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Experimental Analysis of Design Fabrication and Motion Analysis of Portable CNC Router Using GRBL Board

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ABSTRACT: The purpose of this paper is to describe the design and development of a portable 3-Axis CNC router machine based on a microcontroller, which was used to reduce the cost and complexity of the bulky sized engraving machine. This machine can be used for engraving, cutting, reaming, marking, drilling, and milling on wood, acrylic, and PCB materials. First, the component to be manufactured is designed using software that supports image processing (artcam, inkscape). Next, G-codes are generated and sent to the microcontroller through GRBL software using serial communication. Finally, the microcontroller receives the signals from the actuators that perform the necessary motion on the job based on point coordinates. Analyzing the table motion of a 3-axis CNC milling machine tool was the primary objective of the paper. Measuring the machine's motion during idling, including its velocity, acceleration, and delay, as well as its distance travel and time taken, were all part of the investigation. An ultrahigh-speed digital camera and a laser interferometer were used to make the measurements. The results of the motion parameters measured using different techniques are compared. The measurement system in use affects the accuracy of displacement, velocity, and acceleration. It takes time for the acceleration (delay) and velocity parameters to stabilize, depending on the specified feed rate.

KEYWORDS: CNC, router, 3-Axis, image processing, 2D, 3D, GRBL Control

I. INTRODUCTION

Engaging with automatic mechanical equipment necessitates a blend of precision, accuracy, speed, consistency, and adaptability [1]. Numerical Control (NC), also known as Computer Numerical Control (CNC), epitomizes the automated governance of machining tools such as drills, boring tools, and lathes, facilitated by computerized systems. An NC machine refines raw materials (Acrylic Sheet, plastic) to exact specifications through programmed directives, eliminating the need for manual intervention. These machines integrate motorized tools and platforms, both orchestrated by a central computer core, executing tasks as per predefined commands. Operational directives are conveyed to an NC machine via graphical Computer-Aided Design (CAD) files, transmuted into a sequence of control instructions for execution. In contemporary CNC setups, the entire process from mechanical design to manufacturing directives is highly automated. Mechanical parameters are delineated using CAD software, then translated into production directives through Computer-Aided Manufacturing (CAM) software [2]. The prime objective underlying the development of this machine is to engineer a cost-effective miniature CNC apparatus for engraving, cutting, reaming, marking, drilling, and milling on materials such as wood, acrylic, and PCB. This system not only curtails machine and machining expenses but also augments the adaptability of the manufacturing framework.

II. LITERATURE REVIEW

The current work aims to develop a high precision, cost-effective mini three-axis vertical CNC milling machine tailored for rapid prototyping and engraving small features in the electrical and medical industries. The project focuses on exploring theoretical and technical procedures for designing, fabricating, assembling, and testing electromechanical subsystems. The machine features an easy interface, high speed, low power consumption, safety, and durability. It utilizes the Mach3mill G-Code CAD/CAM software package to control its operations, effectively turning a PC into a powerful and economical machine controller. The machine employs the 3Axis CNC driver board Kit TB6560 for smooth driving of selected stepper motors. Following fabrication, the prototype CNC milling machine underwent testing and calibration to assess its accuracy in various parameters such as surface flatness, axes perpendicularity, positioning, straightness under specific tool paths, and feed rate. The results revealed slight misalignments within acceptable tolerances, indicating minor tilting on both the X and Y axes. Subsequent improvements were made in both



electrical and mechanical designs to enhance the machine's performance. Ultimately, the machine demonstrated the capability to mill complex contours on soft metals with considerable accuracy and speed.[1]

The topic discusses the pivotal role of CNC (Computer Numerical Control) machines in the manufacturing sector over the past five decades. It introduces a novel approach to developing a sustainable CNC system by leveraging OAC (Open Architecture Control) and STEP-NC (standard for the Exchange of Product model - Numerical Control) technologies. OAC technology is highlighted for providing a reconfigurable and reusable software and hardware platform, offering adaptability to changing manufacturing needs. On the other hand, STEP-NC data interface model is noted for bringing flexibility, interoperability, adoptability, and intelligence to CNC systems. The paper outlines the implementation of this new method on an older 3-axis CNC milling machine, demonstrating satisfactory performance. This implies that by integrating OAC and STEP-NC technologies, the CNC system can be enhanced in terms of adaptability, intelligence, and overall sustainability, even on older machinery.[2]

