Project report on
XY -Pen Plotter

In partial fulfilment of the requirements for the degree of

Master of Engineering in Mechatronics and Robotics

Under the subject of:

Workshop Mechatronics

Submitted By:
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CERTIFICATE

This is to certify that the project titled "**XY Pen plotter**" submitted by **SANTOSH KONDUSKAR: 316535; ONKAR NANDOSKAR: 316687; TEJAS SHASTRAKAR: 316586; ANAND KADPE: 316664** to the Mechanical Engineering Department of Schmalkalden University of Applied Sciences, in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Mechatronics and Robotics is a record of our own work.

To the best of my knowledge, this report has not been submitted to any other University or Institute for award of any degree

This is to certify that the statements made by the candidate are correct to the best of our knowledge and belief. It is further understood that by this certificate the undersigned do not endorse or approve any statement made, opinion expressed or conclusion drawn herein, but approve the report only for the purpose for which it is submitted

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ACKNOWLEDGEMENT

We would like to put forth our regardful thanks to all those who had helped us in guiding us to get the most out of this golden opportunity to learn the most during this project on XY Pen plotter.

We pay our special thanks to **Prof. Dr.-Ing. Stefan Roth, Prof. Dr.-Ing. Silvio Bachmann & Mr. Joshua Voll,** who provided excellent guidance as well as they had always been supporting and helpful

We also put forth our special thanks to all the concerned persons who have enabled us to have an opportunity to work at the prestigious organization

Thankful,

Anand Kadpe (316664)

Onkar Nandoskar (316687)

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1. Introduction

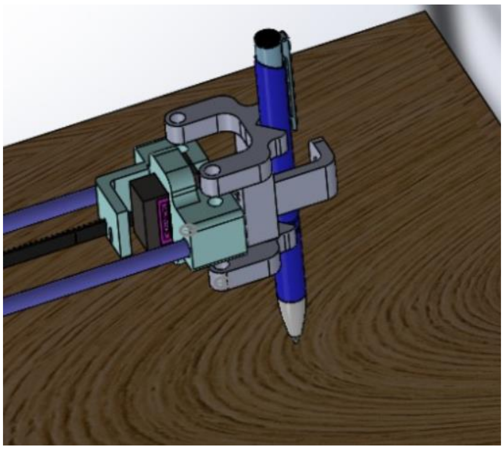


Figure 1.1 Pen Plotter

The 2D pen plotter project is an innovative exploration into automated drawing systems, designed to reproduce detailed and intricate patterns on a flat surface. In this project, we focus on the architectural representation of the Nikolaus House, a structure known for its complex and artistic design. The aim is to develop a machine that accurately translates digital drawings into physical ones through the precise movement of a pen controlled by motors and software algorithms.

Pen plotters operate by moving a pen in two dimensions (X and Y axes) over a piece of paper or a similar surface. This project combines mechanical, electrical, and software components to ensure precise control and synchronization of the system's movements. Key hardware elements, such as geared motors, sensors, and microcontrollers, are integrated to form the physical mechanism that drives the pen. Additionally, custom software is developed to interpret digital images and convert them into commands that control the plotter's motors, allowing for the automated recreation of the Nikolaus House's fine details.

The Nikolaus House was chosen due to its intricate architectural features, which provide an ideal challenge for testing the plotter's ability to handle complex patterns with accuracy and precision. This project not only highlights the technical process of building a pen plotter but also demonstrates its potential applications in fields like art, drafting, architectural visualization, and educational tools.

Through this project, we aim to explore and apply core principles of mechanical design, electronics, and programming, allowing us to bring together various technologies into a single functional system. The result is a machine capable of producing high-quality drawings, demonstrating the fusion of automation with creative expression, and offering insights into the growing field of automated design tools.

2. <u>Project Goals and Project Planning</u>

2.1 Project Goals and Objectives

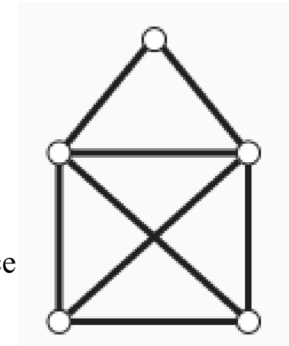


Figure 2.1 Nikolaus Haus

- **Design a Functional 2D Pen Plotter:** Develop a machine capable of moving a pen across a flat surface with precision, allowing it to reproduce Nikolaus House.
- **Accurate Replication of Nikolaus House:** The primary goal is to accurately recreate the the Nikolaus House. This involves ensuring that the plotter's movements are precise and smooth to capture the intricacies of the design.
- **Integration of Hardware and Software:** Achieve seamless integration between the hardware components (motors, sensors, microcontrollers) and the software (algorithms to translate digital images into pen movements). The system should be efficient and reliable
- **Optimize Speed and Accuracy:** Balance the speed of the plotter with its accuracy, ensuring that it can create Nikolaus House in a reasonable amount of time without sacrificing detail or precision.
- **Develop a User-Friendly Interface:** Create a user-friendly interface that allows easy control of the plotter. This interface should enable users to start, stop, and adjust the plotting process with ease.
- **Test and Validate System Performance:** Conduct thorough testing of the pen plotter to evaluate its accuracy, speed, reliability, and ability to handle complex designs like the Nikolaus House. Make iterative improvements based on test results to optimize performance.

2.2 Project Planning

- **Research and Design (2 weeks):** Define the project's requirements and create a conceptual design, including the mechanical and electrical components.
- **Hardware Setup (1 week):** Source motors, sensors, the ESP32 microcontroller, and other materials needed for assembly. Build the mechanical structure and integrate the motors and pen holder for accurate movement along the X and Y axes
- **Software Development (1 week):** Write the control software to interpret drawing commands and translate them into motor movements. Integrate algorithms that control the plotter's path and ensure smooth operation, including pen-lifting via the servo.

- **Testing and Iteration (2 weeks):** Test the system's accuracy by plotting simple designs, then move on to complex patterns like Nikolaus House. Make adjustments to the hardware and software to improve performance, precision, and reliability.
- **Final Integration (1 week):** Combine all hardware and software components, ensuring seamless interaction between motors, sensors, and the control algorithms. Perform final accuracy and speed tests, optimizing the plotter for consistent results.
- **Report and Presentation (1 week):** Document the entire project, including design choices, challenges, and test results. Prepare the final report and a presentation showcasing the plotter's capabilities and outcomes.

