COMPUTER NUMERICALLY CONTROLLED PORTABLE WOOD CARVING MACHINE

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INTRODUCTION

The first numerical control (NC) machines were built back in the 1940s. Thereafter, gradually developed NC machines were built based on the existing tools incorporating controllers such as motors to conduct their operations. Initially, the movements or instructions were fed by punched tape and soon they were replaced with the introduction of computers. The introduction of computer technology into the NC concept created computer numerical control (CNC). Today, both 2 and 3-dimensional (2D and 3D) wood carving machines are available in the market. Most of them require the workpiece which is carved in the horizontal plane to be fixed to the machine horizontally. They do not support carving on a vertical surface. Also, the size of the CNC machine is defined by the size of the whole workpiece not by the size of the carving. Also, they cannot be used to perform a carving on already assembled vertical and horizontal surfaces such as doors, tables, doors of almirahs or walls. The only way is to dismantle the component, fix the machined carve, and then reassemble it. In this study, a CNC wood carving machine was designed and developed to perform the vertical cutting as well. The developed machine could be fixed to the vertical member/surface which needs to be carved to perform the cut without dismantling the member.

METHODOLOGY

The computer numerical controlling was developed on the 3D Cartesian coordinate system (X, Y, Z) which could be handled by the computer via a program that supports computer-aided design and manufacturing (CAD/CAM). The machine works automatically according to the controller commands and the wood plate is cut using cutters to produce a finished part. A computer with the CAD/CAM software installed imports the carving design and converts it to G-code. Then, the controller board controls the stepper motors according to G-code commands. Then, motors connected to three axes (X, Y, Z) move simultaneously and cut the wood plate according to design as shown in Figure 1.

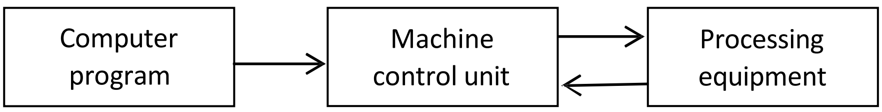

Figure 1: Methodology of CNC machine.

Main parameters of the machine

The following ten parameters were considered and designed in such a way to get a precious carving specifically on a vertical surface.

i. Cutting speed
ii. Depth of the cut
iii. Type & diameter of the tool
iv. Spindle motor speed and power
v. Axis drive motor speed & power
vi. X, Y, Z-Axis gantry movement
vii. Working area
viii. Structure integrity & rigidity
ix. Resolution of cutting
x. Fixed to surface

Cutting speed is the speed difference between the cutting tool and the surface of the workpiece it is operating on. Factors such as work-piece material, tool bit diameter, spindle speed, and surface finish affect the cutting speed. Depth of cut or feed of the cutting tool was optimized as per the machine specifications. Tool type and diameter were selected as per the design specification of the machine. The spindle motor is important since the carving is mainly performed with the assistance of this motor. A motor with sufficient power and speed which could perform with the specified work-piece material, tool bit diameter, cutting speed, feed rate, and drive efficiency of the spindle was selected. Spindle motor power and torque were calculated using standard calculation methods. The x, y, and z axis movements were operated by the drive motor. It was coupled with a linear ball-bearing screw. The Drive motor was selected considering the total gantry weight, cutting force, and friction force due to the movement. The ball screw diameter and pitch affect the torque transformation. Gantries consist of motors, brackets, bearings, etc. that have considerable weight to move. Linear guide rail and ball bearing screw were designed to obtain accurate movements. Design lengths were limited to 600mm (X-axis), 450mm (Y-axis) and 50mm (Z-axis). It depends on the maximum specified carving size. The structural integrity and rigidity of the machine were carefully assessed according to the requirements. The bed of the machine was designed in such a way to damp vibrations to compromise the total weight which is important for a portable machine of this nature, that needs to be fixed to the work surface.

Wood types: the machine is designed to carve on both softwood and hardwood surfaces.

Cutting tools (tool bit): Tool parameters of cutting tools considered were the material of the tool, diameter of the tool, number of flutes, and the helix angle. Since High-Speed Steels have a typical Rockwell hardness range of 62-64 and are readily available, and cost-effective the machine is designed to use HSS tools.

