Complex Engineering Problem

MACHINE DESIGN-I (ME-256)

CNC 3-D PLOTTER

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CNC 3-D PLOTTER

1. Problem Statement:

The problem at hand is to create a 3-axis plotter that can accurately control the movement of a pen or drawing tool along three axes (X, Y, and Z). The plotter should be capable of producing intricate and detailed artwork with high precision and minimal deviation. The key challenge is to design a system that can handle the complex motion control requirements while maintaining ease of use and cost efficiency.

1.1 Introduction:

The purpose of this report is to provide a comprehensive overview of the development of a 3-axis plotter. The project aims to design and build a versatile and precise plotting machine capable of producing high-quality drawings and designs. This report will outline the problem statement, objectives, design considerations, implementation details, challenges faced, and the overall progress made in the project.

1.2 Objective:

The objectives of the project are as follows:

1.2.1 Precision and Accuracy:

Achieve precise and accurate plotting capabilities to ensure the production of high-quality designs with minimal deviation.

1.2.2 Versatility and Flexibility:

Support various drawing techniques, such as line art, shading, and stippling, to cater to different artistic styles. The plotter should also be compatible with different drawing materials, including ink pens, markers, and pencils.

1.2.3 Scalability and Modularity:

Design a scalable and modular plotter that can be easily adapted for different sizes and configurations. This allows for future customization and expansion based on specific requirements.

1.2.4 User-Friendly Interface:

Develop an intuitive and user-friendly interface that enables easy setup, control, and customization of plotting parameters. This includes options for adjusting speed, pen pressure, and plotting patterns.

1.2.5 Compatibility and Connectivity:

Ensure compatibility with standard design software and file formats, allowing users to import and plot their digital creations seamlessly. Provide connectivity options such as USB or wireless interfaces for data transfer and control.

1.2.6 Robustness and Reliability:

Build the plotter with robust and durable components to ensure long-term reliability and stable performance. The plotter should be able to handle continuous plotting sessions without compromising accuracy or encountering frequent breakdowns.

1.2.7 Cost Efficiency:

Optimize cost efficiency without compromising quality. Carefully select components and optimize the design to offer an affordable solution for hobbyists, artists, and small-scale businesses.

2. Design and Implementation:

2.1 Mechanical Design:

The mechanical design of the plotter involves creating a sturdy frame to support the motion control system and hold the drawing tool. The frame is designed to minimize vibrations and ensure stable operation during plotting. Linear guides and precision motors are used to achieve smooth and accurate motion along the X, Y, and Z axes.

2.2 Motion Control System:

The plotter's motion control system consists of stepper motors, motor drivers, and control electronics. Advanced control algorithms are implemented to ensure precise positioning and movement of the pen or drawing tool. The control system is integrated with the user interface for easy operation and customization.

2.3 Enhancing Flexibility and Customizability:

The adaptive design of the plotter has revolutionized the concept of plotting and artistic expression by incorporating flexible and customizable features. This design approach allows users to easily adapt and modify the plotter to suit their specific needs and preferences. By integrating modular components, adjustable parameters, and scalable architecture, the plotter offers a versatile platform for a wide range of applications.

2.4 Modular Architecture and Customizable Parameters:

The plotter's modular architecture enables users to interchange components such as pen holders and drawing tools, facilitating quick customization and reconfiguration. Additionally, the plotter incorporates adjustable parameters, including speed, plotting patterns, and pen pressure, empowering users to fine-tune the plotter's performance based on their artistic requirements. This adaptability enhances the plotter's versatility and user-friendliness, catering to a diverse range of artistic styles and materials.

2.5 Scalability and Upgradability:

The plotter is designed to be scalable and upgradable, ensuring long-term viability and adaptability. It features expansion slots and interfaces that enable users to incorporate additional axes or advanced control modules, expanding the plotter's capabilities as needed. This scalability allows the plotter to keep pace with evolving technological advancements and user demands, making it a future-proof investment.

2.6 Iterative Development and Case Studies:

The plotter's adaptive design is the result of an iterative development process, driven by user feedback and market insights. Through continuous improvement, the plotter has evolved to cater to various artistic techniques and plot sizes. Real-world case studies highlight the plotter's adaptability in different contexts, showcasing its ability to produce intricate designs, handle various drawing materials, and accommodate individual artistic preferences.