2.3 Organization Chart

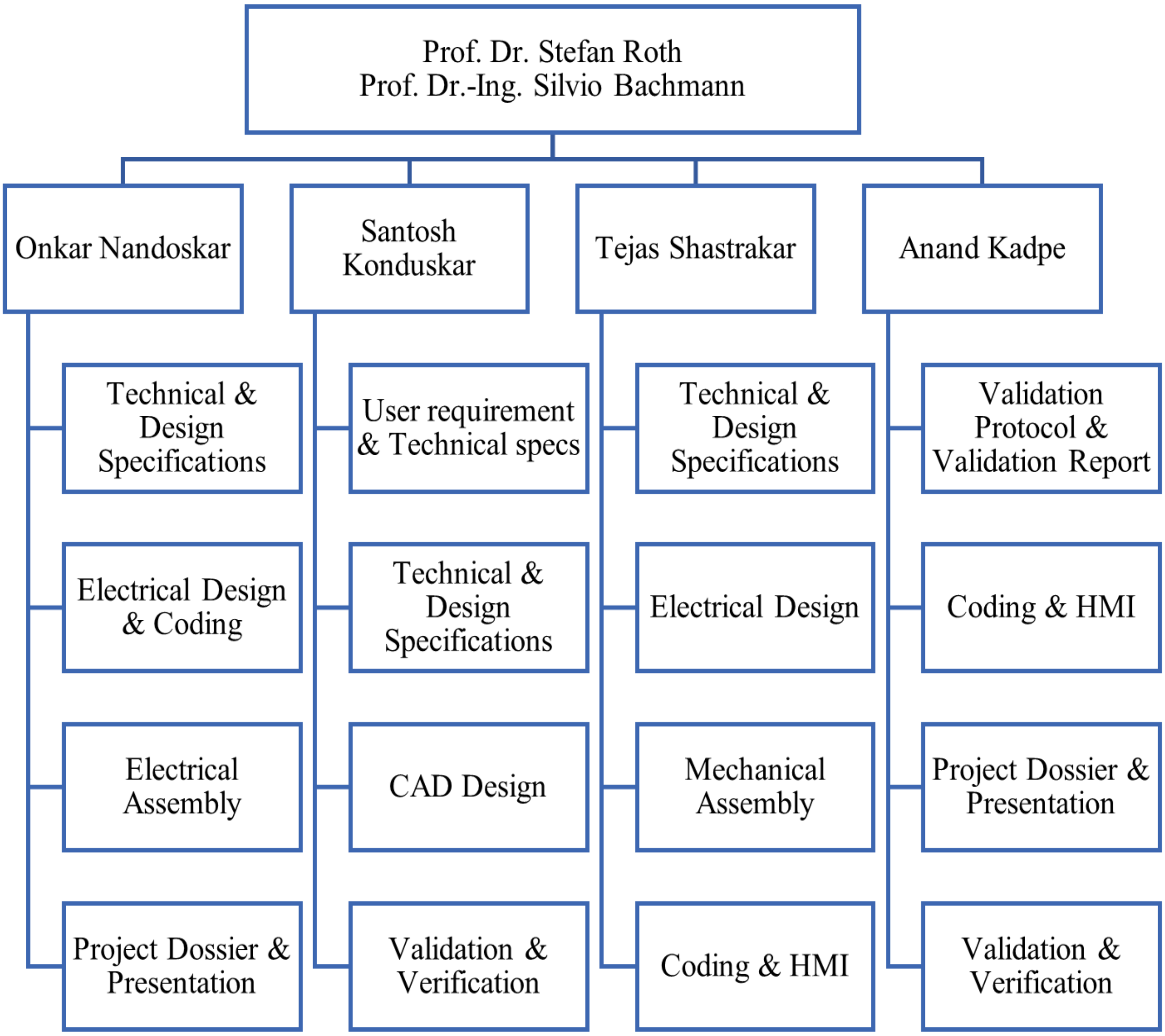


Figure 2.2 Organization Chart

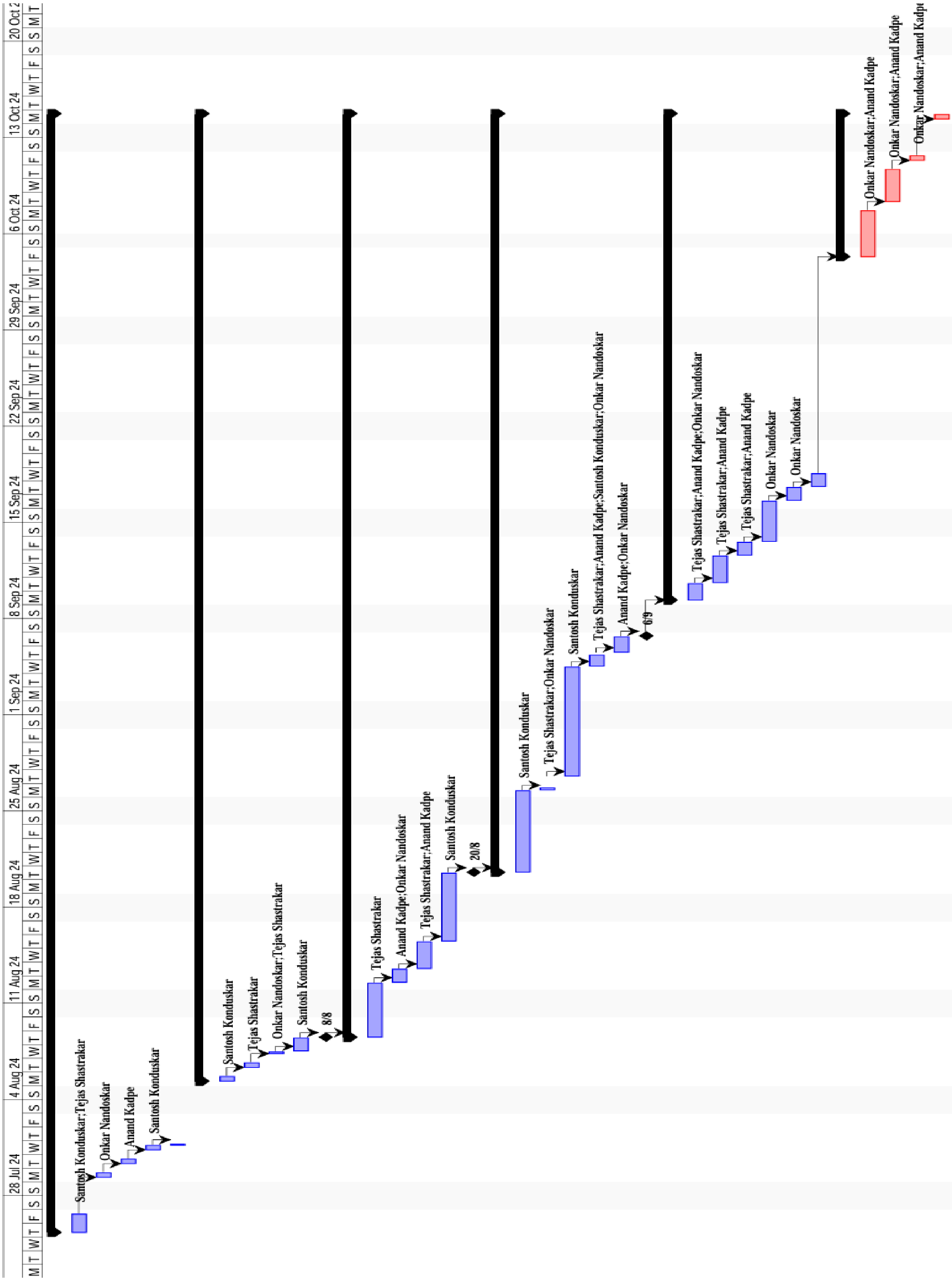
2.4 Project Timeline

The project timeline for the pen plotter includes phases such as research and design, component acquisition, prototyping, testing, and final implementation, spanning a period of more than three months.

