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A PROJECT REPORT
On

TWO-DIMENSIONAL PEN PLOTTER

Submitted in partial fulfillment for the award of the degree of

Master of Engineering
In
Mechatronics and Robotics
By

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DEPARTMENT OF MECHATRONICS & ROBOTICS

DECLARATION

This is to certify that the project work entitled **TWO-DIMENSIONAL PEN PLOTTER** has been successfully completed under the guidance of Prof. Dr. Stefan Roth & Prof. Dr.-Ing. Silvio Bachmann and is a bonafide work carried out by:

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Prof. Dr. Stefan Roth
Faculty of Mechanical Engineering

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Faculty of Electrical Engineering

ACKNOWLEDGEMENT

We extend our sincere appreciation to all those who played a pivotal role in enabling the completion of the "XY PEN PLOTTER" project. A special thank you goes to our dedicated supervisors, Prof. Dr.-Ing. Silvio Bachmann and Prof. Dr. Stefan Roth, whose valuable insights and continuous encouragement significantly contributed to the coordination and development of this project, particularly in the crafting of this dossier.

Furthermore, we express our gratitude to the entire teaching faculty for imparting knowledge crucial to the realization of this project. The guidance and suggestions provided by our professors were instrumental in shaping the direction of our efforts. We also acknowledge our classmates, whose participation in class discussions enhanced our understanding of the subject. Interacting with them was a valuable experience that enriched our comprehension.

Last but not least, heartfelt thanks to all the members of our project group. Collaboratively, we forged an extraordinary experience, learning from one another and achieving remarkable results through our collective efforts. Each member's dedication and contribution played a vital role in making the "XY PEN PLOTTER" project a success.

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1. INTRODUCTION

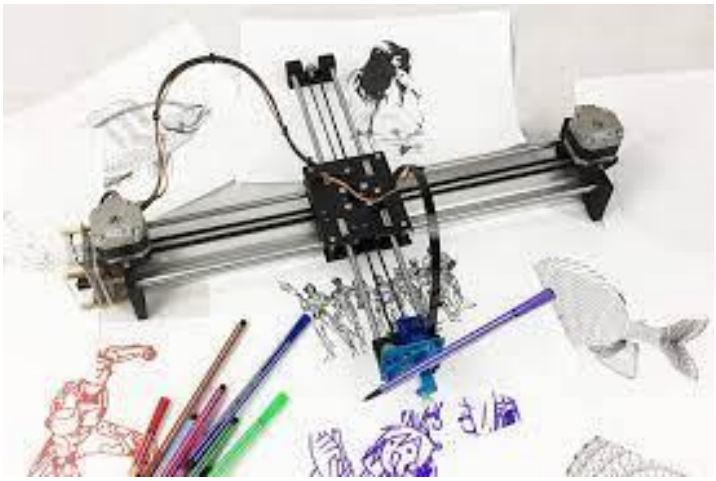


Figure-1: Concept example of XY Pen Plotter

The XY Pen Plotter serves the purpose of plotting two-dimensional data on a rectangular coordinate system, capable of handling both continuous and discontinuous information. Utilizing additive manufacturing materials ensures cost-effectiveness, ease of production, and lightweight components. The manufacturing process relies on digital 3D-CAD data, constructing objects layer by layer, allowing for the creation of intricate shapes without traditional shaping tools.

Additive manufacturing proves economical for complex components that machining processes may struggle to produce. Initially, the 3D CAD data is translated into horizontal layers via an STL file. Printing is executed using devices like Zortrax Ultimaker 300 with a 1.75mm nozzle diameter. The slicing program considers various parameters such as layer height, filler material, printing speed, nozzle temperature, and support structure. The CAD file is then converted to STL format, openly documenting the surface as a triangular mesh. The STL file is exported to the 3D printer, initiating the manufacturing process of XY pen plotter components.

The XY Pen Plotter, a sophisticated device designed for precise and accurate drawing, operates through computer-driven programs. It exemplifies a mechatronic system, integrating electrical, software, and mechanical elements. Originating from early analog measuring devices like seismographs, the pen plotter employs a two-axis control, enabling movement along both the X and Y axes. Some advanced designs include a specialized writing assembly for pen elevation or depression, featuring a dedicated slot at the far end for pen accommodation.

1.1 Task Description:

The main aim of this project is to design, fabricate and program a XY pen plotter using 3D printing that can draw the Nikolaus House (a simple diagram of a house made up of 8 lines) as shown in the figure below, without any errors.

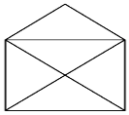


Figure-2: Nikolaus House

2. PLANNING AND CONCEPTUALIZATION

At the beginning of our initial development of our designs we went through different designs and techniques of previously done projects via the internet and did some research through trial-and-error method. Here in this part, we provide the details of our course of action and the series of steps we have taken.