This article discusses the advancement of Computer Numeric Control (CNC) technology through the creation of a small-scale prototype CNC machine. The focus lies on developing a modular system with USB communication capabilities. It also covers the creation of essential electronic components required for operating a CNC machine. Additionally, the article introduces a software solution developed in lab view to facilitate communication between the CNC machine and a computer. The primary goal of this project is to provide a platform for future research endeavors aimed at assessing process performance. Furthermore, the machine serves educational purposes, offering a tangible demonstration of the components involved in CNC machinery. Through this development, the article contributes to enhancing understanding and exploration within the realm of CNC technology.[3]

This research aimed to revolutionize traditional woodcraft in Bali by introducing a Computer Numerical Control (CNC) based router machine specifically designed and fabricated for wood engraving. The primary objective was to enhance productivity and efficiency for artisans. The CNC router machine, powered by stepper motors and employing a 3-axis motion system, ensures precision and uniformity in wood engraving. Utilizing G-code programs through MACH 3 software for Computer-Aided Manufacturing (CAM) processing, the machine boasts a spacious workspace of 800 mm x 500 mm. The integration of TB 6600 drivers with stepper motors, coupled with ball screws on linear bearings, guarantees meticulous motion control. Through rigorous testing, the machine demonstrated an impressive accuracy rate of approximately 99.5% for both X and Y axes, and 96% for the Z axis. This innovation not only preserves the essence of traditional craftsmanship but also propels it into a more efficient and precise realm, ultimately empowering artisans in their craft.[4]

The adoption and exploitation of technology rose dramatically as a result of the rapid rise of CNC systems are used in industries, however they are somewhat costly. To lower the price and complexity of CNC systems, the concept of building a low-cost CNC router was proposed. This essay addresses the creation of an inexpensive CNC router with simultaneous interpolated operation in three dimensions. By combining the capabilities of a conventional PC interface with a CNC system based on a microcontroller into an embedded system based on Arduino, the cost is reduced. Additionally, the system has an offline G-Code parser that is interpreted via a USB connection on the microcontroller. The system uses better practices to minimize computational overheads when operating a 3-axis CNC machine without sacrificing any performance.[5]

LOW COST AUTOMATION FOR CNC MACHINING CENTER

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LOW COST AUTOMATION FOR CNC MACHINING CENTER

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There are several meanings for the phrase automation. It appears that the term was originally used to refer to automatic material handling in the early 1950s, specifically to equipment used for loading and unloading stamping machinery. These days, the phrase is used generally to describe a variety of tasks carried out automatically, including information management, material handling, assembling, manufacturing, and inspection of goods (i.e., as an automatic operation without human intervention). Currently, manufacturers are faced with the challenge of continuously needing to find new ways to reduce the cost of their loading and unloading processes in machining centres in order to address the low efficiency and high cost issue in the process of CNC machines. But the stakes are much higher and the game is much tougher in today's globally connected society.[6]

This essay addresses the layout and installation of inexpensive three-dimensional CNC (computerized numerical control) equipment for industrial usage. This CNC machine with a microcontroller as its main component is used to cut metal into the desired shape. The communication between a personal computer (PC) and a numerical control unit is the main topic of this discussion. The need for flexibility and cutting with respect to edge quality led to the goal of creating a computer controlled cutting machine. The device uses an embedded 8-bit microcontroller to maintain the necessary accuracy and dependability for complicated shapes while still being cost-effective. Accuracy is achieved by the system's core, which consists of an embedded mechanical system and an intelligently designed mechanical system. [7]

A new paradigm called STEP-NC for data transfer between CAD/CAM and CNC enables the specification of the machining process as opposed to tool movements with regard to the machine axes. A novel type of CNC controller known as STEP-NC allows for the smooth integration of this high-level model into the CAD-CAM-CNC chain. There have been several STEP-NC CNC controller prototypes created thus far, most of them are based on industrial pcs. Rather, in this work, we demonstrate how a low-cost microcontroller incorporated in the CNC machine can be used to build a STEP-NC CNC controller; this objective has been achieved by precisely parallelizing the machining process's duties. [8]