FEM analysis of CNC machine structure: All the structural components of the machine were analyzed for structural integrity using SolidWorks software. For maximum loading conditions, deformations, von Mises stresses of the main outer frame, round shafts, Z-axis frame, supporters and brackets, etc. were analyzed to assure a safe operation. Table 1 shows the stress and deformation of machine components using FEM (Finite Element Method) analysis.

Table 1: Maximum stress and deformation

Parts	Material	Yield strength (N/m^2)	Maximum von Mises stress (N/m^2)	Maximum Deformation (mm)
Outer frame	Galvanized steel	2.039×10^8	3.18×10^5	0.0005
Round shafts	Stainless steel	2.920×10^8	1.719×10^7	0.003
Z-axis frame	Aluminum 6061	5.514×10^7	7.911×10^5	0.001
Bracket	Aluminum 6061	5.514×10^7	7.911×10^5	0.002
Tool bit	Tungsten carbide	3.700×10^8	1.719×10^7	0.1

Clamping forces and clamping method: clamping force was calculated and the effect on the machine was investigated using FEM analysis with the SolidWorks software. The reaction forces in x, y, and z directions were analyzed both vertically and horizontally with maximum operating levels, and how they affect the total process was investigated. The machine was fixed to the ground surface by four brackets and the total machine weight of 27kg and the external forces were applied on the body and the maximum axial cutting force and the tangential cutting force were applied on the tool bit. The results are shown in Table 2.

Table 2: Clamping forces using FEM analysis

	Vertical	Horizontal
X direction reaction force (N)	8.4	7.11
Y direction reaction force (N)	13.2	12.6
Z direction reaction force (N)	13.2	52.9

A rigid base is needed to clamp the machine as the total weight falls on the base. The clamp is used to cover tangential forces, vibration effects and stay fixed to a uniform surface. Figure 2 shows how to clamp the CNC machine for vertical carving at a height of more than 50cm from the ground and how clamping is done on a horizontal table.

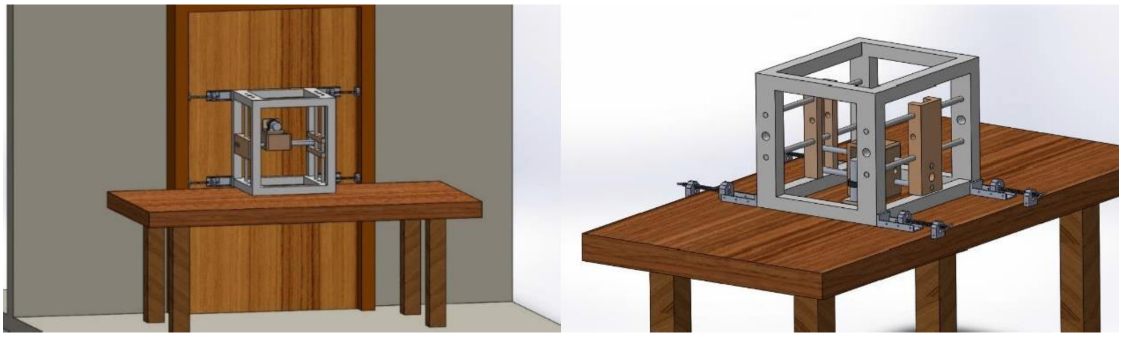

Figure 2: Clamp method for vertical and fixed surface carving

RESULTS AND DISCUSSION

The pictorial view of the prototype of the machine is shown in Figure 3. The fixing attachment is to be used for vertical wood carving applications.

Resolution of cutting: Resolution is the smallest increment of the scale of the tool bit that can be moved. A stepper motor of 1.8 degrees per step which means 200 steps per resolution was used with a lead screw of 3 mm pitch which gives 0.015 mm per step.

Accuracy and error: Accuracy is the closeness of the agreement between a measured value and the true value. Error is the difference between a measurement and the true value of the measurand. The average accuracy is 99.81% which is acceptable for carvings.