Table 2.1 Project Timeline

		Name	Duration	Start	Finish	Predecessors	Resource Names
1		**Idea Phase**	**59.125 day...**	**25/7/24 8:00 AM**	**14/10/24 5:00 PM**		
2		Market Research	2 days?	25/7/24 8:00 AM	26/7/24 5:00 PM		Santosh Konduskar;Tejas S...
3		Benchmarking models of ...	1 day?	29/7/24 8:00 AM	29/7/24 5:00 PM	2	Onkar Nandoskar
4		Brainstorming for new fe...	1 day?	30/7/24 8:00 AM	30/7/24 5:00 PM	3	Anand Kadpe
5		Set User Requirement	1 day?	31/7/24 8:00 AM	31/7/24 5:00 PM	4	Santosh Konduskar
6		Idea phase finished, Deli...	0 days?	31/7/24 5:00 PM	31/7/24 5:00 PM	5	
7		**Project Planning**	**52.125 day...**	**5/8/24 8:00 AM**	**14/10/24 5:00 PM**		
8		Budget and Resource ...	1 day?	5/8/24 8:00 AM	5/8/24 5:00 PM		Santosh Konduskar
9		Set-Up Project Team	1 day?	6/8/24 8:00 AM	6/8/24 5:00 PM	8	Tejas Shastrakar
10		Technical Specification	0.5 days?	7/8/24 8:00 AM	7/8/24 1:00 PM	9	Onkar Nandoskar;Tejas Sha...
11		Design Specification	1 day?	7/8/24 1:00 PM	8/8/24 1:00 PM	10	Santosh Konduskar
12		Project Planning Phase...	0 days?	8/8/24 1:00 PM	8/8/24 1:00 PM	11	
13		**Development Phase**	**48.625 day...**	**8/8/24 1:00 PM**	**14/10/24 5:00 PM**	**12**	
14		Concept Development	2 days?	8/8/24 1:00 PM	12/8/24 1:00 PM		Tejas Shastrakar
15		Electrical Design	1 day?	12/8/24 1:00 PM	13/8/24 1:00 PM	14	Anand Kadpe;Onkar Nandos...
16		Software Design	2 days?	13/8/24 1:00 PM	15/8/24 1:00 PM	15	Tejas Shastrakar;Anand Ka...
17		Mechanical / CAD De...	3 days?	15/8/24 1:00 PM	20/8/24 1:00 PM	16	Santosh Konduskar
18		CAD Model & Electric...	0 days?	20/8/24 1:00 PM	20/8/24 1:00 PM	17	
19		**Prototyping & Fab...**	**40.625 day...**	**20/8/24 1:00 PM**	**14/10/24 5:00 PM**	**18**	
20		3D printing of test ...	4 days?	20/8/24 1:00 PM	26/8/24 1:00 PM		Santosh Konduskar
21		Test piece printing ...	0.5 days?	26/8/24 1:00 PM	27/8/24 1:00 PM	20	Tejas Shastrakar;Onkar Nan...
22		3D printing of plast...	6 days?	27/8/24 1:00 PM	4/9/24 1:00 PM	21	Santosh Konduskar
23		Assembly	0.75 days?	4/9/24 1:00 PM	5/9/24 1:00 PM	22	Tejas Shastrakar;Anand Ka...
24		Electrical Wiring	1.5 days?	5/9/24 1:00 PM	6/9/24 5:00 PM	23	Anand Kadpe;Onkar Nandos...
25		Prototype Complete	0 days?	6/9/24 5:00 PM	6/9/24 5:00 PM	24	
26		**Testing and calib...**	**27.125 day...**	**9/9/24 8:00 AM**	**14/10/24 5:00 PM**	**25**	
27		Programming and...	1.667 days?	9/9/24 8:00 AM	10/9/24 2:20 PM		Tejas Shastrakar;Anand Ka...
28		X and Y Axis calib...	2 days?	10/9/24 2:20 PM	12/9/24 2:20 PM	27	Tejas Shastrakar;Anand Ka...
29		Testing drawing ...	1 day?	12/9/24 2:20 PM	13/9/24 2:20 PM	28	Tejas Shastrakar;Anand Ka...
30		Verification Proto...	1 day?	13/9/24 2:20 PM	16/9/24 2:20 PM	29	Onkar Nandoskar
31		Validation Protoc...	1 day?	16/9/24 2:20 PM	17/9/24 2:20 PM	30	Onkar Nandoskar
32		Testing and calib...	1 day?	17/9/24 2:20 PM	18/9/24 2:20 PM	31	
33		**Documentation**	**8.125 days?**	**4/10/24 8:00 AM**	**14/10/24 5:00 PM**	**32**	
34		Project Present...	3.125 days?	4/10/24 8:00 AM	7/10/24 5:00 PM		Onkar Nandoskar;Anand Ka...
35		Project Dossier	3 days?	8/10/24 8:00 AM	10/10/24 5:00 PM	34	Onkar Nandoskar;Anand Ka...
36		Bill of material	1 day?	11/10/24 8:00 AM	11/10/24 5:00 PM	35	Onkar Nandoskar;Anand Ka...
37		Documentation...	1 day?	14/10/24 8:00 AM	14/10/24 5:00 PM	36	

Table 3.2 Gantt Chart



2.5 DEVELOPMENT OF DOCUMENTATION ACCORDING TO V-MODEL

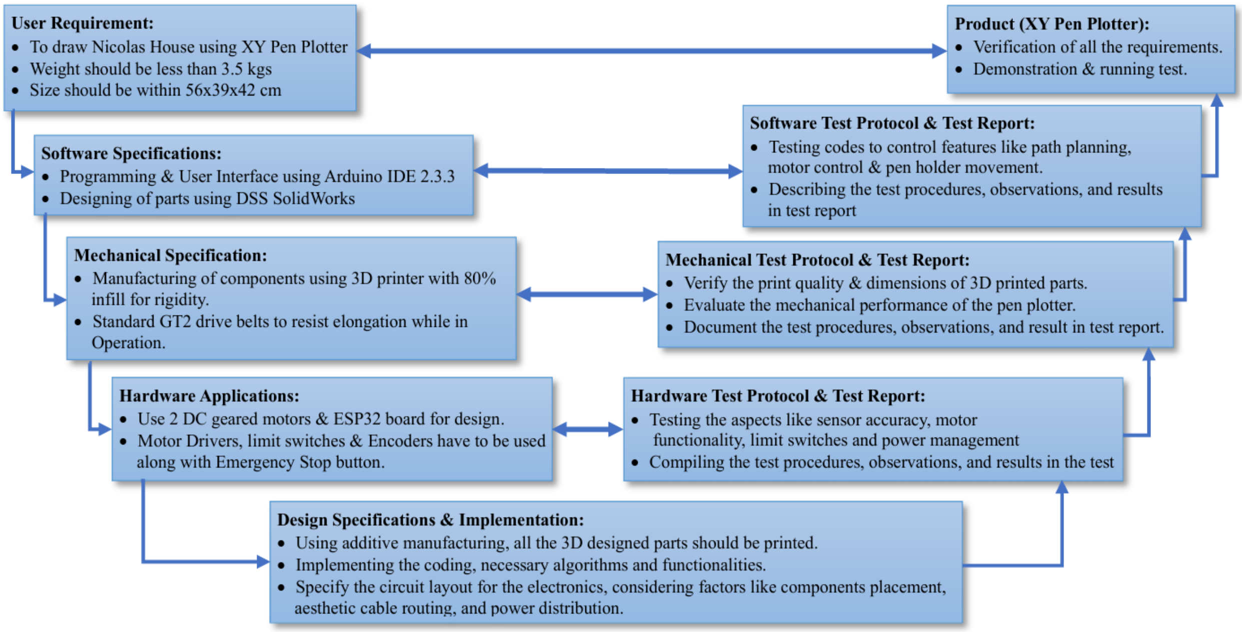


Figure 2.3 V-Model

The V-model of the pen plotter project provides a comprehensive framework for its development, ensuring a systematic and structured approach. The project begins with the User Requirement stage, where the specific needs and expectations of the users are gathered and documented. This information forms the foundation for the subsequent stages. The Technical Specification stage focuses on defining the detailed specifications of the pen plotter system, considering aspects such as size, resolution, speed, and accuracy. The Software Requirements stage identifies and documents the necessary software functionalities, user interface design, and programming requirements. The Mechanical Requirements stage specifies the mechanical components, materials, and design considerations, ensuring the robustness and functionality of the pen plotter's physical structure. The Electrical Requirements stage involves determining the electrical components, circuitry, and power requirements for the pen plotter.

The Implementation stage encompasses building the pen plotter system, including the assembly of mechanical and electrical components, integration of control systems, and software development. In the System Integration stage, the individual subsystems are combined and tested to ensure proper interaction and functionality. The Verification of Design stage involves rigorous testing and evaluation to ensure that the pen plotter design meets the specified requirements. System Testing is conducted to validate the overall performance, functionality, and reliability of the pen plotter under various conditions. The Test Report documents the results and findings from the system testing phase, including any issues encountered and their resolutions.

Finally, the completed and tested product, the XY Pen Plotter, is ready for deployment and use.

By following the V-model, the pen plotter project ensures a systematic and thorough approach to its development, resulting in a reliable and high-quality pen plotter system.

2.6 MORPHOLOGICAL CHART

Figure 2.4 Morphological Chart

The morphological chart for the pen plotter project is a visual tool that presents various design options and their corresponding features. It helps in systematically exploring and selecting components such as motors, controllers, sensors, pens, and user interface elements, enabling informed decision-making for the pen plotter's design and functionality.