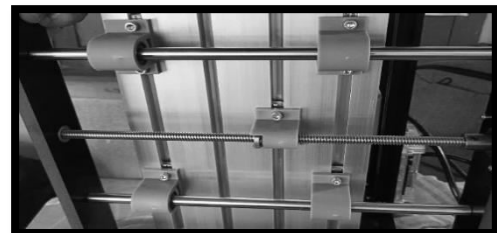
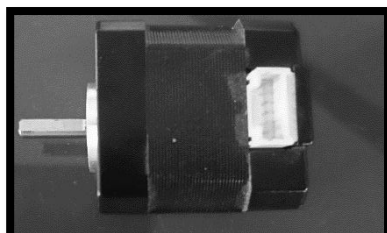
The manufacturing sector has seen significant upheaval since the advent of CNC machines. Cutting curves and straight lines is simple, producing complicated three-dimensional structures in the manufacturing process is not too difficult, and the amount of machining work that needs to be done by hand has significantly decreased. The need for more affordable, portable machines has led to the development of tiny, low-cost 3-axis CNC milling machines. CNC machining has made manufacturing processes more automated, making this possible. Error frequency is decreased with CNC automation, giving CNC operators more time to complete other duties without sacrificing material integrity. Additionally more flexibility in the way parts are kept during the manufacturing process and the amount of time needed for the machine to create are made possible by CNC automation.[9]

The growing need for portable and inexpensive machines is what gave rise to the concept of creating a small, affordable 3-axis CNC milling machine. With the swift advancement of technology and software accessibility. Since it is not difficult, we made a machine that can mill thin sheets, metal, plastic, and wood. A precision stepper motor is used in the design and fabrication process, along with a belt and pulley arrangement on an aluminium gantry structure. The x and y axes of the structure slide smoothly on rail bearings, and the z axis is moved up and down using a threaded rod arrangement, which increases the accuracy of the result. This embedded system uses an Arduino Uno microcontroller and has a standard PC user interface. [10]

III. METHODOLOGY/ MATERIAL

Mechanical System:- As far as engraving machines go, the mechanical systems are the most crucial component. The mechanical system's precision determines the outcome of wood craft engraving in terms of shape accuracy. There are several components that make up mechanical systems:

1. **Stepper Motors:** These motors control the movement of the CNC router's axes, enabling precise and incremental motion.
2. **Ball Screw and Nut Assembly:** A 12mm ball screw and nut assembly is appropriate for both the X and Y axes in order to bear load and thrust caused by cutting forces.
3. **Linear guide rails and blocks:** These are the greatest options for the slides' stability and smooth motion as well as the axis's strength and stiffness to bear vibrations.

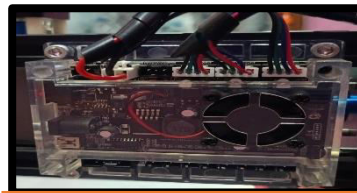


Component used in Mechanical system: a. Stepper motor b. Ball screw c. Linear Guide

Electrical system:

GRBL Board: CNC machine movements can be managed using an open-source firmware called GRBL. It works with Arduino boards, particularly those that are atmega328-based, and is intended for use with do-it yourself CNC machines. The "G-Code Reference Block Library" (GRBL) converts G-code directives into CNC motion control instructions. Applications such milling, laser cutting, and metal engraving are excellent fits for GRBL.

Stepper motors are driven by GRBL by translating G-code motion commands into electromechanical signals in accordance with the predetermined motion and speed. The CNC machine uses it as a "middle person" to translate G-code commands into motion, which the machine then outputs.

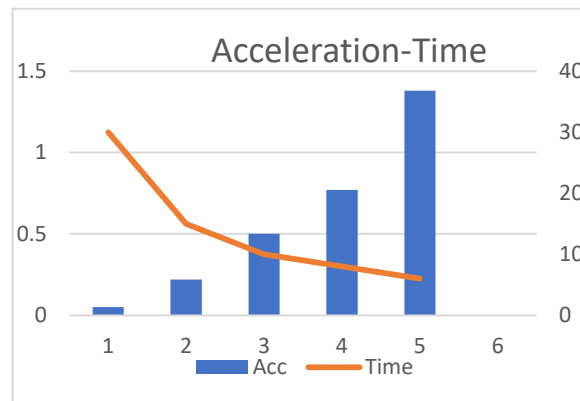
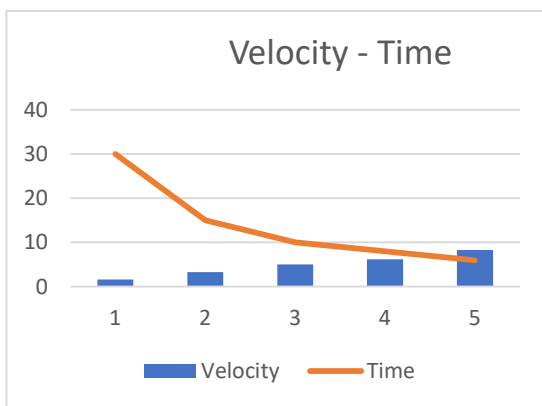