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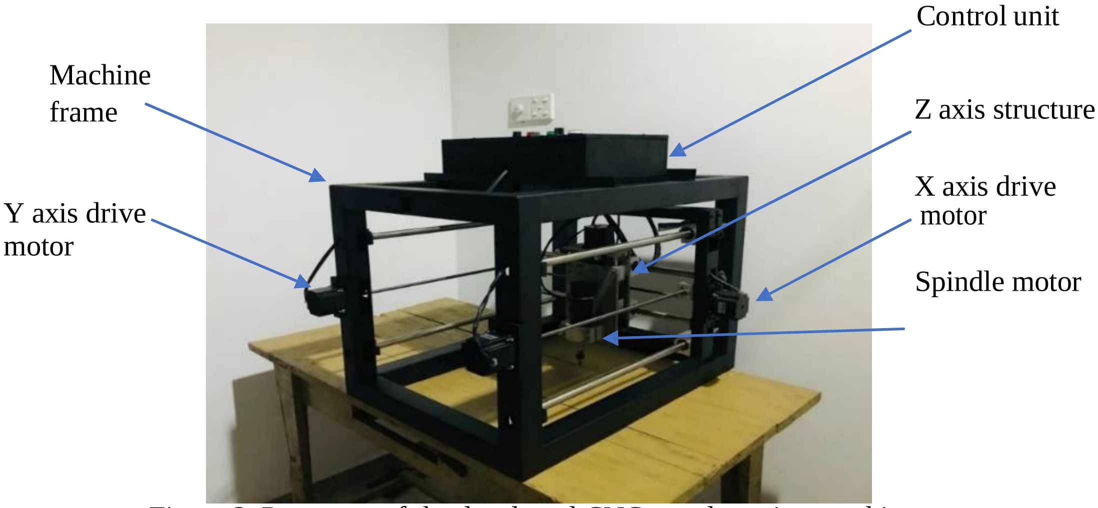

Figure 3: Prototype of the developed CNC wood carving machine.

The specifications and limitations of the machine are given in Table 3. The machine was tested in full capacity in both vertical and horizontal carving on different kinds of wood. Then, the resolution and accuracy of the carvings were examined. This machine operates with aid of the standard industrial software named “Mach 3”. It has advantageable functions like switch control, emergency stop switch, and all axis location visual system. Further, values with four decimal points are displayed in high resolution. This machine maintains a 0.015mm resolution. Therefore, carvings have a smooth surface finish and high-quality details. Also, this machine can be used for letter cutting and engraving. The total power consumption is less than 1kW. Therefore, the machine can be operated with a UPS power supply in case of an instant power disruption.

Table 3: Specification of the machine

Machine dimension	650mm X 450mm X 450mm (Length, Height, Width,)
Carving area limitation	500mm X 350mm X 50mm (X, Y, Z Axis)
Weight	27kg
Operating voltage	230V AC, single phase
Power consumption	800W
Current rating	3.4A
Tool diameter	1mm to 6mm
Spindle speed	10000rpm
Percentage error	0.19%
Resolution	0.015mm

The machine performing a vertical carving on a door of an existing wardrobe and another finished carving are shown in Figure 4 (a) and (b) respectively. Also, completed 3D carvings on mahogany and teakwood are shown in Figure 5.

(a) (b)

Figure 4: Vertical surface carving

Figure 5: Completed 3D Carving on mahogany and teakwood.

CONCLUSIONS

A CNC wood carving machine was designed and developed to enable both vertical and horizontal carving. The existing CNC machines are of high cost and difficult to maintain while they require highly skilled operators and need the workpiece fixed on the machine bed. This CNC machine overcomes these problems. It is of low cost and easy to control while it does not need highly skilled operators. The total cost incurred was Rs.90,000 for developing the prototype without the workmanship cost and the expected selling price of the complete machine with all features is Rs.120,000. It can be used for long hours at a stretch. The machine can be used to carve on vertical and horizontal surfaces such as wooden tables, doors, windows, beds, and any flat wood or plastic surface without removing any part. This machine can be widely used for wood furniture processing, home decoration, wooden door manufacturing, wooden crafts processing, relief carving products, as well as wood and plastic engraving. Applicable materials are solid wood panels, artificial boards, acrylics, PVC and MDF.

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