MODULES	CONCEPT - 1	CONCEPT - 2	CONCEPT - 3
POWER SUPPLY	DC POWERED (ADAPTER 12V)	DC POWERED (BATTERY 5V)	SOLAR POWERED
USER INTERFCE	WEB BASED GRAPHICAL USER INTERFACE	SERIAL COMMAND BASED	BLYNK BASED IoT APP INTERFACE
DRIVE MODILES	DC GEARED MOTOR	STEPPER MOTOR	SERVO MOTOR
FABRICATION PROCESS	3D PRINTING	INJECTION MOLDING	METAL FABRICATION
MOTOR DRIVERS	L298N	SPARKFUN QWIC MOTOR DRIVER	TB6560
MICROCONTROLLER	ESP32 BOARD	ARDUINO UNO	RASPBERRY PI
LIMIT SWITCH	MICRO LIMIT SWITCHES	MAGNETIC PROXIMITY SENSOR	OPTICAL ENDSTOPS
ENCODER	MAGNETIC ENCODERS	OPTICAL ENCODERS	ROTARY ENCODERS
PEN LIFTING	DC SOLENOID	SERVO MOTOR	MANUAL METHOD

2.7 PAIRWISE COMPARISON AND DECISION MATRIX

To determine the winning pen plotter design concept from the three concepts resulting from the morphological chart, pairwise comparison and decision matrix techniques were employed. Firstly, a set of criteria was established, such as accuracy, speed, cost, reliability, and ease of use. These criteria were essential in evaluating the design concepts. With pairwise comparison, each design concept was systematically compared against the others based on the identified criteria. A relative preference or value was assigned to each concept for each criterion. By comparing all possible pairs of concepts, a comprehensive assessment was made. Next, a decision matrix was constructed. The identified criteria were listed as columns, and each design concept was listed as rows. Weights were assigned to each criterion based on its relative importance. Then, each concept was evaluated against each criterion, and scores were given based on its performance. The scores were multiplied by the respective weights and summed up to obtain a total score for each concept. Finally, by analysing the total scores, the concept with the highest score was determined as the winning pen plotter design concept. This systematic approach ensured an objective evaluation and facilitated the selection of the most suitable design concept based on the specified criteria.

MORE IMPORTANT \ AS	COST	DRAWING QUALITY	DRAWING SPEED	DURABILITY	PORTABILITY	UI / EASE OF USE	SUM Σ	PERCENTAGE %
COST		3	5	1	1	1	11	12.2%
DRAWING QUALITY	3		5	5	5	3	21	23.3%
DRAWING SPEED	1	1		1	5	5	13	14.4%
DURABILITY	5	1	5		5	5	21	23.3%
PORTABILITY	5	1	1	1		1	9	10.0%
UI / EASE OF USE	5	3	1	1	5	5	15	16.7%
			CHECK SUM					100%

Criterion A Is More Important Than **Criterion B** => **5 Points** For **A**

Criterion A Is Equal to **Criterion B** = **3 Points** For **A** and **B**

Criterion A Is Less Important Than **Criterion B** =< **1 Points** For **A**

Figure 2.5 PAIRWISE COMPARISON AND DECISION MATRIX

CRITERIA	RATING RAGE	WEIGHT	CONCEPT 1		CONCEPT 2		CONCEPT 3	
			POINTS	POINTS*WEIGHT	POINTS	POINTS*WEIGHT	POINTS	POINTS*WEIGHT
COST	1- >200€ 3- 150€ to 200€ 5- <150€	12.2%	5	0.61	1	0.12	3	0.37
DRAWING QUALITY	1- Accuracy > 5mm 3- 1mm < Accuracy < 5mm 5- Accuracy < 1mm	23.3%	5	1.17	3	0.70	1	0.23
DRAWING SPEED	1- Drawing Time > 2min 2- 1min < Time < 2min 5- Drawing Time < 1min	14.4%	3	0.43	5	0.72	1	0.14
DURABILITY	1- Comprerssed wood construction 2- Wood construction 3- Metal base construction	23.3%	1	0.23	3	0.70	5	1.17
PORTABILITY	1- >5 kg 3- 3.5kg to 5kg 5- < 3.5kg	10.0%	5	0.50	3	0.30	1	0.10
UI / EASE OF USE	1- Coding Interface 3-IOT Interface 5-HTML WebUI GUI	16.7%	5	0.83	1	0.17	3	0.50
CHECK SUM		100%	24.00	3.78	16.00	2.17	14.00	2.51

1-3-5 POINT SYSTEM

3. DESIGN STAGE

3.1 Components

a. **D.C. Motor:** DC motor is used in pen plotter project precise, rotary motion for controlling pen movement, enabling accurate plotting and drawing on various surfaces.

Figure 3.1 DC Motors

b. **D.C. Geared Motor:** A 6V high torque gear motor is used to provide strong rotational force at lower speeds, making it ideal for applications requiring powerful yet compact movement. It's commonly used in robotics, automation, and small machinery.

Figure 3.2 D.C. Geared Motor

c. **ESP32 Board:** ESP32 board used in pen plotter project versatile microcontroller with built-in Wi-Fi and Bluetooth, providing wireless connectivity and control for precise pen plotting and automation.

Figure 3.3 ESP32 Board

d. **L298N Motor Driver:** L298N Motor Driver used in pen plotter project dual H-bridge module controlling motor speed and direction, enabling precise movement and positioning of the pen in the plotter.

Figure 3.4 L298N Motor Driver

e. **Pulley**: Pulley used in pen plotter project mechanical component with grooves, facilitating smooth and controlled rotation of belts or cables for accurate pen positioning and movement.

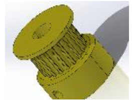


Figure 3.5 Pulley

f. **Linear Ball Bearings**: Linear ball bearings used in pen plotter project rolling element bearings providing smooth and low-friction linear motion, ensuring precise and stable movement of the plotter carriage along the rails.

Figure 3.6 Linear ball bearing

g. **TFT Display:** TFT display used in pen plotter project compact, high resolution screen for real-time visualization of plotter status, settings, and feedback, enhancing user interface and control.

h. **Adapter 12V (DC Power):** 12V DC Adapter used in pen plotter project provides regulated power supply to the plotter system, ensuring stable and reliable operation of the components and motors.

Figure 3.7 TFT display

i. **GT2 Driver Belt:** GT2 driver belt used in pen plotter project high quality toothed belt for precise and synchronized movement, transferring rotational motion to linear motion with minimal backlash.

Figure 3.8 GT2 driver belt

j. **Screws and Fasteners:** Screws and fasteners used in pen plotter project securely fasten components, ensuring structural integrity and precise alignment for stable and accurate operation of the plotter system.

Figure 3.9 Screws and Fasteners

k. **Micro Limit Switch:** Micro Limit Switch used in pen plotter project small, mechanical switch with precise actuation, providing accurate end stop detection for pen movement control and positioning accuracy.

Figure 3.10 Micro Limit Switch

l. **49E Hall Sensor:** 49E Hall Sensor used in pen plotter project magnetic field sensor detecting changes in magnetic field intensity, providing feedback for precise position sensing and control in the plotter system.

Figure 3.11 49E Hall Sensor

m. **DC-DC Voltage Converter:** DC-DC voltage converter used in pen plotter project converts input voltage to desired output voltage, providing power flexibility and stability for various components in the plotter system.

Figure 3.12 DC-DC voltage

n. **Push Button**: Push button (kill switch) used in pen plotter project emergency stop button for immediate system shutdown, ensuring operator safety and preventing potential accidents during operation.

