Journal of Information Technology, computer science and Electrical Engineering (JITCSE)
Vol. 1, No. 3, October 2024, pp. 01~12
ISSN: 3046-4900, DOI: 10.30596/jitcse

Design and Construction of Computer Numeric Control (CNC) Machines Based on Microcontrollers

Iqbal rasikin[1], Hamdani[2], Pristisal Wibowo[3]
[1,2,3]department of Electrical Engineering, Universitas Pembangunan Panca Budi, Indonesia

ABSTRACT

Computer Numerical Control (CNC) is a technology that allows automatic control of machine tools through programmed commands. This research aims to design and build microcontroller-based CNC machines for material cutting applications. The use of microcontrollers as the main control is expected to provide flexibility and efficiency in CNC machine operations.The research methodology includes the stages of conceptual design, component selection, electronic system manufacturing, operational testing, and engine performance evaluation. The designed CNC machine uses a microcontroller controller to drive the stepper motor and control the cutting process based on G-Code data. The results show that this microcontroller-based CNC machine is able to produce cuts with an adequate level of accuracy and precision for material processing applications. Performance evaluations show that the machine can operate a wide range of sizes and types of cuts with consistent results. The implementation of microcontroller-based CNC machines can be an effective alternative in the development of material processing technology with reliable and adaptive automatic control to various industrial applications.

Keyword : design; Computer Numerical Control; **Microcontroller**.

Corresponding Author:
Iqbal rasikin,
Department of Electrical Engineering
Panca Budi Development University
Jl. Gatot subroto km 4.5 medan, 20122, Indonesia.
Email : rasikin@gmail.com

Article history:
Received Sep 1, 2024
Revised Sep 6, 2024
Accepted Sep 9, 2024

1. INTRODUCTION

The rapid development of technology in this modern era has brought significant changes in various fields, including in the world of instrumentation and control systems. One of the results of this development was the discovery of high-performance electronic components that were used as hardware and followed by the development of software. A control system, which is defined as a system to control, command, and regulate circumstances that produce certain value as its output, provides many advantages that can improve the performance of a system, such as reducing production costs, improving product quality, and efficiency on time.

The development of control and instrumentation systems that have started since 1930 until now is influenced by two main factors, namely user needs and technological developments. One form of technological development in this field is machine tools with a computer-based automatic control system. These machines are able to handle a variety of complex tasks in a short time, making it easier for various human activities.

Computer Numerical Control (CNC) machine is one of the technological developments of machine tools with a control system that is operated automatically through commands that are programmed in the abstract and stored in the storage medium. This is different from the previous method where machine tools are usually controlled manually using hand rotation or simple automation using Computer Aided Manufacturing (CAM) (Muchlis et al., 2021). The current development of CNC machines is an update of the pre-existing machine tools, which are less effective in terms of time and cost (Imran et al., 2019).

CNC machines have various types based on the media used, including: Plasma CNC machines (using laser or fire media), CNC Router machines (using cutter media or drill bits), and others (Anrinal et al., 2022).

CNC Router Machining is a combination of CNC technology with Router machines (Sujadi, 2019). CNC is used to control the movement of the cutting process, whereas Router is used as a cutting tool rotator. CNC Router machines utilize the rotation of the cutting edge that rotates on its axis to perform milling, engraving, and cutting work (Ma'arif et al., 2021).

One example of the development of machine tool technology is the Computer Numerical Control machine or better known as a CNC machine. CNC machining is an innovation of machine tools that are automatically controlled by commands that are programmed abstractly and stored in storage media, in contrast to traditional machine tools that are controlled by hand rotation or simple automation using Computer Aided Manufacturing (CAM).

CNC machines come in various types, including Plasma CNC machines that use laser or fire media, and Router CNC machines that use cutter media or drill bits. CNC Router Machining is a combination of CNC technology with Router machining, where CNC functions to control the movement of the cutting process, while Router is used as a cutting tool rotater. CNC Router machines are used for various jobs such as milling, engraving, and cutting.

The advantages of CNC machines lie in their higher levels of precision, accuracy, and flexibility compared to traditional tooling machines. The numerical control system on CNC machines runs well because of the presence of a set of control system components that support the operation of the machine, which are then assembled in such a way as to form a specific electronic device. CNC machining is also highly efficient in mass production, reducing dimensional variation, and minimizing defective products.