2.1 Conceptual Design:

In our course of action, we implemented different ideas and added some of our own to create the best design possible. A series of trial and error led us to jotting it down to two ideas as elaborated below.

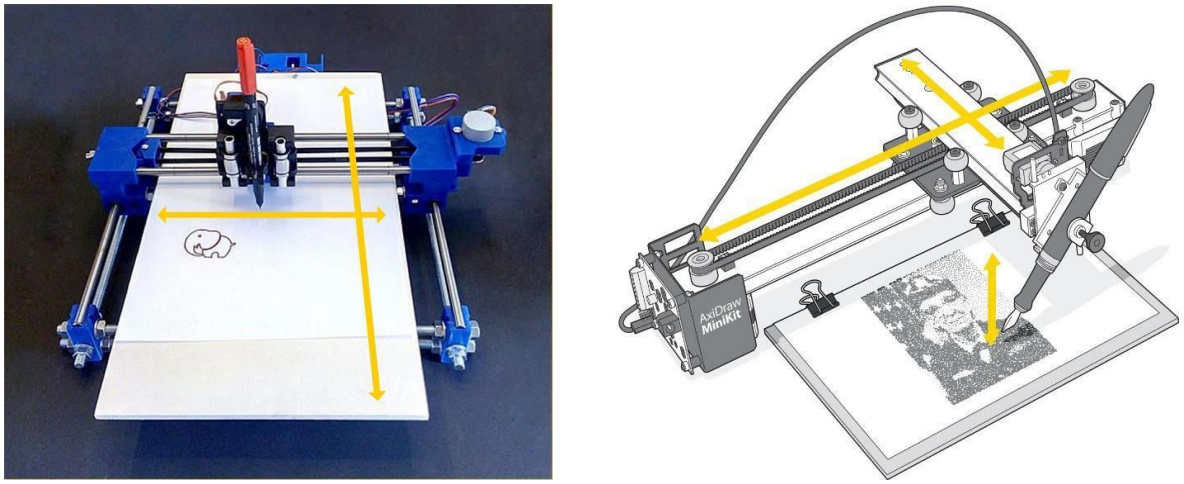


Figure-3: Idea A and Idea B

Idea A:

Demonstrates the initial concept, revealing two dynamic axes. The Y-axis functions as a mobile platform for paper placement, while the X-axis incorporates a pen for drawing; both axes operate independently for motion. This concept imposes the condition of placing paper solely on the mobile bed, ensuring its dimensions align appropriately with the bed size.

Idea B:

Presents an alternative concept featuring a pair of axes, yet, unlike the previous design, these axes are interconnected in their motion. The Y-axis mechanism is affixed to the X-axis mechanism, offering enhanced flexibility as it can be positioned in various locations. Consequently, we opted to proceed with the development of Idea B based on this design.

2.2 Working Mechanism of X-Y Pen Plotter:

Our design is rooted in the concept of Idea B, and we utilized thingsverse.com as a point of reference for this model. Beginning with our own ideas, we devised the XY plotter, incorporating insights from the website. Unlike conventional XY plotters employing two DC motors to drive motion along the x and y axes separately, our approach involves siting both motors at opposite ends of the x-axis rail. The drive belt is threaded through the movable chassis and along the y-axis, enabling a unique movement pattern. By turning one motor while keeping the other stationary, the penholder moves along a 45-

degree angle to the rails, akin to the NE to SW line on a compass. Similarly, turning the other motor, with the first one held still, shifts the penholder along the NW to SE line, as depicted in Figure 4.