Figure 3.13 Push button

3.1 ELECTRICAL DESIGN

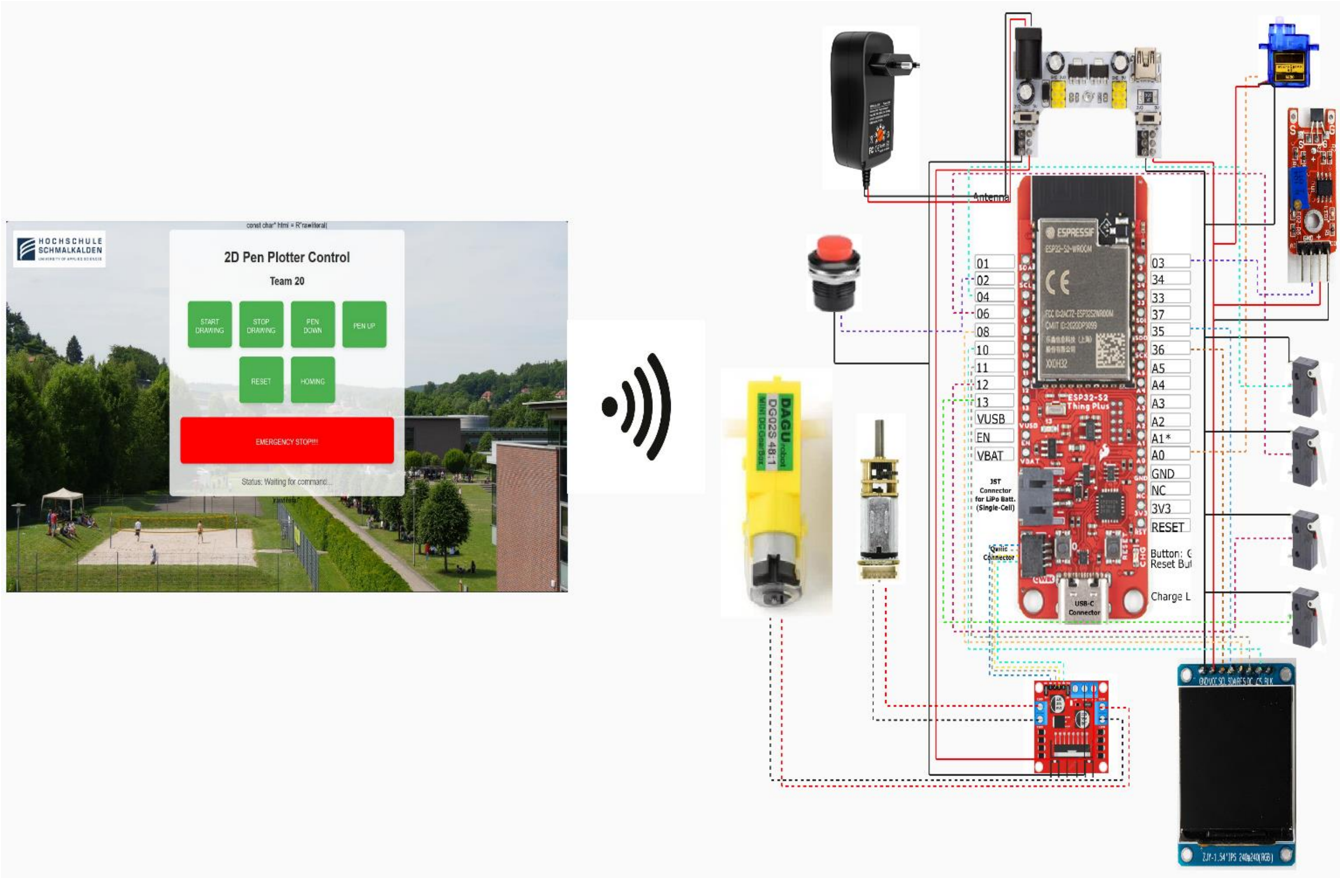


Figure 3.14 Electric Circuit Diagram

The electrical schematic diagram showcases the circuit configuration of a pen plotter project, demonstrating a well-structured and efficient design. The key components are carefully interconnected to ensure accurate and controlled plotting operations.

The core of the circuit revolves around the ESP32 microcontroller, serving as the main controller, controlling X & Y axis motors independently using L298N motor driver. The motor driver allows precise control over the motor speed and direction, enabling smooth and accurate movement of the pen plotter. This configuration ensures that precise drawings can be achieved.

To control the vertical motion of the pen, a servo motor is used. The microcontroller adjusts the servo's angle to raise or lower the pen onto the plotting surface with precision, allowing for accurate drawing or lifting to avoid unwanted marks.

To provide visual feedback and display the operational status of the plotter, a 2.0-inch TFT display is integrated into the circuit. This display offers a clear and concise interface to convey information such as the current progress of a drawing, error messages, or user prompts. It enhances the user experience by providing real-time updates and facilitating interaction with the plotter.

The circuit also incorporates four Hall sensors as encoders to provide precise position feedback. These sensors detect and measure magnetic fields, allowing the microcontroller to accurately determine the pen's position on the plotting surface. This feedback loop ensures precise and reliable plotting, enabling the creation of intricate and well-defined designs.

To establish boundaries in the X-Y plane and prevent any potential damage, limit switches are strategically positioned. These switches act as end stops, halting the movement of the pen plotter when it reaches predefined limits. By triggering the microcontroller upon activation, the limit switches provide an added layer of safety and prevent the plotter from exceeding its designated working area.

The circuit is constructed on a breadboard, ensuring reliable and stable operation. Additionally, a 3D-printed board is used to display the TFT and create a housing for the breadboard and wires, providing a secure and organized platform for the components, contributing to the overall robustness of the pen plotter system.

3.3 MECHANICAL CAD DESIGN

As per requirements, the planning phase regarding the design was done and the below procedure was followed:

Initially, the following components were designed accurately by using DSS SolidWorks:

a) Frame and Structure

b) Carriage and Slides

c) Pulley and its fixtures

d) Pen Holder

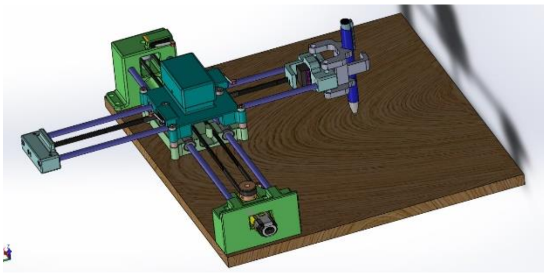


Figure 3.15 CAD Design

NOTE: Standard components like DC geared motor, ESP32 microcontroller board, L298N motor driver, 2.0” TFT display, micro servo motor, etc. were downloaded and dimensions were verified with those of physical components.

a. **Pen holder:** It is a mechanical component designed to securely hold the pen, enabling controlled and precise movement during plotting. It accommodates different pen sizes, allows for quick pen changes, and ensures consistent pen pressure for accurate and smooth drawings.

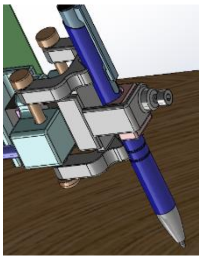


Figure 3.16 Pen Holder

b. **Shaft Guiding Block:** It is a sturdy component that supports and guides the shaft, ensuring smooth and precise linear motion of the pen plotter carriage along the rails. It reduces friction, minimizes vibrations, and enhances the overall stability of the system for accurate plotting.

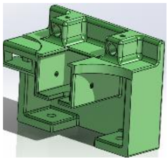


Figure 3.17 Shaft Guiding

c. **Gantry:** The top gantry moves the pen horizontally (X-axis), while the bottom gantry controls vertical movement (Y-axis). Motors, typically stepper motors, drive these gantries for precise plotting. Combined, they enable accurate positioning of the pen on the drawing surface.

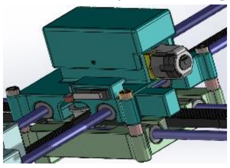


Figure 3.18 Gantry

d. **Base Plate:** The base plate in a pen plotter project serves as the foundational chassis on which the entire assembly is mounted. Typically made of wood, it provides stability and support to the various components, ensuring a rigid structure for accurate and reliable pen plotting operations.

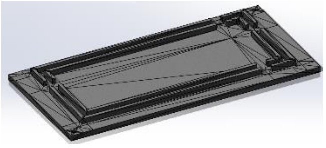


Figure 3.19 Base Plate

e. **Control Interface Block:** The control interface block in a pen plotter project is a specially designed 3D printed block that serves as a housing for electrical wirings, buttons, and the controller chip. It provides a convenient and organized arrangement, securing and protecting these components, simplifying the wiring connections, and facilitating easy access for control and operation of the pen plotter system.

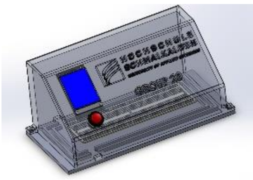


Figure 3.20 Control Interface Block

3.4 KEY DESIGN DECISION

Decisions related to design play a crucial role in shaping the user experience of the Pen Plotter. Choosing the right components, materials, and mechanisms ensures that the Pen Plotter performs its intended tasks effectively and efficiently. By making user-centric design decisions, the Pen plotter can be more user-friendly, aesthetically pleasing and enjoyable to operate. Following are the optimal design choices made by our team.