In an effort to improve the accuracy and precision of products produced by CNC machines, several researchers have conducted research on the design and construction of CNC Router machines using stepper motor and microcontroller technology. Microcontrollers that are often used in the manufacture of CNC machines are USB Board Mach 3 and Arduino Uno R3. Previous research has shown that the Arduino Uno R3 microcontroller has quite good results in terms of accuracy, but the processing time and production amount produced are still low.

Based on these problems, it is considered necessary to conduct further research on the design and construction of a 4-axis CNC Router machine control system with high accuracy and precision. The CNC Router machine that will be designed measures 50 cm x 70 cm x 15 cm, using a USB Mach 3 controller that is able to control up to 4 axes in real-time with the help of Mach 3 software. The Nema-23 stepper motor will be used to control the rotation of the shaft with high precision, supported by the TB6600 series motor driver which has a larger peak current capacity. This research is expected to produce CNC Router machines with high accuracy and precision, so that it can improve product efficiency and quality.

2. LETERATURE REVIEW

Computer Numerical Control (CNC)

Computer Numerical Control Machine, or commonly called CNC machine, is a term used to describe a machine operating system that is controlled by an internal computer. CNC technology is the best method today to meet the market demand for manufactured components due to the precision and efficiency it possesses (Firsa et al., 2015). In general, a CNC machine is a machine controlled by a numerical and letter code that automatically executes manufacturing operations according to the commands arranged in the numerical code (NC Code).

CNC technology is the best method today to meet the market demand for manufactured components, thanks to the precision and efficiency it has. The working system of CNC technology is more synchronous between computers and mechanics, so that when compared to similar tool machines, CNC machines are more reliable, more precise, and more flexible (Pratama et al., 2022). The reliability of CNC machines is inseparable from its supporting components, such as the operator (brainware), hardware (hardware), and software (software). These components must support each other to obtain satisfactory work results (Syahriza, 2015).

CNC has various types based on the medium used, including: CNC Router (using cutter media or drill bits), CNC Plasma (using laser or fire media), and others (Anrinal et al., 2022).

CNC Router Machine

CNC Router is a tool that is widely used in the cutting and engraving processes in small to medium-scale industries. CNC Router machines are computer-controlled work machines using numerical language (numbers and letters) (Budhi et al., 2021) that produce unique components that are precise and complex parts (Firdaus and Yuhas, 2022).

CNC Router Machines combine CNC and Router technology, with cutters that are able to cut the shapes of wood sheets or other soft materials that have complex shapes and require precision in manufacturing. This combination then forms a computer-controlled cutting machine, using a router machine to cut various materials such as wood, composite, aluminum, soft steel, acrylic glass, plastic, and foam, by adopting CNC technology.

The cutting movement and cutter trajectory for the X, Y, and Z axes and the A and B axes come from a computer program based on the drawings or contour designs that have been created (Salam et al., 2019).

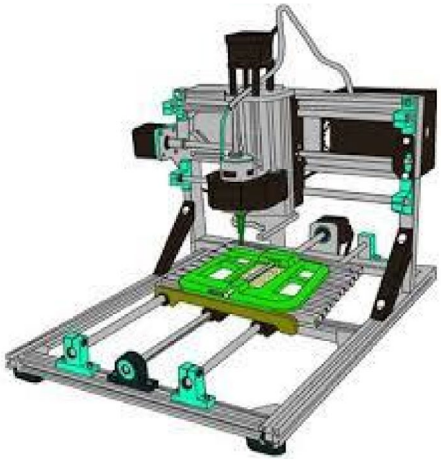

Figure 1. CNC Router Machine (Nayorama, 2016).

CNC Router Machine

The main tool used in CNC Router machines is a blade that is shaped similar to a drill bit. This knife will rotate at a predetermined speed and will cut the wood until it is shaped according to the desired workpiece. Based on their shape and function, Router blades are divided into four types:

1. Groove Maker Knife: This knife is used to make a wide variety of grooves and can be used to make joints.
2. Wood Shaping Knife: This knife is used to form the edges of wood.
3. Edge Leveling Blade: This knife is used to level the edges of wood.
4. Small Groove Making Knife: This knife is used to form a variety of decorative indentations on the edges of wood (Nayorama, 2016).

CNC Router Machines have three main functions:

1. Cutting: This function allows the machine to cut the material according to the wishes of the operator who operates it using a computer. This minimizes errors in cutting.
2. Engraving: This function allows the machine to decorate the material so that it looks nicer and more unique. The resulting product will be very satisfying and beautiful.
3. Marking: This function allows the machine to mark the wood to be used. That way, the finishing will be more appropriate and neat.