3.0 Product Usage in Plotter:

Motor Power Requirements: Determine the power requirements by considering factors such as the desired speed, torque, and acceleration of the plotter. Calculate the power consumption of the stepper motors using the formula: Power (W) = Voltage (V) x Current (A). Consider the power required for all the stepper motors used in the plotter.

3. 0.1CNC Shield Board for A4988 Stepper Motor Driver for Arduino V3 (SKU: 0623):

The CNC Shield Board (see fig 3.0.1) is used to interface the stepper motor drivers with the Arduino controller. It provides the necessary connections and power distribution for controlling the stepper motors.

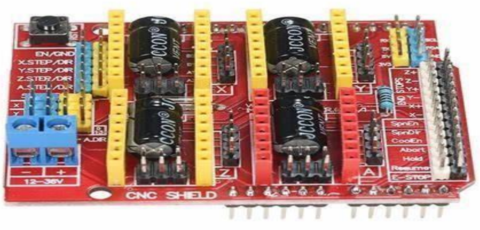

Figure 3.0.1:CNC Shield Board

3.0.2A4988 Stepper Motor Driver Module with Heatsink (SKU: 0624):

The A4988 stepper motor (fig 3.0.2)driver modules are used to control the Nema17 stepper motors. These modules provide the necessary current control and step pulse generation to accurately control the movement of the motors.

Figure 3.0.2:Stepper Motor Driver with Heatsink

3.0.3 Nema17 6-12V Stepper motor 1.8/step 6 Wire (SKU: 1591):

The Nema17 stepper motors (figure 3.0.3) are the main actuators in the plotter. They provide precise movement along the X, Y, and Z axes to control the position of the pen or drawing tool. The 6-wire configuration allows for bipolar operation, ensuring accurate control.

Electrical Specification:

Step Angle: 1.8 deg

Holding Torque: 42Ncm(59.49oz.in)

Rated Current/phase: 1.50A

Phase Resistance: 2.3ohms

Inductance: 4.0mH ± 20%(1KHz)

Physical Specification Frame Size: 42 x 42mm B

Calculations:

Based on the electrical specifications of the Nema17 stepper motor, we can calculate the torque using the following formula:

Torque (Nm) = Holding Torque (Nm) × Rated Current/phase (A) / √2

Using the given values:

Holding Torque = 42 Ncm = 0.042 Nm

Rated Current/phase = 1.50 A

Plugging these values into the formula:

$$\text{Torque} = 0.042\ \text{Nm} \times 1.50\ \text{A} / \sqrt{2} \approx 0.059\ \text{Nm}$$

Therefore, the calculated torque for the Nema17 stepper motor is approximately 0.059 Nm.

Figure 3.0.3:Stepper motor

3.0.4 GT2 6mm Open Timing Belt for 3D Printer (SKU: CNC-099):

The GT2 timing belt (figure 3.0.4) is used in the plotter to transmit motion from the stepper motors to the pulleys. It provides high torque transfer capability and precise positioning.

General Specifications

The GT2 timing belt is a popular choice for 3D printers and other precision motion control systems. It offers high precision and low backlash, allowing for accurate positioning and smooth motion. The neoprene rubber body provides flexibility and durability, while the fiberglass tensile cords provide strength and stability. The tooth facing material, made of nylon, ensures reliable engagement with the pulley system.

The 2GT-6mm specification indicates that the belt has a 2mm pitch, meaning that each tooth is spaced 2mm apart. The width of the belt is 6mm, which determines the contact area with the pulley.

These specifications make the GT2 6mm Open Timing Belt suitable for transmitting motion and power in applications where precision and reliability are essential, such as 3D printers.

3.0.4.1 Belt Length Calculation:

To calculate the belt length, we need the center-to-center distance between the pulleys or sprockets (C), and the diameters of the first (D1).

3.0.5 Center-to-center distance (C) = 100mm

3.0.6 Diameter of the first pulley/sprocket (D1) = 20mm
3.0.7 Diameter of the second pulley/sprocket (D2) = 40mm

Using the formula:

Belt Length (L) = 2C + [(π × (D1 + D2)) / 2]

Substituting the given values:

Belt Length (L) = 2(100mm) + [(π × (20mm + 40mm)) / 2]

Belt Length (L) = 200mm + [(π × 60mm) / 2]

Belt Length (L) = 200mm + (π × 30mm)

Belt Length (L) ≈ 200mm + 94.25mm

Belt Length (L) ≈ 294.25mm

Therefore, the calculated belt length for the GT2 6mm Open Timing Belt is approximately 294.25mm.