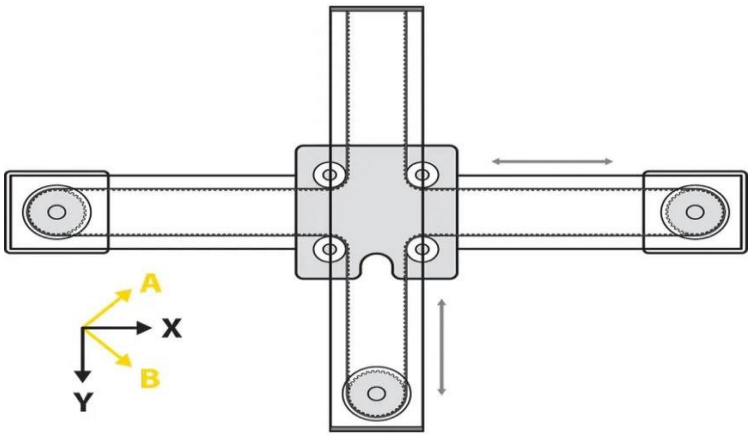


Figure-4: Demonstration of the working of the XY Plotter

2.3 DEVELOPMENT OF V-MODEL

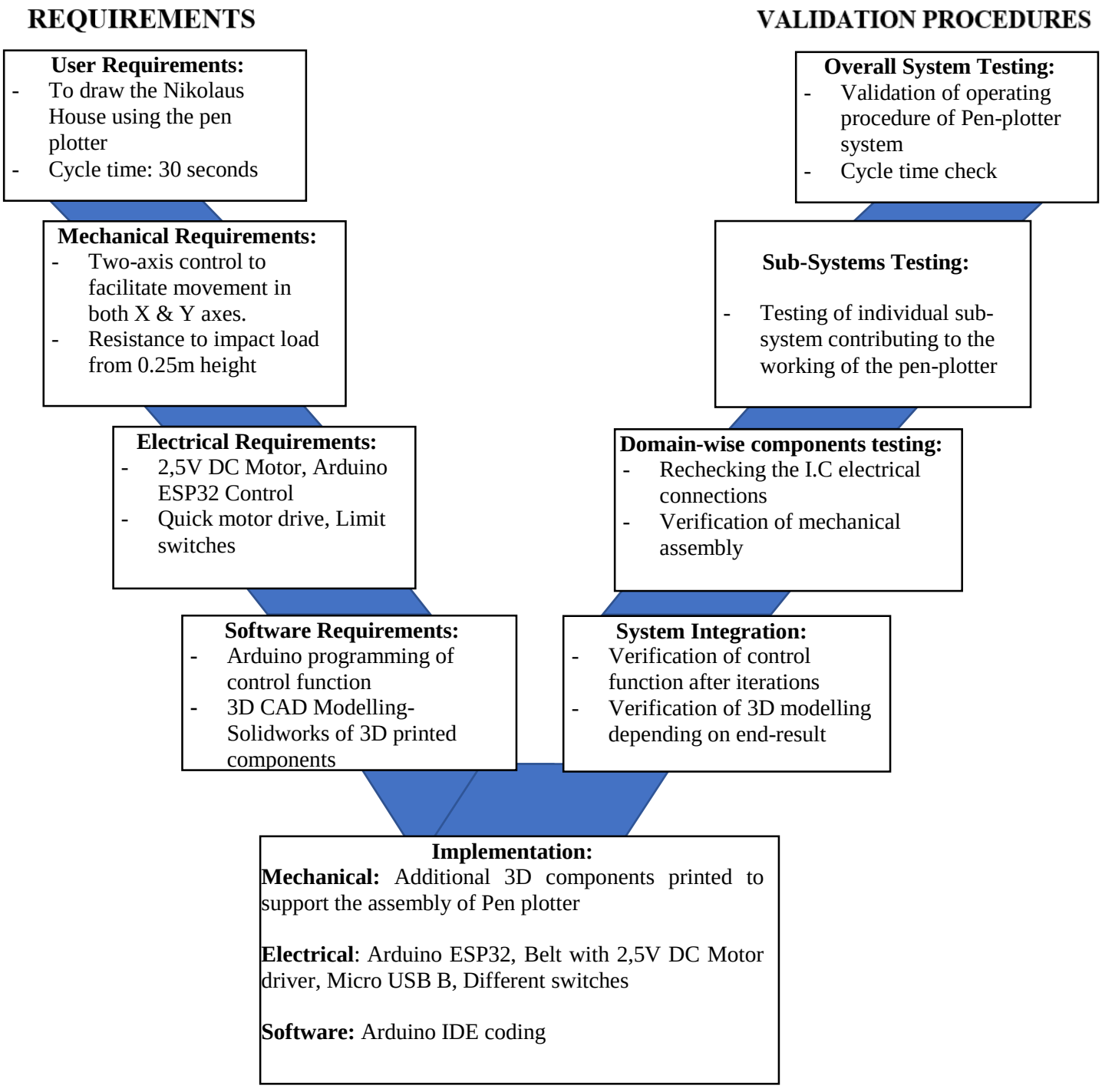


Figure-5: V-Model

2.4 USER REQUIREMENTS

The detailed user requirements essential for the design of the XY pen Plotter are mentioned as follows:

2.4.1 Intended use:

- After programming, the XY-pen plotter is intended to draw Nikolaus' home.
- Students of Master's Degree Program in Mechatronics and Robotics, both male and female and primarily between the ages of 20 and 30, make up the main focus group for the XY-Pen plotter.

2.4.2 Use case:

- The house of Nikolaus must be accurately drawn with the pen plotter.

2.4.3 General functions:

- In order to make transporting a pen plotter easier, it must be lightweight and portable. Assembling and disassembling should be relatively simple.