CNC Laser Machines

CNC Laser (Light Amplification by Stimulated Emission of Radiation) is a tool that has the function of engraving or printing various writing and calligraphy automatically on various media such as acrylic, fiber, aluminum, and wood (Muchlis et al., 2021). CNC laser machines are capable of performing two types of machining processes, namely cutting and engraving.

The cutting process is a process used to cut materials, while the engraving process is a process used to scratch the surface of the material so that the result resembles carving (Marcelina et al., 2021). The CNC laser machine uses laser technology to cut the material with the working principle of directing the high-power laser to the material to be cut, and its movement is controlled by the computer.

CNC laser machines are widely applied in the manufacturing industry due to their ability to cut and engrave with high precision and efficiency.

CNC Plasma Cutter Machine

A CNC plasma cutter machine is a machine used to cut metal or wood in two dimensions. CNC plasma cutters use plasma torches to pierce wooden or metal sheets. The power required by the CNC plasma cutter is not as much as the power used in the CNC Router.

Plasma is a form of the fourth phase of matter after the solid, liquid, and gaseous phases. If heat is added, ice will change its form from solid to liquid, and if given excess heat, the liquid substance will turn into steam. If the steam is added to the heat again, it will turn into plasma. High electrical voltage is needed to apply force to the electrons of electric current so that it can pass through metals that have high resistance, where as a result of the addition of electrical voltage there is heat (Rahman et al., 2019).

Driver CNC

Parallel ports or known as Line Print Terminals (LPT) are used as a communication medium between CNC machines and computers. Parallel ports have the advantage of communication between computers and other devices controlled using computers, namely being able to send and receive data simultaneously at the same time. The use of parallel ports allows for real-time data communication.

In addition to the use of parallel ports, the operation of CNC machines can use another platform, namely microcontrol which can be used as the main control of CNC machines by using the Universal Serial Bus (USB) which is more flexible in its operation. The use of USB as a communication medium ensures that high-spec computers are not a problem, with several advantages such as hosts/senders and the design process being done on the same computer. USB communication is much faster and in real time compared to parallel communication (Nugroho et al., 2020).

Mach CNC USB Module is a hardware to control CNC machines by managing the G-Code data from the computer and providing a protection system. Meanwhile, Mach 3 works with parallel communication to ensure the speed of data sent and received in real time (Febryanto and Kartikasari, 2022).

Driver Motor Stepper TB6600

The stepper motor driver is a component that functions to communicate the controller with the actuator and amplify the output signal from the controller so that it can be read by the actuator. Stepper motor drivers are used to regulate the direction and rotation speed of the stepper motor. This driver controls the source of voltage that goes into the stepper motor coming from the microcontroller (Choirony et al., 2021).

In this study, a TB6600 driver board motor was used for 4-axis CNC. This motorcycle driver has several ports that will later be connected to each port such as input signal, stepper motor, driver switch setting, and DC power supply (Harrizal et al., 2017).

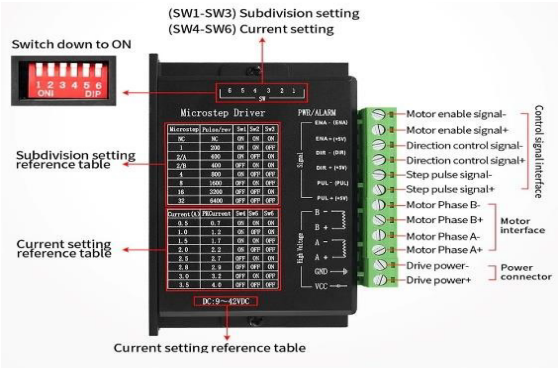

Figure 2. Pin Layout Driver Motor TB6600

Explanation of the TB6600 Driver Pin Layout In the image above, the TB6600 driver layout pin is shown which is divided into three interface control signals. The control signal consists of:

- Positive Pulse Signal Input (PUL+)
- Negative Pulse Signal Input (PUL-)
- Positive Directional Signal Input (DIR+)
- Negative Directional Signal Input (DIR-)
- Enabling Offline Positive Signal Input (EN+)
- Enabling Offline Negative Signal (EN-)

The power connector consists of DC (+) and D (-) which are connected by a power supply with a voltage of 12 – 48VDC. The motor interface consists of phase B-, B+, A-, and A+ motors connected to a two-phase hybrid stepper motor (Anonymous, 2021).