1. **Position of limit switch for better wiring:** The fixtures were made considering the wiring network of Limit switches, preventing localized wire dispersal and unsightly visibility.

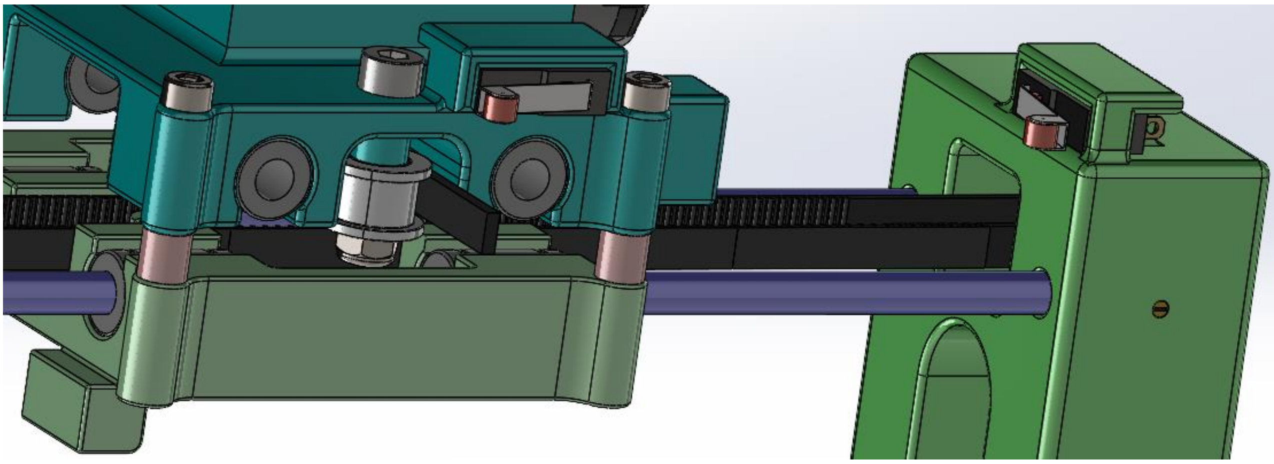


Figure 3.21 Position of Limit Switch

2. **Use of Display Screen:** We have used 2.0inch TFT display to following features:

- Welcome Screen
- Intro Screen
- Preview of Nikolaus Haus
- Nikolaus Haus drawn following same lines of X-Y Pen Plotter

Figure 3.22 TFT Display

3. **Enclosure for Electronic circuitry**:
In the pen plotter project, an enclosure is created to conceal the wiring network and electronic circuit components. The enclosure features an OLED display for real-time visualization, an Emergency Stop button for immediate system shutdown, and an ON/OFF switch for easy power control. This housing ensures a clean and organized appearance while providing convenient access to essential controls.

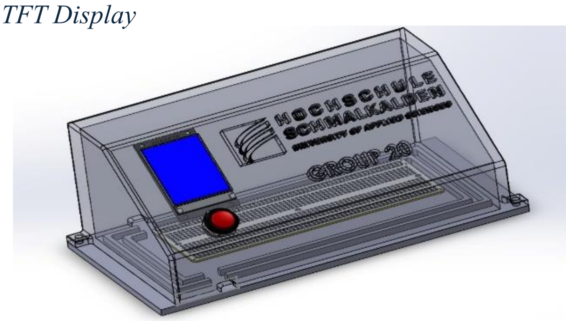


Figure 3.23 Enclosure for Electronic circuitry

4. **Graphical User Interface and its features:** Using HTML code, we have designed a web user interface which has the following features:
    - Control the movements of pen carriage in XY plane
    - Placing the carriage in the drawing area at the home location.
    - Raising or lowering the pen against the drawing surface.
    - The status of specific Limit Switches changes to when the X or Y carriage slides at the extreme boundaries of the XY plane.
    - Intro and Motor Preview on TFT Display showing preview animation of Nikolaus Haus
    - Either click the "Emergency button" on the webpage or hold down the "red button" on the Circuitry enclosure for 2 seconds to entirely stop the plotter's activity. This results in a red blinking website.

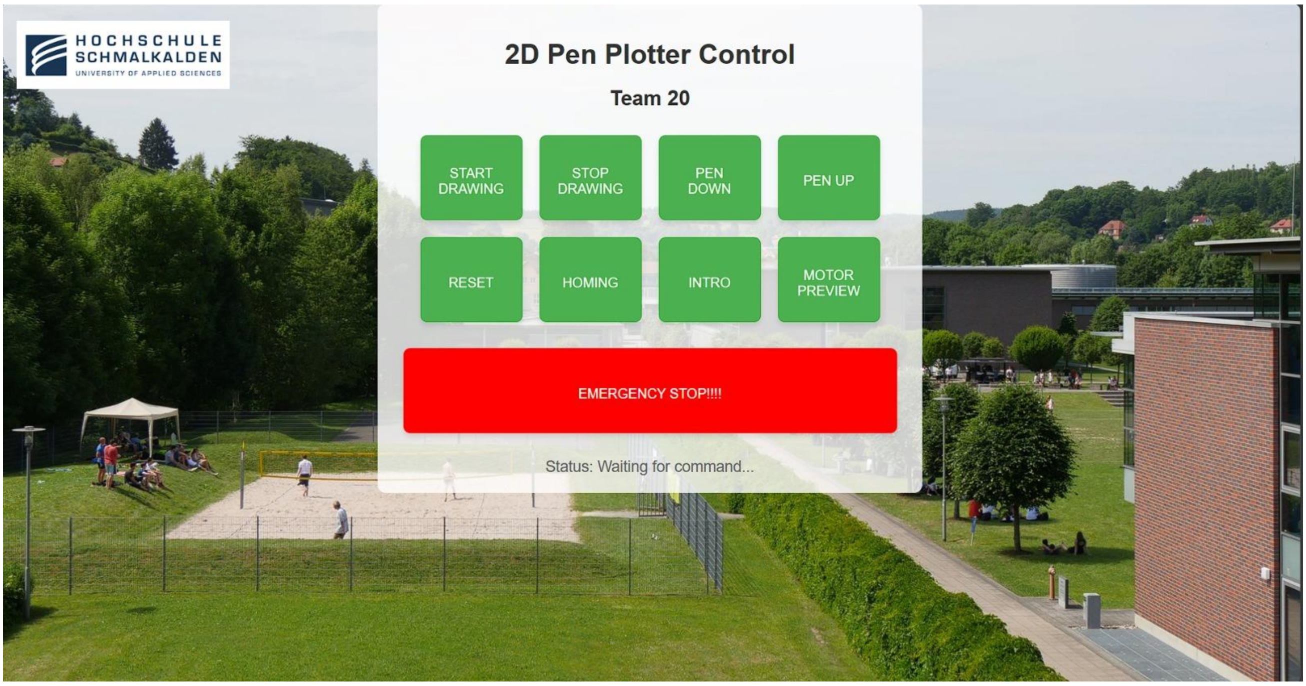


Figure 3.24 Pen-Plotter Web UI

4. DEVELOPMENT AND FABRICATION STAGE

4.1 PROCESS USED TO DEVELOP THE PEN PLOTTER
The development and fabrication stage of the pen plotter involves transforming the initial concept into a fully functional device. This includes designing the mechanical structure, selecting and integrating components, fabricating and assembling the physical components, testing the system for functionality and accuracy, and documenting the process for future reference and improvement.

4.2 SELECTION OF MATERIALS
In the common FDM printing process, PLA (Polylactic Acid) is the perfect entry-level filament and can be easily processed by any standard 3D printer. PLA has been chosen for due to:
• Good printability
• Lower distortion (warping) during printing.
• Ease of use • Affordability, and
• Compatibility with 3D printing technology
• Eco-friendliness
• All the 3D designed components were printed in “QIDI TECH X-MAX 3D Printer” available in the AKT lab, Haus D

Figure 4.1 3D Printer

4.3 USE OF TEST PIECE

The use of a test piece in 3D printing allows for evaluating print quality, identifying potential issues, and optimizing printing parameters for correct tolerance and fitment before producing the final parts. It helps ensure accuracy, functionality, and compatibility, minimizing errors and reducing material and time wastage.