2.4.4 Module function: mechanical

Frame & Base Plate: To give other modules the bare minimum support, the base plate installation must be solid and robust. To minimize operational mistakes, the base plate's surface must be level. To reduce unnecessary vibrations and jerks, the frame and base plate must be sturdy enough.

Drive belt: Drive belt is used in the assembly to connect the motor and other pulleys. To avoid slippage situations, they must be strong enough and have evenly spaced serrations.

Drive Pulley: Power is transferred from the Gear motors via drive pulleys and drive belts. To prevent slippage conditions that might impair the operation of the pen plotter, the drive pulleys and drive belts must be precisely linked. Furthermore, transmission noise levels must be kept to a minimum.

Guide Rods: The primary axle rods that hold the entire pulley system together are known as guide rods. For the assembly to move easily, guide rods are necessary. This allows the pen to be moved more easily.

Ball Bearing: The guide rods are put into the ball bearings, which are the mechanical parts. For the complete assembly to operate smoothly and precisely, there should be the least amount of friction possible between the guide rods and the ball bearings.

2.4.5 Module function: software

3D CAD Modelling: To create the necessary 3D drawings of secondary and tertiary components, a well-known and user-friendly CAD program must be utilized.

Programming: The complete pen plotter's control functions must be developed using user-friendly software to allow for repeated testing and validation rounds.

IC-Layout Design: To create the necessary IC layout design, appropriate user-friendly software must be used.

2.4.6 Module function: electrical hardware

Power supply: A current CE certification is required.

Motor driver: The motor module must be a high-quality Geared motor.

Emergency: Emergency power on and off switch must be used for safety purposes.

Controller: Use a reliable, user-friendly controller to make programming and setting up connections easier.

Limit switch: Limit switches must be employed to prevent the pulley assembly from damage.

2.5 Technical requirements

In order to develop the XY pen Plotter while carefully taking into account the above-mentioned user needs, the following specific technical criteria must be met:

2.5.1 Intended use:

- The XY-pen plotter is intended to draw a Nikolaus' house after programming, and all technological components operating concurrently must aid in drawing the same without defects.

2.5.2 Use case:

- The pen plotter has to draw the Nikolaus' house precisely on the A4 size of paper.

2.5.3 General functions:

- The total weight of the pen-plotter assembly is about 3.5kg.
- This pen plotter can operate for up to 5 cycles without experiencing any problems, and it can last for a year.
- The complete XY pen plotter is robust enough to survive a 25cm drop.

2.5.4 Module function: mechanical

Frame & Base Plate: The frame doesn't weigh more than 1 kg. Fine grade 3D printed material is used to create the base plate mounting material. To survive unneeded vibrations, the 3D printed material must be stiff and strong enough.

Drive belts: To provide a smooth connection with the pulley, plastic drive belts with evenly spaced serrations are employed.

Drive Pulley: In order to transfer motion, drive pulleys that were 3D printed and had the appropriate serrations are employed. The noise level is in the 50–55 db range.

Guide Rods: To provide the least amount of friction possible between the guide rods and the ball bearings, the proper grade material (Stainless Steel) must be utilized.

Ball Bearing: To achieve enough strength, the ball bearings must be cast from fine quality iron material.

2.5.5 Module function: software

3D CAD Modelling: Using Solidworks, the 3D models of the secondary and tertiary parts needed for assembly were created.

Programming: The pen-plotter's control system was programmed using open-source software known as Arduino IDE.

IC-Layout Design: The I.C components needed for the complete assembly were designed using the Fritzing program.

2.5.6 Module function: electrical hardware

Power supply: CE certified battery pack or power bank is used.

Motor driver: 6V Gear motor having ratio 1:48 designation is used for this application.

Emergency: Standard CE Emergency Power ON and OFF toggle switch is used for safety Reasons.

Controller: The controller called ESP-32 is used to create the necessary electrical connections in accordance with the planned IC configuration.

Limit switch: Limit switches that are standard and CE approved have been used.

3. DESIGN PHASE:

3.1 Mechanical Design:

We started designing the parts and assembled everything on SolidWorks. After this, the STL files were sent for 3D printing. All the following figures are specifically 3D printed as part of the mechanical sub-components required for assembly.