In Table 1. The following explains the specifications of the TB6600 motorcycle driver.

Type	TB6600
Interference capabilities	Anti-high frequency
Input flow	0-5.0A
Output current	0.5-4.0A
Maximum power	160W
Micro step	1, 2/A, 2/B, 4, 8, 16
Temperature	-10~45°C
Moisture	Non-condensing
Heavy	0.2 kg
Dimension	96x56x33 mm

Motor Stepper

Stepper motor is one type of motor that is widely used as an actuator, such as a read or write head drive on a disk drive to set the position of the read or write head on the surface of a diskette, a head drive on a printer, and a robotic linefeed. With the help of a microcontroller or microprocessor, the rotation of the motor can be precisely and programmatically controlled. Stepper motors work to convert electrical energy into mechanical energy in the form of discrete (intermittent) motor movements called steps using electromagnetic principles (Supriyadi et al., 2020).

The main difference between stepper motors and DC motors is that DC motors have fixed magnets on the stator, whereas stepper motors have fixed magnets on the rotor. By applying the voltage to each phase in sequence, the stepper motor will rotate step by step. This step can be adjusted using a computer to achieve the right position and control the speed, so stepper motors are suitable for work that requires high precision (Fatoni, 2022). In addition, stepper motors are chosen because they can be controlled easily and have high precision (Harrizal et al., 2017). At low speeds, stepper motors will produce large torque. To drive a stepper motor, a stepper motor controller is needed that generates periodic pulses, such as a motor driver.

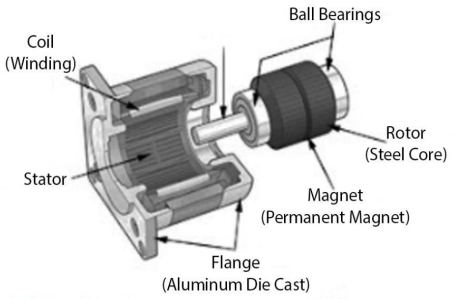

Figure 3. Stepper Motor Construction

In this study, a Nema-23 stepper motor was used. The Nema-23 stepper motor has a torque of 178.5 oz-inches (1.26 Nm), which is suitable for driving materials such as PCB, acrylic, wood, and aluminum.

3. Research Methods

In the design research of the 4 Axis Router CNC machine, the research method involves a series of systematic stages to ensure the successful implementation and evaluation of the machine. And it consists of several systematic stages to ensure the success and evaluation of the machine:

1) Machine Design: Designing all engine components in detail, including material selection and technical specifications such as stepper motor driver and USB Mach 3 controller.
2) Mechanical System: Making the machine frame using holo iron to guarantee the stability and reliability of the machine when operating.
3) Control System: Using Mach 3 USB board as the main controller connected with the stepper motor driver to control the engine's motion axis.
4) G-Code Program Creation: Generate G-Code programs from designs using Aspire software to guide cutting and engraving operations on materials.
5) Axis Calibration: Tests and calibrates the X, Y1, Y2, and Z axes to ensure the desired precision and speed of movement.
6) Operational Testing: Conducting operational tests to observe the performance of the machine under real-world conditions, including cutting materials at varying speeds.
7) Data Analysis: Analyze test result data to evaluate the accuracy, speed, and reliability of the machine in meeting the set goals.
8) Conclusion: Summarize the results of the evaluation to assess the successful implementation of the 4 Axis CNC Router machine as well as provide recommendations for future development.

With this approach, research can be conducted in a structured manner and provides a solid foundation for the development of better and more efficient CNC machining technology.

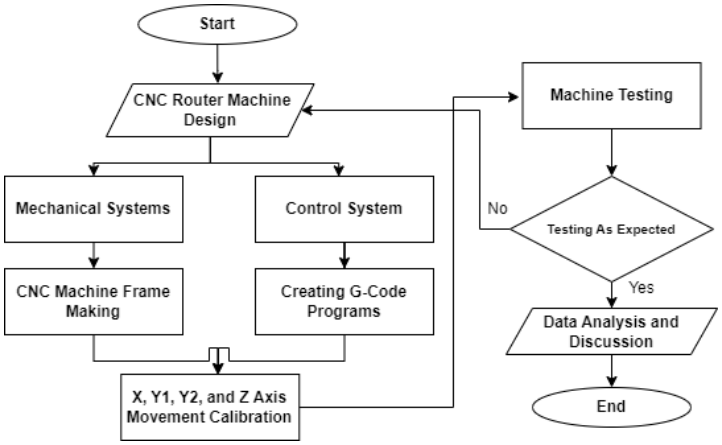

Figure 4. CNC machine designing flowchart

The following is a block diagram of the control system design that will be used on a 4 axis CNC Router machine shown in Figure 5.