3.0.4.2 Speed Ratio Calculation:

To calculate the speed ratio, we need the number of teeth on the driving pulley/sprocket (N1) and the number of teeth on the driven pulley/sprocket (N2). Let's assume:

3.0.5 Number of teeth on the driving pulley/sprocket (N1) = 16
3.0.6 Number of teeth on the driven pulley/sprocket (N2) = 32

Using the formula:

Speed Ratio = (N2 / N1)

Substituting the given values:

Speed Ratio = 32 / 16
Speed Ratio = 2

Therefore, the calculated speed ratio for the GT2 6mm Open Timing Belt is 2.

Figure 3.0.4:Timing Belt

3.0.5 Toothless 3mm GT2 Timing Belt Idler Pulley with Bearing For 3D Printer (SKU: CNG-106):

The toothless GT2 (figure 3.0.5) timing belt idler pulleys are used to guide and redirect the timing belt, ensuring smooth and accurate motion.

Figure 3.0.5 Idler Pulley

3.0.6 8mm, 10mm, 12mm Linear Rail Shaft Smooth Rod For CNC Machine And 3D Printer - 8mm, 500mm (SKU: CNC-112-500):

The linear rail shafts (figure 3.0.6) provide linear guidance for the movement of the plotter's components. They ensure smooth and precise motion along the axes, enhancing overall accuracy.

Figure 3.0.6 Linear Rail Shaft Smooth Rod

3.0.7 LM8UU 8mm Linear Ball Bearing Bush Bushing (SKU: CNC-024):

The LM8UU linear ball bearing bushings (figure 3.0.7) are used in conjunction with the linear rail shafts. They provide low-friction movement and stability, minimizing any play or wobbling during operation.

Figure 3.0.7 Ball Bearing Bush Bushing

3.0.8 Nema17/23/14 Stepper Motor Angle Mount Bracket for CNC & 3D (SKU: CNC-072):

The Nema17/23/14 stepper motor (figure 3.0.8) angle mount brackets are used to securely mount the stepper motors to the frame or other structural components. They provide stability and proper alignment for the motors.

Figure 3.0.8 Angle Mount Bracket

3.0.9 GT2 20 Teeth 5mm Bore Timing Aluminum Pulley for Stepper Motor (SKU: CNC-058):

The GT2 timing pulleys (figure 3.0.9) are attached to the stepper motor shafts and are used in conjunction with the timing belt. They provide the necessary mechanical advantage and torque transmission for accurate motion control.

These components, when integrated and properly configured, enable the precise and controlled movement of the plotter, allowing it to create intricate designs and drawings with high accuracy and quality.

Figure 3.0.9 Bore Timing Aluminum Pulley

4.0 Software Design:

Custom software is developed to interface with the plotter and control its functions. The software allows users to import digital designs, specify plotting parameters, and control the plotter's motion. Compatibility with standard design software and file formats is ensured to facilitate seamless integration with existing workflows.

4.1 CAD Model:

The 3D model is developed using Cinema4D software.

(a) (b)

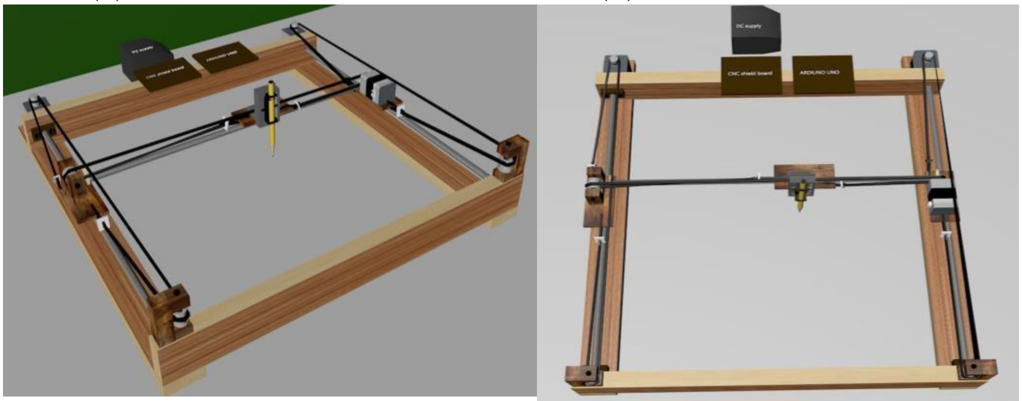

Figure 4.1(a)**CAD Model Isometric View(b) CAD Model Top View**

4.2 During Manufacturing:

After buying materials from the market, we made our physical model.