Figure 4.2 Test piece

4.4 CHALLENGES FACED DURING DEVELOPMENT STAGE:

Issues related Wire routing:

In electronic design, one of the crucial tasks is concealing the wiring network to enhance the visual appeal of the product. Exposed wires not only create a cluttered and unattractive appearance but also undermine the overall design and professionalism of the product. Moreover, the vulnerability of exposed wires to snagging, bending, or accidental tampering can lead to electrical malfunctions or even complete failure of the device. To address these concerns, we have developed an enclosure with an inbuilt wire routing channel that effectively houses all the wiring connections and electronic components. The inclusion of plastic cable ribbons facilitates the routing of wires to the X and Y carriages, ensuring a clean and organized internal structure for improved functionality and reliability.

Figure 4.3 Wires and Cables

5. TESTING AND ITERATION

The testing and iteration stage in building a pen plotter project involves thoroughly evaluating the system's functionality, performance, and reliability. This includes testing motion control, pen actuation, and plotter coordination, identifying any issues or limitations, and making iterative refinements to optimize the project's overall performance and accuracy.

5.1 TESTING PROCEDURE:

- **Limited Color Range**:

Pen plotters typically utilize one color of pen or marker, which limits the usage of color in the artwork to monochrome or a small range of colors. With just pen plotters, it might be difficult to create color combinations that are lively and varied.

- **Slow Speed**:

In comparison to other printing technologies, pen plotters work at comparatively slower speeds. Their effectiveness for large-scale or time-sensitive tasks is constrained by the mechanical nature of the device and the accuracy needed for accurate charting, which can lead to lengthier processing and plotting periods.

- **Positional accuracy**:

Pen plotters may work with DC geared motor as well as Stepper motor. However, with micro stepping, stepper motors offer superior positional accuracy over dc geared motors.

- **Limited Media Compatibility**:

Pencil plotters function best on flat materials like paper or cardstock. When attempting to plot on unusual or uneven terrain, they could run into problems. The limited media compatibility might prevent experimentation with and examination of various artistic mediums.

5.2 DESIGN ITERATION:

The CAD design of the pen plotter project incorporates carefully designed cable routing paths to ensure efficient cable management and minimize potential cable entanglement or obstruction during operation. The aim is to maintain a clean and organized layout while facilitating smooth movement of the plotter. By strategically planning cable routes, potential issues such as cable interference with moving parts, signal interference, and overall system reliability are addressed. Attention is given to factors like cable length, flexibility, and secure attachment points to ensure optimal performance and minimize the risk of cable-related malfunctions. The design considerations emphasize the importance of cable management to maintain a streamlined and efficient operation of the pen plotter.

VerR #	ref. to VerP #	verification criterion, the target value	Actual value	Criterion passed/failed	remark	ref. # (i.e. test report, etc)	Domain (HW/SW/ME/ALL)
Application							
VerR 1	VerP1	(the product should not weight more than 3kg)	2.3 KG	Passed		PenPlotter_MERO_TEAM_20	All
VerR 2	VerP2	The maximum size of Nikolaus house must be maximum of 50mm x 50 mm	50mm x 50 mm	Passed		PenPlotter_MERO_TEAM_20	
VerR 3	VerP3	set up	Set up completed by all the required materials	Passed		PenPlotter_MERO_TEAM_20	HW
VerR 4	VerP4	Switch controlling	Switches are working properly	Passed		PenPlotter_MERO_TEAM_20	HW
VerR 5	VerP5	9V power supply to connect the barrel connection of the setup.	Fulfilled the required power supply	Passed		PenPlotter_MERO_TEAM_20	HW
VerR 6	VerP6	A micro servo is used for the up & down movement of the pen.	Up & down movement of the pen accurately	Passed		PenPlotter_MERO_TEAM_20	ME

Table 5.1 Verification Protocol

VerR #	ref. to VerP #	verification criterion, the target value	Actual value	Criterion passed/failed	remark	ref. # (i.e. test report, etc)	Domain (HW/SW/ME/ALL)
Application							
VerR 1	VerP1	(the product should not weight more than 3kg)	2.3 KG	Passed		PenPlotter_MERO_TEAM_20	All
VerR 2	VerP2	The maximum size of Nikolaus house must be maximum of 50mm x 50 mm	50mm x 50 mm	Passed		PenPlotter_MERO_TEAM_20	
VerR 3	VerP3	set up	Set up completed by all the required materials	Passed		PenPlotter_MERO_TEAM_20	HW
VerR 4	VerP4	Switch controlling	Switches are working properly	Passed		PenPlotter_MERO_TEAM_20	HW
VerR 5	VerP5	9V power supply to connect the barrel connection of the setup.	Fulfilled the required power supply	Passed		PenPlotter_MERO_TEAM_20	HW
VerR 6	VerP6	A micro servo is used for the up & down movement of the pen.	Up & down movement of the pen accurately	Passed		PenPlotter_MERO_TEAM_20	ME

Table 5.2 Verification Report

Validation Protocol				
ValP #	**ref. to UR #**	**Validation procedure (description of routine)**	**ref. # (i.e. validation protocol, customer test, etc..)**	**Validation criterion, target value**
ValP1	UR1, UR2, UR3, UR4	Set-up pen plotter at the university's lab, start pen plotter by student, draw Nikolaus Haus.	PenPlotter_MERO_TEAM_20	Plotter must draw Nikolaus Haus in one run.
ValP2	UR5	Put the pen plotter into a box of 56x39x42 cm provided by Uni Lab.	PenPlotter_MERO_TEAM_20	Fits perfectly
ValP3	UR20	Place the pen plotter assembly on a measuring scale with an accuracy of ± 10gm	PenPlotter_MERO_TEAM_20	Total weight <= 3kg
ValP4	UR9	Performed drop tests from a height of 50 mm and confirm the device's functionality and structural integrity post-impact.	PenPlotter_MERO_TEAM_20	Withstands a fall from 50mm
ValP5	UR16	Executed a sketching task with the pen plotter using a predefined "Nicolous house" pattern, and assess the accuracy of the drawing against the expected design specifications.	PenPlotter_MERO_TEAM_20	Perfectly draw a Nikolaus Haus without any error
ValP #	**ref. to UR #**	**Validation procedure (description of routine)**	**ref. # (i.e. validation protocol, customer test, etc..)**	**Validation criterion, target value**
ValP6	UR33	Maximum pen diameter of 10mm	PenPlotter_MERO_TEAM_20	Pen diameter <=10mm
ValP7	UR42	The emergency stop functionality in the plotter underwent rigorous user validation to ensure immediate and reliable cessation of operation.	PenPlotter_MERO_TEAM_20	Successful test confirmed the plotter's emergency stop feature is effective and reliable.

Table 5.3 Validation Protocol

Validation Test Report			
ValR #	**ref. to ValP #**	**Criteria (passed/failed)**	**ref. # (i.e. test report, etc..)**
ValR1	ValP1	Passed	PenPlotter_MERO_TEAM_20
ValR2	ValP2	Passed	PenPlotter_MERO_TEAM_20
ValR3	ValP3	Passed	PenPlotter_MERO_TEAM_20
ValR4	ValP4	Passed	PenPlotter_MERO_TEAM_20
ValR5	ValP5	Passed	PenPlotter_MERO_TEAM_20
ValR6	ValP6	Passed	PenPlotter_MERO_TEAM_20
ValR7	ValP7	Passed	PenPlotter_MERO_TEAM_20

Table 5.4 Validation Report

6. CONCLUSION AND ACKNOWLEDGEMENTS

In conclusion, our pen plotter project has successfully come to fruition, showcasing the seamless integration of a diverse range of components. The project has been a testament to our team's dedication, expertise, and collaborative effort. The utilization of key components such as DC motors, an ESP32 board for efficient control, a DC-DC converter for optimized power management, a Hall sensor for precise positioning, Guide rod (3-D printed) for smooth pen movement, pulleys for accurate belt drive, a micro servo-motor for pen lifting, an TFT display for intuitive user interaction, and micro limit switches for reliable end stop detection has resulted in a high-performing and user-friendly pen plotter.