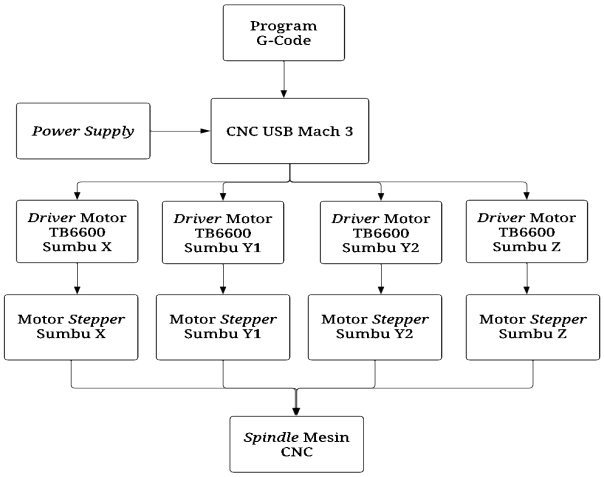

Figure 5. System Design Block Diagram

4 Axis Router CNC Machine Control System

This 4 axis CNC Router machine control system uses USB Mach 3 as a controller to control the whole system, from input, output, to data transmission to stepper motors and spindle motors. The power supply is used as a power source on the network. The input from the Aspire software is in the form of G-Code to be read by the CNC module. The incoming data will be sent to the Mach 3 microcontroller via serial USB. USB Mach 3 is connected with the TB6600 stepper motor driver. This driver functions to receive and read data, then generates an output to control the four stepper motors. The four stepper motors drive the X, Y1, Y2, and Z axes and give commands to the DC motor to drive the drill bit. The Mach 3 USB board is also connected with a limit switch that functions to provide a limit on the stepper motor so that it does not pass through the predetermined work area.

The following are the stages in manufacturing a 4 axis CNC Router machine:

Control System Design:

This stage begins with creating a circuit schematic and hardware design of a 4 axis CNC machine. The motor drivers used are TB6600, Nema-23 type stepper motor, and Mach 3 USB Board.

Programming:

This stage aims to run the axis of motion of the CNC machine using Aspire software for design and Mach 3 software to convert images into G-Code with Mach 3 USB Board controllers.

Accuracy Testing and Calibration:

This stage aims to test the ability, accuracy, and precision of the 4 axis CNC Router machine. Testing is performed on all axes used (X, Y1, Y2, and Z axes). Calibration is performed against the movement of the machine to ensure that the size of the movement of the machine is in accordance with the commands given by the computer. Measurement of the distance of the machine's movement is carried out after moving the axis using software with a predetermined distance.

By systematically carrying out these stages, it is hoped that the 4 axis CNC Router machine can operate with high efficiency and precision according to the needs of various industrial applications.

Results and discussion

Machine Design and Design
In this study, a 4 axis CNC Router machine was designed and designed using holo iron material and the control system used a Mach 3 USB board module as a controller, a TB6600 motor driver, a Nema-23 stepper motor, and Mach 3 software. The following is the design of the 4 axis CNC Router machine presented.

For this research, a 4 axis CNC Router machine was designed and designed using hollow iron material with a control system that relies on a Mach 3 USB board module as the main controller. This engine uses a TB6600 motor driver and a Nema-23 stepper motor, as well as Mach 3 software. Here is the design description of the 4 axis CNC Router machine:

For this research, a 4 axis CNC Router machine was designed and designed using hollow iron material with a control system that relies on a Mach 3 USB board module as the main controller. This engine uses a TB6600 motor driver and a Nema-23 stepper motor, as well as Mach 3 software. Here is the design description of the 4 axis CNC Router machine:

4 Axis Router CNC Machine Design

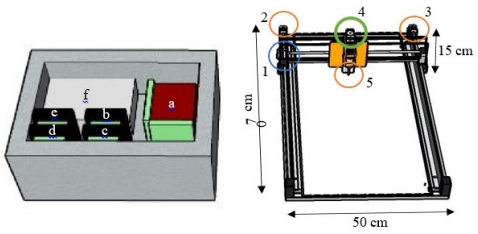

Figure 7. 4axis cnc machine design and electronic component box

- Construction Material: The material used is hollow iron with a machine size of 50 cm x 70 cm x 15 cm.
- Main Components:
  1. TB6600 Stepper Motor Driver: Connected with a Nema-23 stepper motor mounted on the engine frame for each axis.
  2. Stepper Motor:
     - X-Axis

- Y1 axis
- Y2 Axis
- Z-axis

3. Blade Blade: Used for the process of cutting or engraving on the material being machined.

- Electronic Components Box:

  - Located on the machine and containing the components of the CNC machine controller, including: a. CNC microcontroller board Mach 3 USB b. TB6600 motor driver for X c axis. TB6600 motor driver for Y1 axis d. TB6600 motor driver for Y2 e axis. TB6600 motor driver for Z f-axis. Power supply g. Fan for cooling.

With this design, it is hoped that the 4 axis CNC Router machine can operate stably and can produce precise work results according to the needs of various manufacturing applications.

Schematic of Mach 3 Board Control System Circuit

In this study, a USB Mach 3 motion card was used as a microcontroller board. TB6600 motor driver is used to control the direction and speed of the stepper motor. The Nema-23 type stepper motor will be used to convert electrical energy into mechanical energy in the form of DC motor movement. The TB6600 motor driver is chosen to regulate the direction and speed of the stepper motor, while the Nema-23 type stepper motor functions to convert electrical energy into mechanical movements necessary for machine operation. The Mach 3 Board control circuit used in this study has been designed to integrate all components efficiently, including pin settings for each motor driver and connections to auxiliary devices such as limit switches, emergency stops, and relays for external device control.

The control system circuit of the Mach 3 CNC Router 4 axis machine, which was used in this study is shown in this Figure:

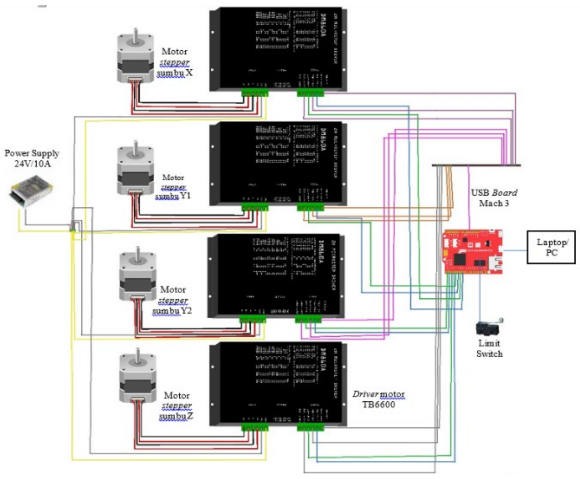

Figure 8. CNC Machine Control System Series

Here is an explanation of the schematic of the CNC machine control system circuit shown in Figure 8:

1. X-Axis Motor Driver:
   - The DIR pin (-) is connected to the XD pin on USB Mach 3.
   - The PUL pin (-) is connected to the XP pin on USB Mach 3.
   - Requires a voltage of 24V to operate the X-axis motor driver.
2. Y-Axis Motor Driver:
   - The DIR (-) pin is connected to the YD pin on USB Mach 3.
   - The PUL pin (-) is connected to the YP pin on USB Mach 3.

- Requires a voltage of 24V to operate the Y-axis motor driver.

3. Z Axis Motor Driver:
   - The DIR (-) pin is connected to the ZD pin on USB Mach 3.
   - The PUL pin (-) is connected to the ZP pin on USB Mach 3.
   - Requires a voltage of 24V to operate the Z-axis motor driver.
4. A-Axis Motor Driver:
   - The DIR (-) pin is connected to the AD pin on USB Mach 3.
   - The PUL pin (-) is connected to the AP pin on USB Mach 3.
   - Requires a voltage of 24V to operate the A-axis motor driver.
5. Power Interface Motor Driver:
   - Pins A+, A-, B+, B- are connected on the 2-phase hybrid stepper pins of the Nema-23 motor to determine the direction of rotation of the stepper motor.
6. Limit Switch:
   - The Mach 3 USB motion card 3 input pins are connected with a limit switch pin arranged in parallel for each axis, serving as a restriction of the movement of the machine.
7. Emergency Stop:
   - The Mach 3 USB motion card 4 input pins are connected with the emergency stop pin, to stop the operation of the machine instantly in an emergency.
8. Relay:
   - Pin out 4 USB motion card Mach 3 is connected with a relay pin, used to control external devices such as coolant pumps or sprayer systems.
9. USB Port:
   - The USB port on the USB motion card Mach 3 is used to connect the machine with a laptop/PC to send G-Code data and control the operation of the machine.