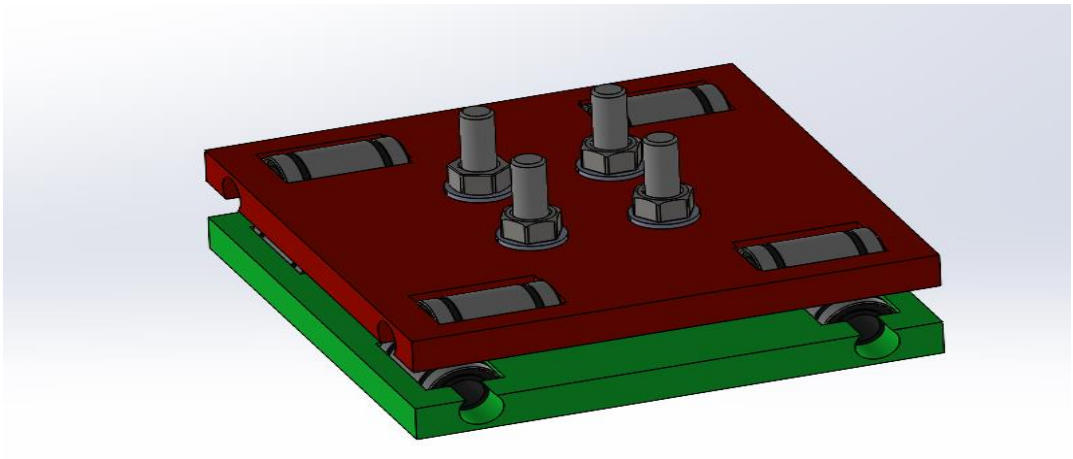


Figure-6: Middle Support Brackets for Bearing Mounting

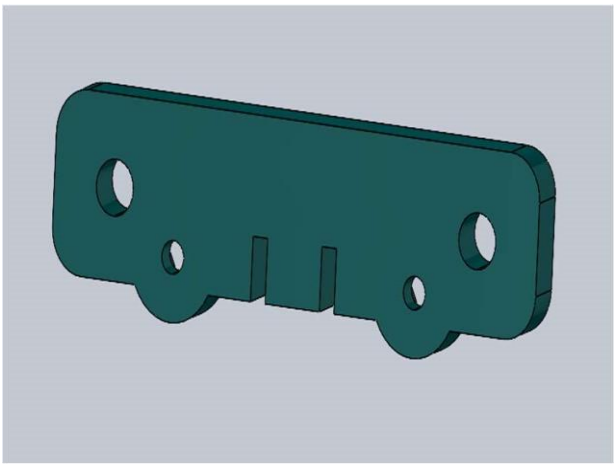


Figure-7: Support Bracket Configuration for Y-Axis

Figure-8: Pulley

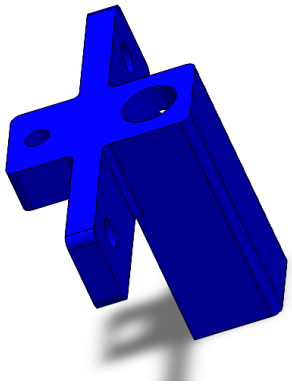


Figure-9: Pen Holder Bracket

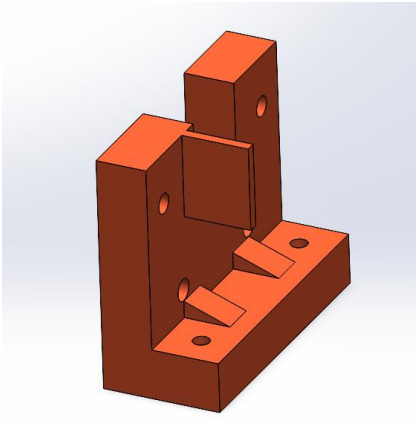


Figure-10: Support Bracket Configuration for X-Axis

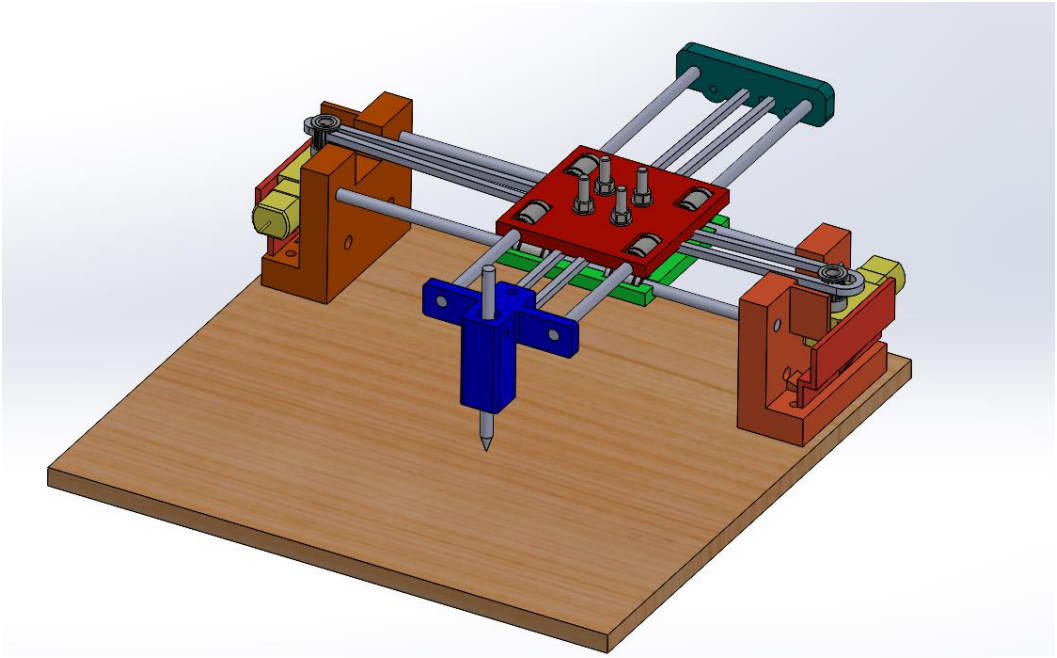


Figure-11: Isometric view of 3D Printed Support Structure Assembly of XY Pen Plotter

The entire procedure of 3D printing the sub-components was a tedious and iterative procedure since, we had to make some minor adjustments during every iteration to finalize the assembly of the fundamental support system. Eventually, we were able to build the entire support structure assembly comprising of 3D printed mechanical sub-components whose layout is depicted in the figure below.

3.2 Electronics Hardware Design:

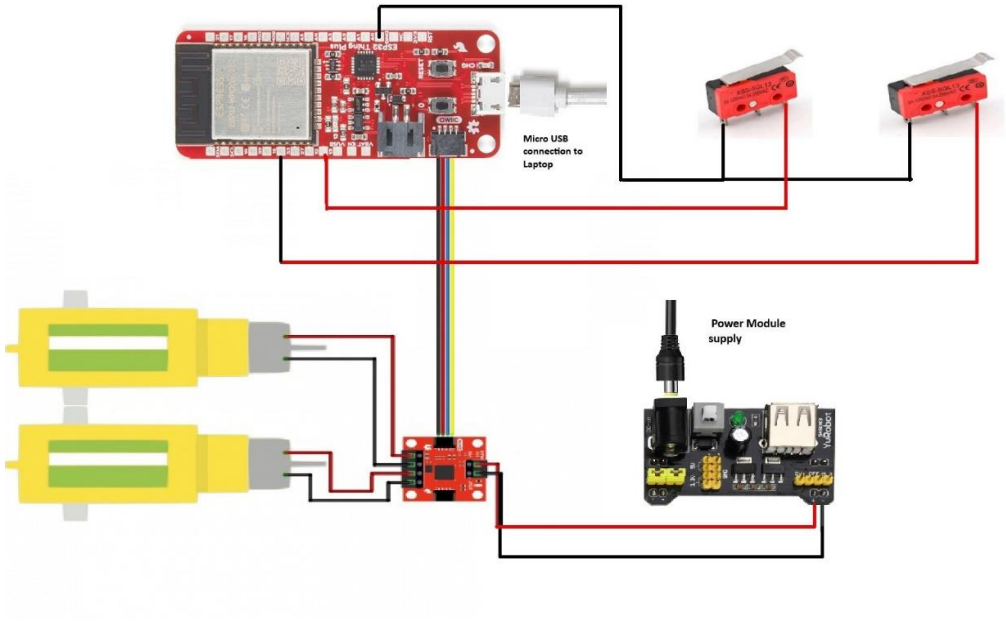


Figure-12: Electronic Circuit Layout

We utilized an external program called Fritzing for creating and making the necessary adjustments to the electronic circuit architecture shown in the top image. The following is a list of the specific part descriptions for the electronic parts utilized in our layout:

Power Supply: CE certified Power Bank 1000 mAh /Adaptor Cable/USB 2.0

Serial Communication: A standard CE certified Breadboard component

Microcontroller: Spark fun ESP32-S2 Thing plus

Motor Driver Controller: QWIIC motor driver

Motors: 2 x 6V DC motors with gear box

Limit switches: XSS-5GL13 Limit Switch

A L298N H-Bridge Motor Drive Controller is used to control two 6V DC Servo motors that are part of the layout. The microcontroller used to program the control function for the complete pen plotter assembly is called an ESP-32. An external power bank with a 1000 mAh /Adaptor Cable/USB 2.0 powers both of these controllers. The two controllers' secondary and tertiary connections are 18 made using a serial breadboard. In order to prevent a collision between the pulley assembly and the support structures, two limit switches are employed simultaneously.