GRBL Board

OBSERVATION

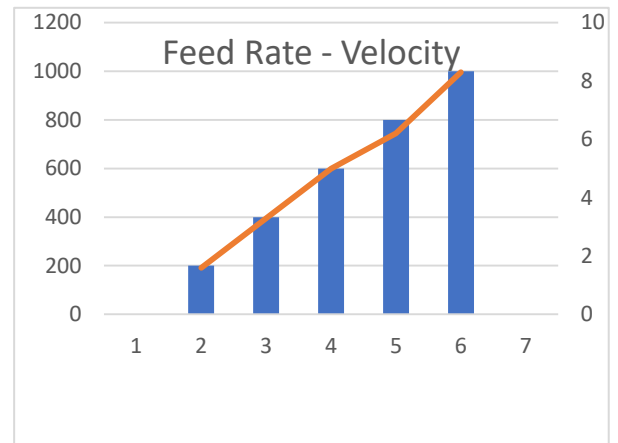
Feed Rate(mm/s)	Distance(mm)	Time (sec)	Velocity(mm/s)	Acceleration(mm/s ²)
F200	50mm	30	1.6	0.05
F400	50mm	15	3.3	0.22
F600	50mm	10	5	0.5
F800	50mm	8	6.2	0.77
F1000	50mm	6	8.3	1.38

Graph on the basis of above table



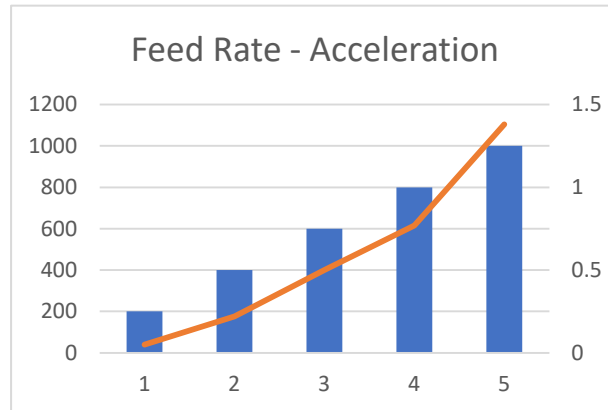
Velocity - Time

Acceleration - Time



Feed Rate - Time

Feed Rate - Velocity

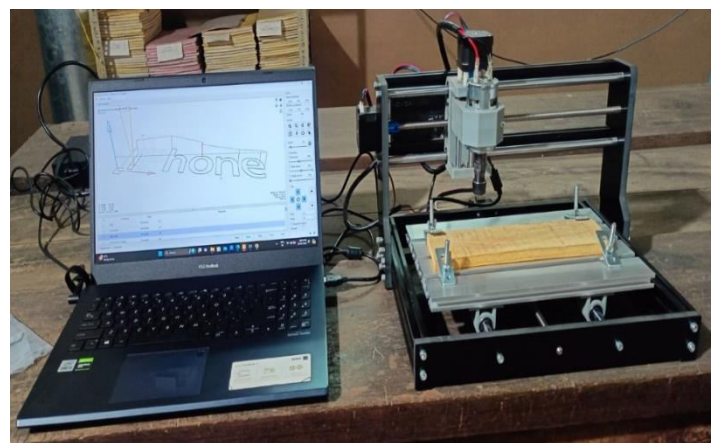
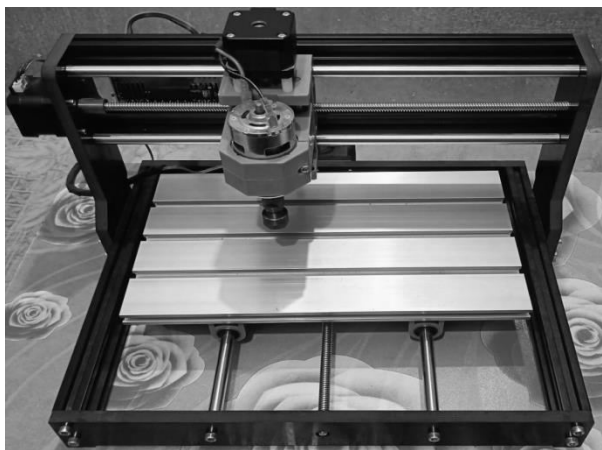