With this configuration, the CNC machine control system can work effectively in moving all axes (X, Y, Z, A) according to commands given through software such as Mach 3, maintaining safety with limit switches and emergency stops, and regulating auxiliary devices using relays.

To perform the analysis of observation data of the test results of the 4 axis CNC Router machine on a rectangular shape, here are the adjustments and revisions on the tables and graphs mentioned:

Table 3. Rectangular Shape Results

It	Feedrate (mm/min)	Measurement Input Value (mm)	Measurement Result Value (mm)	Accuracy (%)	Process Time (minutes)
1	50	50 70	50 70	100	3
2	100	50 70	50 70	100	3
3	150	50 70	50 70	100	3

Observational Data Analysis

After testing and calibrating the machine, the measurement results on a rectangular shape with a length of 50 mm, a width of 30 mm, and a depth of 5 mm show that the measurement result value (X, Y, Z) corresponds to the measurement input value with an accuracy of 100%. The processing time for each trial is 3 minutes.

Curve Graph

A curve graph reflecting the observation data of the test results can be presented to visualize the consistency and accuracy of the 4 axis CNC Router machine in carrying out cutting and engraving operations. Thus, this data provides an overview of the machine's performance and facilitates evaluation to ensure that the machine can produce precise shapes according to the desired design.

Discussion

This study examines the design and implementation of a 4 axis CNC Router machine that uses a USB Mach 3 board module as the main controller, supported by a TB6600 motor driver and a Nema-23 stepper motor. The machine is designed using hollow iron construction materials with compact dimensions of 50 cm x 70 cm x 15 cm. The integrated control system includes detailed configurations for each motor driver and connections to additional components such as limit switches, emergency stops, and relays. The test was conducted with a focus on the accuracy and precision of cutting on acrylic materials, showing that the machine was able to achieve an average accuracy level of 99.59% for the X-axis, 99.21% for the Y1 and Y2 axes, and 97.17% for the Z-axis. In conclusion, these CNC machines are successfully designed and implemented for manufacturing applications with high precision requirements in material cutting and engraving, offering an effective solution in the modern production industry.

Conclusion

This research has successfully designed and implemented a 4-axis CNC Router machine based on a USB Mach 3 board module, a TB6600 motor driver, and a Nema-23 stepper motor. Based on the results of testing and data analysis, several conclusions can be drawn:
Machine Performance: CNC Router machines are able to maintain a high level of accuracy with an average of 99.59% for the X-axis, 99.21% for the Y1 and Y2 axes, and 97.17% for the Z-axis.
Control System Reliability: The use of the Mach 3 USB board module as the main controller is proven to regulate the movement of all axes efficiently and consistently. The well-integrated configuration of the electronic circuit provides ease of operation and programming.
Manufacturing Applications: These machines are suitable for manufacturing applications that require high precision in cutting and engraving materials such as acrylics. The test results show that the machine can be used for various types of projects with consistent and satisfactory results.

Recommendations

Software Optimization: Performs updates and optimizations to Mach 3 software to improve operational efficiency and expand machine programming capabilities.
Safety Development: Strengthened safety features by adding more advanced safety sensors and monitoring systems to reduce the risk of accidents during machine operation.
Materials Research: Conduct further research on the ability of machines to cut harder and more complex materials, such as metals or composite materials.
Increased Production Capacity: Increasing machine capacity to expand production capabilities on a small to medium industrial scale.
By implementing these recommendations, it is hoped that the 4 axis CNC Router machine can continue to improve its performance and become a more effective solution in the modern manufacturing industry.

ACKNOWLEDGEMENTS

"We would like to express our immense gratitude for the support and contributions provided in this research. Without the assistance and cooperation of all parties involved, our achievements and results would not have been possible. Thank you to everyone who played a role in providing insights, technical support, and enthusiasm at every step of this research. Our hope is that the results of this study can bring meaningful benefits and make a positive contribution to the field. Thank you once again for all the assistance and collaboration.".