3.3 Final assembly of the pen plotter

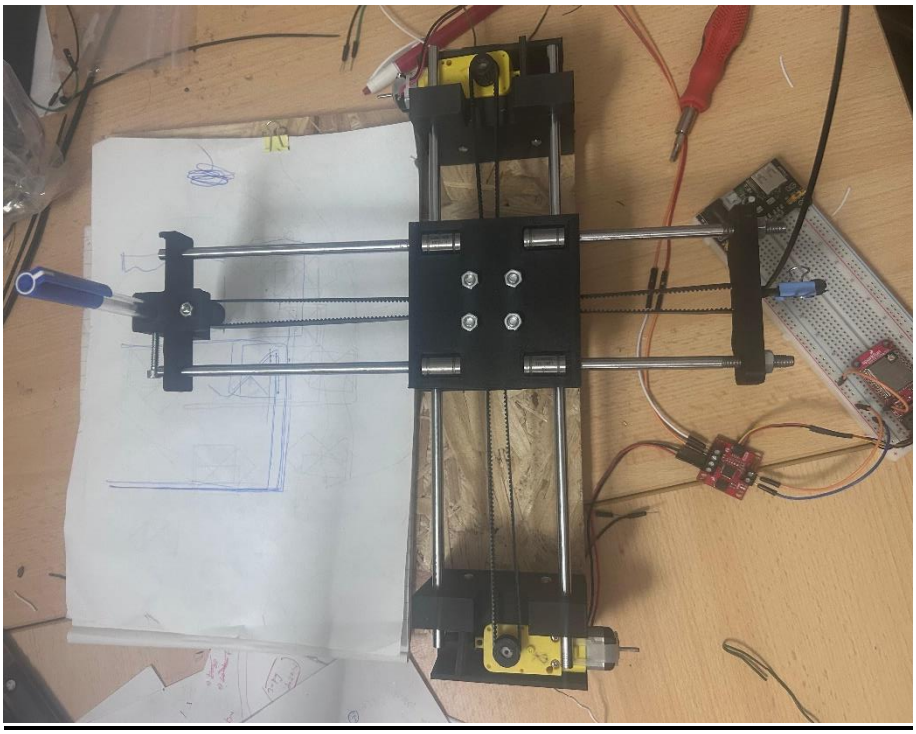


Figure-13: Assembly of Mechanical components and Electrical Circuit Layout

3.4 Software Design:

Creating the control function for the pen plotter is a crucial and meticulous task that necessitates proficiency in programming skills within the required fields. As previously discussed, we utilized the Arduino Uno and its corresponding programming software to develop a control function program capable of guiding the motion of the pen plotter assembly for drawing the required Nikolaus House. The final program is the outcome of a thorough and iterative procedure, and it is outlined as follows.