Feed Rate – Acceleration

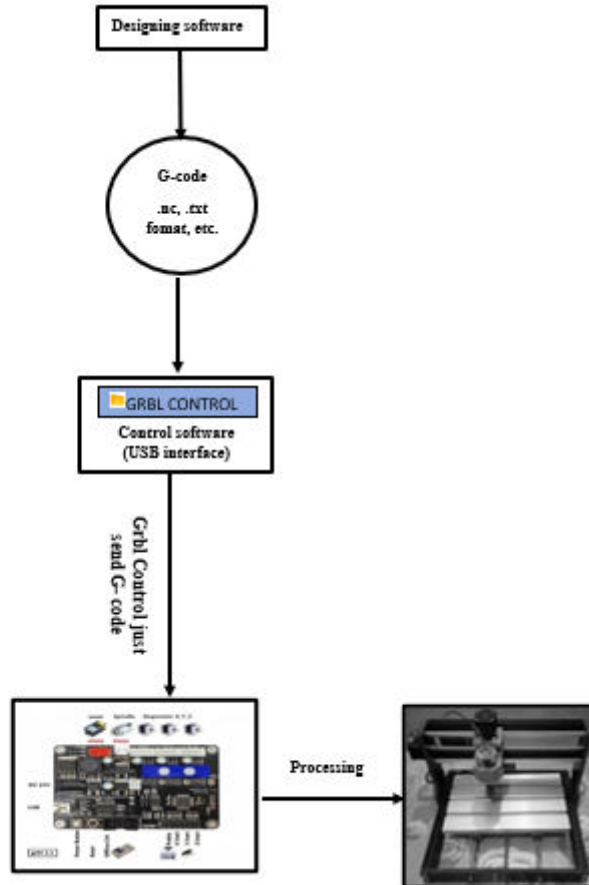
IV. FABRICATION WORK

The process of fabrication involves several processes, including marking and measuring, gas cutting, welding, grinding, drilling, and fitting mechanical parts that are ready for immediate assembly. The machine-building process is outlined below, step-by-step, after all the metal components and accessories needed for assembly have been gathered.

1. Beginning at the base put in four Y axis walls.
2. Install Z axis (Router) and the primary support for it.
3. Install the Z-axis motor and leadscrew after assembling and tightening the slides.
4. Construct the XY axis by starting at the top with the table and installing the screw nut connector beneath it.
5. Fit and adjust leadscrews
6. Install the X axis cross roller guide. Put in two motors to finish the XY



BLOCK DIAGRAM



APPENDIEES

Specifications of CNC Machine:

Model: CNC Machine

- Control Software: GRBL
- Material: Aluminum + plastic
- Color: silver & black
- Working Area: 300*180*40mm (11.8*7.1*1.6 in)
- Frame Size: 420*355*280mm (16.5*14*11 in)
- Spindle: 775 spindle motor (12-36V) 24V: 7000r/min, 36V: 9000r/min
- Spindle Chuck: ER11
- Step Motor: 1.3A/0.25N.m
- Power Supply: 24V/5.6A (110-240V)
- Supported System: windows XP / win 7/ win 8/win 10
- Can Carve Materials: plastic, wood, acrylic, pvc, pcb and more (depend on)
- Supported Formats: jpg/bmp/png
- Communication Port: micro USB

IV. CONCLUSION

In summary, the design, construction, and motion analysis of a portable CNC router employing a GRBL board were experimentally analyzed and the results showed notable improvements in precision machining capabilities. The study effectively demonstrated the fusion of open-source software with reasonably priced hardware to increase accessibility to CNC technology. The router achieved great precision and dependability when key performance criteria like

accuracy, repeatability, and efficiency were assessed. The small size guarantees portability without sacrificing functionality. Motion analysis demonstrated smooth and reliable operations, confirming the GRBL control system's effectiveness. All things considered, this project highlights its potential for broad application by providing a workable solution for prototyping, small-scale manufacturing, and instructional reasons.

V. FUTURE SCOPE

It looks hopeful that GRBL boards will be used in future experiments to analyze the design, manufacture, and motion of portable CNC routers. Improvements in compact, economical, and effective CNC technology for small enterprises and hobbyists may result from this research. For a variety of uses, such as woodworking, prototyping, and teaching, it can improve accuracy, save costs, and allow adaptations. It is possible to obtain advancements in toolpath precision, automation, and user interface by refining the GRBL firmware and hardware integration. Although there are portable CNC routers on the market, this study can offer insights into cost-cutting, increased performance, and new features that set new models apart from older ones with better functionality and design.

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