REFERENCES

Amala, M., & Widyanto, S. A. (2014). Software Development of CNC Trainer Milling Machine Operating System. Journal of Mechanical Engineering S-1, 2(3), 204-210.

Anrinal, Putra, M. I., & Viola, R. O. (2022). View of Manufacturing System Design of a CNC Laser Engraver. Journal of Mechanical Engineering, 12(1), 32–38.

Arkundato, A. (2018). Measurement and Uncertainty. Physics Module, 3(1), 1-35.
Bisono, F. (2017). The X, Y, and Z axis calibration process on the 3 Axis Wooden Router CNC machine uses the help of dial indicator and block gauge. In Proceedings Conference on Design Manufacture Engineering and its Application, 1(1), 350-356.
Budhi, A., Taufik Qurahman, M., & Rasyid, A. (2021). Design of 3 Axis Router CNC Machine Assisted by Autodesk Inverter Software. Journal Mechanical Engineering, 10(1), 1-5.
Choirony, I. V., Hariyanto, M. S., Ulum, M., Ubaidillah, A., Haryanto, & Alfita, R. (2021). Design and build Acrylic Engraver and Cutting Machine using microcontroller-based 3 axis CNC milling. Journal of Electricity, 13(1), 13-21.
Draganescu, F., Gheorghe, M., & Doicin, C.V. (2003). Models of machine tool efficiency and specific consumed energy. Journal of Materials Processing Technology, 141(1), 30-35.
Elmiawan, P., Dharmanto, Adik, Fazalul, M., & Arief, R. (2022). Mach Based Low Budget CNC Router Machine Accuracy 3. Journal of ROTOR, 15(2), 70-75.
Elvys, E. Y., & Sirama. (2015). Improvement of Movement Accuracy in 3-Axis CNC Milling Machine Prototype. Proceedings of the Annual National Seminar on Mechanical Engineering, XIV.
Febryanto, I. D., & Kartikasari, S. D. (2022). The design of the 3 Axis Router CNC Machine is based on the Quality Function Deployment (QFD) method. Journal of Industrial Engineering and Management, 17(1), 13-21.
Firsa, T., Tadjuddin, M., Husaini, S., & Syahriza. (2015). Design and Manufacture of Prototype of PC-Based 4 Axis CNC Machine (Personal Computer). Journal of Mechanical Engineering Unsyiah, 3(2), 75–79.
Harrizal, I.S., Syafri, S., & Prayitno, A. (2017). Design and Build 3 axis CNC Milling Machine Control System using Close Loop System. JOM FTEKNIK, 4(2), 1-8.
Hasibuan, M. R. A., Muhaimin, & Hardi, S. (2019). Design and Build 3 Axis CNC Milling Machine For Arduino Uno Based PCB Anggrave. Journal of TEKTRO, 3(1), 40-47.
Jufrizaldi, M., Ilyas, & Marzuki. (2020). Design and Build CNC Milling Machine Using GRBL Control System for PCB Layout Making. Journal of Applied Mechanical Sciences, 4(1), 37-44.
Marcelina, T., Kusuma Wijaya, D., Tjahyono, R., & Suprijono, H. (2021). Optimization of Acrylic Material Cutting Process on CNC Laser G-Weike LC6090 with Simplex Centroid Design Method and Multi-Response Plot Optimization. GIGA Scientific Journal, 24(1), 23–34.
Miftah. (2013). Implementation of Kuzzy Logic Sugeno Method on Microcontroller-Based Storage Room Temperature Regulation. Library of the University of Education Indonesia, 2(1), 1-10.
Morris, A.S., & Langari, R. (2016). Measurement and Instrumentation: Theory and Application Second Edition. United States of America: Elsevier Inc.
Muchlis, A., Ridwan, W., & Nasibu, I. Z. (2021). Design and Build CNC (Computer Numerical Control) Laser Machines with the Design for Assembly Method. Jambura Journal of Electrical and Electronics Engineering (JJEEE), 3(1), 23–27.
Nugroho, A. B., Auliq, M. A., & Alrasyid, M. Z. (2020). Comparative Analysis of the Performance of CNC Machine Accuracy (Computer Numerical Control) Router Based on Mach 3 and Arduino Uno Using the SQC (Statistical Quality Control) Method. Journal of Electrical and Computational Engineering (ELKOM), 2(2), 75–86.