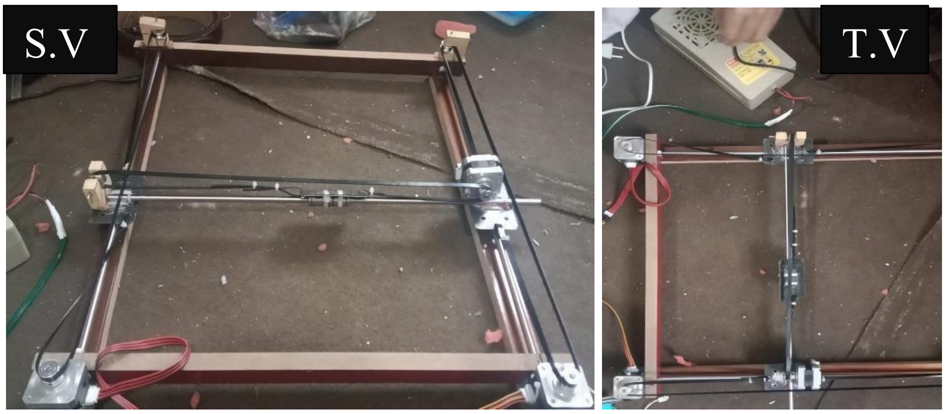

Figure 4.2:3D CNC Plotter (a)side view(b)Top view

5.0 Challenges Faced:

Throughout the project, several challenges were encountered and addressed:

5.1 Motion Control Optimization:

Achieving smooth and accurate motion control along three axes required fine-tuning of control parameters and optimization of control algorithms.

5.2 Mechanical Rigidity:

Ensuring the mechanical rigidity of the plotter frame was a challenge to minimize vibrations and maintain precision during operation. Additional reinforcements and damping techniques were implemented to address this issue.

5.3 Software Integration:

Integrating the plotter with various design software and ensuring seamless data transfer and control posed a challenge that required close collaboration with software developers and thorough testing.

6. Future Work:

There are several aspects to address in future development:

6.1 Enhanced User Interface:

Further improvements can be made to the user interface, providing more intuitive controls, additional customization options, and real-time feedback on plotting progress.

6.2 Advanced Drawing Techniques:

Exploring and implementing advanced drawing techniques, such as gradient shading and hatching patterns, would expand the plotter's artistic capabilities.

6.3 Remote Control and Collaboration:

Adding remote control capabilities and collaboration features would allow users to control the plotter from a distance and collaborate on projects with others.

6.4 Optimization and Cost Reduction:

Continued optimization of the plotter's components and manufacturing processes can further enhance performance and reduce production costs.

7.0 Cost Analysis:

Product	Quantity	Price
CNC Shield Board for A4988 Stepper Motor Driver for Arduino V3 Engraver 3D Printer SKU: 0623	1	350
Nema17 6-12V Stepper motor 1,8/step 6 Wire SKU: 1591	3	1200

A4988 Stepper Motor Driver Module with Heatsink SKU: 0624	3	810
GT2 6mm Open Timing Belt for 3D Printer SKU: CNC-099	4	1200
Toothless 3mm GT2 Timing Belt Idler Pulley With Bearing For 3D Printer SKU: CNG-106	3	750
8mm, 1Omm, 12mm Linear Rall Shaft Smooth Rod For CNC Machine And 3D Printer- 8mm, 500mm Diameter: 8mm Length: S00mm SKU: CNC-112-500	3	2100
LM8UU 8mm Linear Ball Bearing Bush Bushing SKU: CNC-024	6	1320
Nema17/23/14 Stepper Motor Angle Mount Bracket for CNC& 3D SKU: CNC-072	3	750
GT2 20 Teeth 5mm Bore Timing Aluminum Pulley for Stepper Motor SKU: CNC-O58	3	390

8.0 Conclusion

In conclusion, the development of a 3-axis plotter has progressed significantly, with achievements in mechanical design, motion control, software development, and testing. The objectives of precision, versatility, scalability, user-friendliness, compatibility, reliability, and cost efficiency are addressed through careful design considerations and iterative improvements. Challenges faced during the project have been overcome through collaborative problem-solving and thorough testing. The future work outlined will further enhance the plotter's capabilities and usability.