We extend our heartfelt gratitude to all those who have contributed to the success of this project. Our appreciation goes to the team members who worked diligently on every aspect, from design to implementation, ensuring the functionality and performance of the pen plotter. We would also like to acknowledge the support and guidance provided by our mentors and advisors, whose expertise has been invaluable throughout the project's development.

The successful completion of this pen plotter project opens up new possibilities in creative expression and design, and we look forward to further refining and expanding its capabilities in the future.

6.1 BILL OF MATERIALS:

BILL OF MATERIALS									
RT NUME	GROUP	PART NAME	SPEC	MATERIAL	QTY	SOURCE	MEASURING CRITERIA	NIT PRIC	ESTIMATED COST
E01	ELECTRICAL COMPONENTS	DC Motor	DAGU - DG01D 48:1 Mini DC GearBox		1	Lab Kit	Piece	€ 4.23	€ 4.23
E02		DC Motor							
E03		Micro Controller	SparkFun Thing Plus ESP32 S2 WROOM WRL 173811		1	Lab Kit	Piece	€ 3.20	€ 3.20
E04		Motor Driver	SparkFun Qwiic Motor Driver		1	Lab Kit	Piece	€ 3.00	€ 3.00
E05		Bread board	BoardMB-102 Plug-in board 830 pins603200251		1	Lab Kit	Piece	€ 5.00	€ 5.00
E06		Power Supply module	Breadboard Power Supply TS11711		1	Lab Kit	Piece	€ 1.80	€ 1.80
E07		Hall Effect Sensor	Module magnetic detector 49E LM393TS01451		1	Lab Kit	Piece	€ 2.40	€ 2.40
E08		AC - DC Adapter	variable 3-12V		1	Amazon	Piece	€ 10.00	€ 10.00
E09		Micro Servo	Tower Pro SG 90		1	Amazon	Piece	€ 5.40	€ 5.40
E10		Limit Micro Switch	XSS-5GL13		4	Lab Kit	Piece	€ 1.00	€ 4.00
E11		Push Button	15 dia x 24 mm length		1	Lab Kit	Piece	€ 1.00	€ 1.00
E12		Jumper Cables			65	Lab Kit	Piece	€ 0.10	€ 6.50
E13		Copper wires	5 meter each		3	Amazon	Length	€ 2.00	€ 6.00
E 14		ST8879V	2.0 TFT Display						
H01	HARDWARE & ASSEMBLY COMPONENTS	Base Board	305mm x 305mm x 15mm	Wood	1	Helweg	piece	€ 5.00	€ 5.00
H02		Timing Belt	2mm pitch, 6mm wide, 2m length	Nylon	1	Lab Kit	length	€ 2.00	€ 2.00
H03		Hard steel guide Shaft	6dia x 300mm legth	steel	4	Lab Kit	piece	€ 3.00	€ 12.00
H04		Linear Ball Bearing	LMU-N6	steel	8	Lab Kit	piece	€ 1.10	€ 8.80
H06		M4 Bolt	25 mm length	steel	4	Lab Kit	piece	€ 0.20	€ 0.80
H07		M4 Nut		steel	3	Lab Kit	piece	€ 0.10	€ 0.30
H08		M4 washer		steel	2	Lab Kit	piece	€ 0.10	€ 0.20
H09		M5 Bolt	16 mm length	steel	5	Lab Kit	piece	€ 0.20	€ 1.00
H10		M5 Bolt	30 mm length	steel	8	Lab Kit	piece	€ 0.20	€ 1.60
H11		M5 Nut		steel	8	Lab Kit	piece	€ 0.10	€ 0.80
H12		M6 Bolt	30 mm length	steel	4	Lab Kit	piece	€ 0.20	€ 0.80
H13		M6 washer		steel	4	Lab Kit	piece	€ 0.10	€ 0.40
H14		M6 Nut		steel	4	Lab Kit	piece	€ 0.10	€ 0.40
H15		M3 Nut		steel	4	Lab Kit	piece	€ 0.10	€ 0.40
H16		Screw	10 mm tdrx plus M3	steel	5	Amazon	piece	€ 0.10	€ 0.50
H17		storage box	560mm x 390mm x 280mm	plastic	1	Lab Kit	piece	€ 10.00	€ 10.00
H17		Motor Gear Pulley		Plastic	2	Lab Kit	piece	€ 0.50	€ 1.00
H18		Zip tie	2.5mm x 100mm	plastic	2	Amazon	piece	€ 0.50	€ 1.00
H19		Spiral wiring Sleve	500 mm	plastic	0.5	Amazon	length	€ 2.00	€ 1.00
H20		Super Glue	adhesive		10	Amazon	grams	€ 0.50	€ 5.00
H21		Insulation Tape	10mm wide		1	Amazon	piece	€ 0.50	€ 0.50
P01		Bottom Gantry	Designed as per technical specification	plastic	1	3D Printed	piece	€ 0.50	€ 0.50
P020		Top Ganty	Designed as per technical specification	plastic	1	3D Printed	piece	€ 0.50	€ 0.50
P03		Bush	Designed as per technical specification	plastic	1	3D Printed	piece	€ 0.50	€ 0.50
P04		Guide Disk	Designed as per technical specification	plastic	1	3D Printed	piece	€ 0.50	€ 0.50
P05		Guide Rod	Designed as per technical specification	plastic	1	3D Printed	piece	€ 0.20	€ 0.20
P06		Pen Tightner	Designed as per technical specification	plastic	1	3D Printed	piece	€ 0.50	€ 0.50
P07		Pen Lifter	Designed as per technical specification	plastic	1	3D Printed	piece	€ 0.50	€ 0.50
P08		Pinion	Designed as per technical specification	plastic	1	3D Printed	piece	€ 0.50	€ 0.50
P09		Support Block	Designed as per technical specification	plastic	4	3D Printed	piece	€ 0.50	€ 2.00
P10		X-Axis Motor end	Designed as per technical specification	plastic	1	3D Printed	piece	€ 1.00	€ 1.00
P11		X-Axis Other end	Designed as per technical specification	plastic	1	3D Printed	piece	€ 1.00	€ 1.00
P12		Y-Axis Lifter end	Designed as per technical specification	plastic	1	3D Printed	piece	€ 1.00	€ 1.00
P13		Y-Axis Other End	Designed as per technical specification	plastic	1	3D Printed	piece	€ 1.00	€ 1.00
P14		Controller Cabin	Designed as per technical specification	plastic	1	3D Printed	piece	€ 1.00	€ 1.00
						TOTAL ESTIMATED COST			€ 116.73

6.2 FUTURE SCOPE:

Pen plotters have a bright future with lots of room for innovation and growth. In order to create immersive and interactive artistic experiences: Use of higher-quality DC geared motors with finer gear ratios to achieve more accurate positioning and smoother movement. Working on the design and making it more reliable and efficient so that the vibrations can be reduced and quality of the drawing can be improved. Future designs might focus on reducing the size and weight of the plotter while maintaining its functionality and performance.

In addition to the points mentioned above, the future of pen plotters holds several possibilities for innovation and growth:

- **Integration of AI and Machine Learning**: By integrating artificial intelligence (AI) and machine learning algorithms, pen plotters can gain the ability to analyse and reproduce complex artistic styles or patterns. This would enable the creation of unique and customized drawings based on user preferences or learned artistic techniques.
- **Multi-Colour and Mixed-media Capabilities**: Expanding the capabilities of pen plotters to accommodate multiple colours or even different drawing mediums (such as pencils or markers) can open up new avenues for creativity and artistic expression.
- **Collaborative Features**: Developing collaborative features, allowing multiple pen plotters to work together on a single drawing or synchronized artwork, could facilitate group projects, interactive installations, or even live art performances.

Overall, the future of pen plotters is bright, with the potential for advancements in accuracy, connectivity, control systems, AI integration, and collaborative capabilities, promising immersive and interactive artistic experiences for users.