Longitudinal traverse(X) ≥ 160 mm, Vertical traverse(Y) ≥ 170 mm, Trans-verse traverse(Z) ≥ 130 mm

Machine Overall size – 410 * 450 * 530 mm

Frame material – PVC with Rigidity

Feed drive- Nema 17 Stepper drive with re-circulating lead screw for all linear axes cutting feed rate ≥ 1000 mm/min

Spindle – Air-cooled, 500 W, 12000 RPM Spindle motor

Tool mounting – ER 16 Collet

Control system – Arduino Based GRBL Control

Supported file type - .nc & .tap

Power supply – 24 V, 10 A

Machinable material – Wood, Acrylic and machinable wax



Figure 20. Sample product milled in plastic using ShopBot Desktop D2418

6.2.2 Characteristics of 3 axes CNC Milling Machine prototype

1. Capable of managing most machining needs
2. Capable of producing the same products as machines with more axes
3. Suitable for automatic or interactive operation, cutting sharp edges, drilling holes, milling slots, etc.
4. Simplest machine setup
5. Less expensive, it costs nearly around 25000 only.
6. Only requires one workstation
7. Basic knowledge requirements for operators
8. Higher levels of quality
9. Lower levels of efficiency

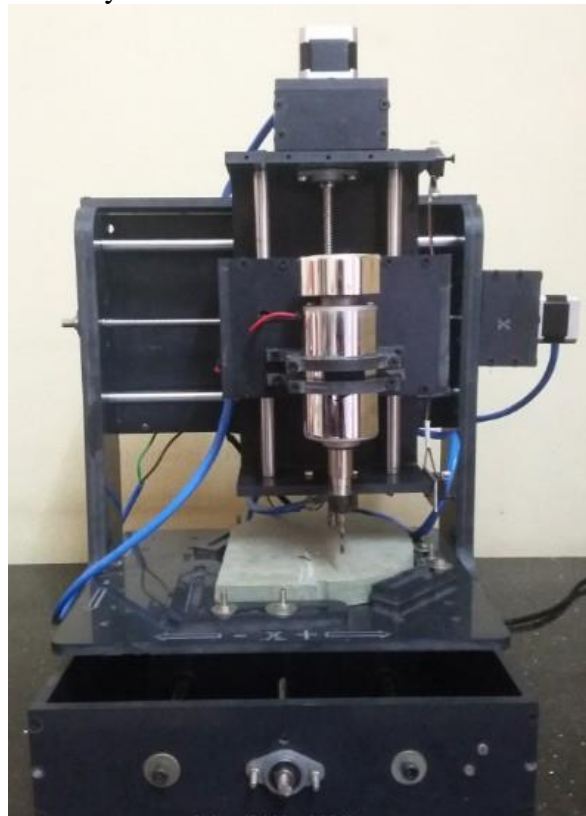


Figure 21. CNC mill prototype



Figure 22. Sample product milled in wax using CNC mill prototype

Table 3. Cut quality comparison

Material	Quality
Wax	High
MDF	Low

Acknowledgments

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