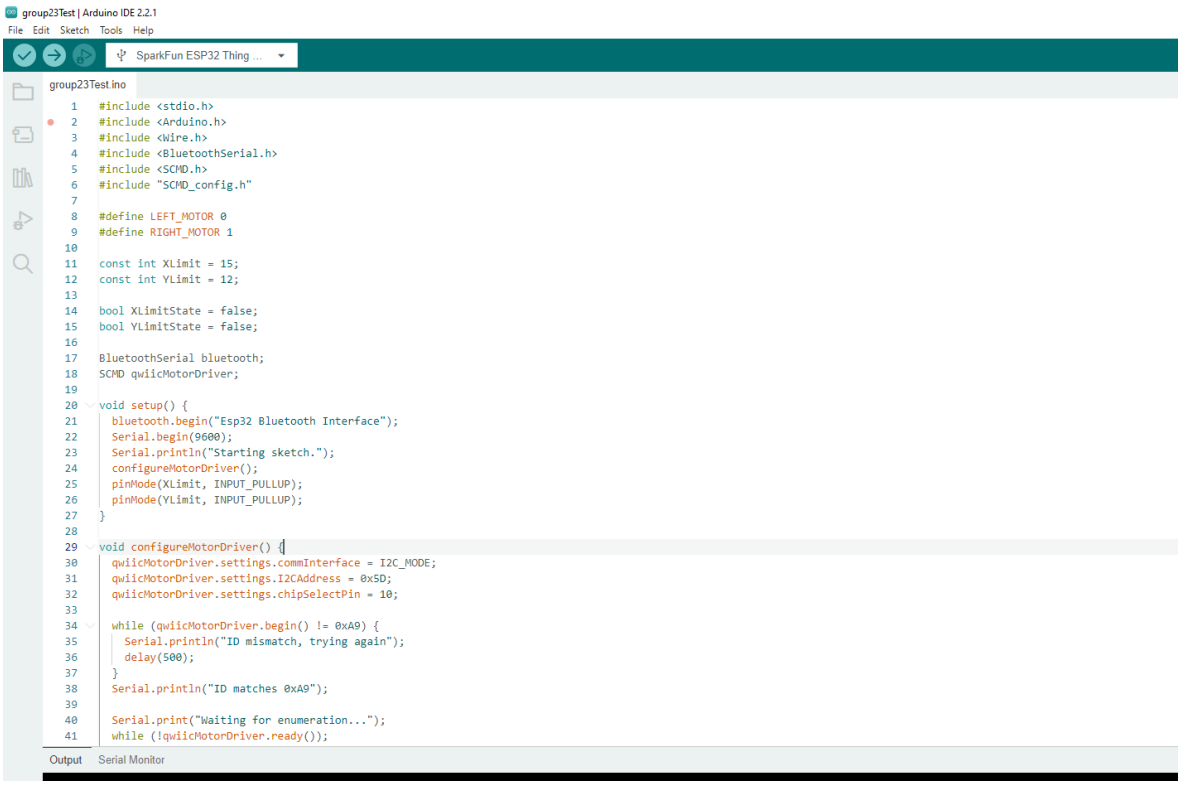


Figure-14: X-Y Pen Plotter Code

SCAN ME!

3.5 HMI (Human Machine Interface):

A Bluetooth serial terminal application serves as the Human-Machine Interface (HMI) for controlling and operating a Pen Plotter. This application enables users to interact with the Pen Plotter wirelessly via Bluetooth technology, providing a user-friendly interface to input commands and control the movements and actions of the plotter. Through this HMI, users can send instructions, such as directional commands and drawing patterns, allowing for precise and customized plotting tasks. The Bluetooth serial terminal application acts as a pivotal bridge between the user's commands and the Pen Plotter's functionality, offering convenience and flexibility in its operation.

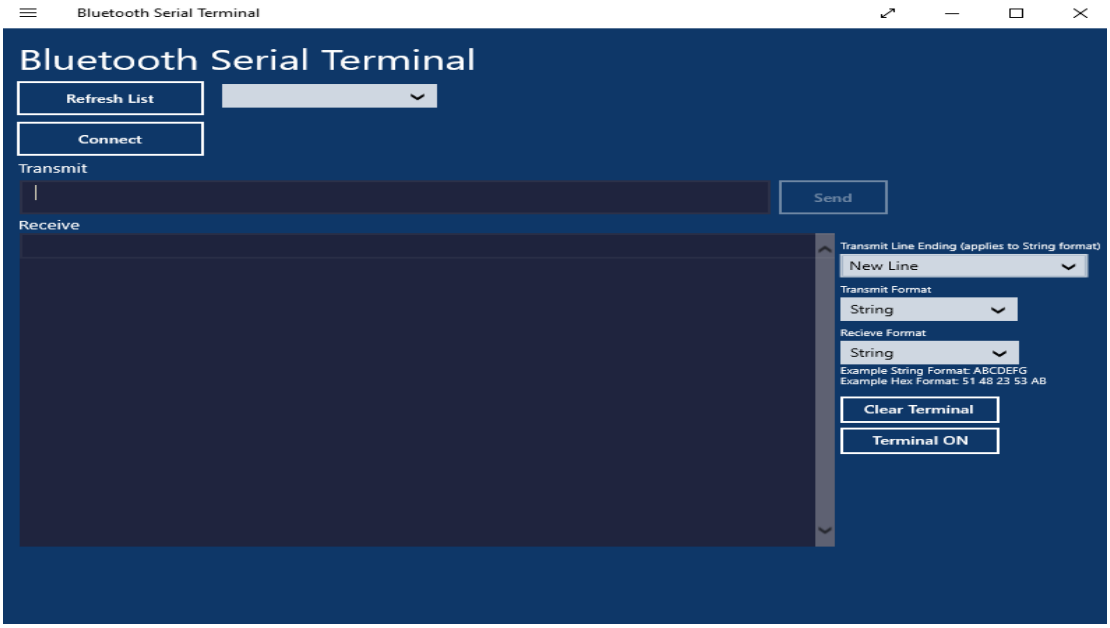


Figure-15: HMI via Bluetooth Terminal

Functions:

This directional commands to operate the pen plotter.

- ✓ Start (Draw Nicholas House) “1”
- ✓ STOP “0”
- ✓ Emergency Break “3”
- ✓ Home Position “2”

4. VERIFICATION & VALIDATION PHASE:

In this stage, the resulting XY Pen plotter model with the required electrical connections and uploaded control program is validated for the output and tested to see if it produces the Nikolaus' House desired output as intended.

We were able to reduce the mistakes found in the Nikolaus' House final product after several revisions. With a few adjustments to the pen plotter's control program, the disparities that had previously been seen were eliminated

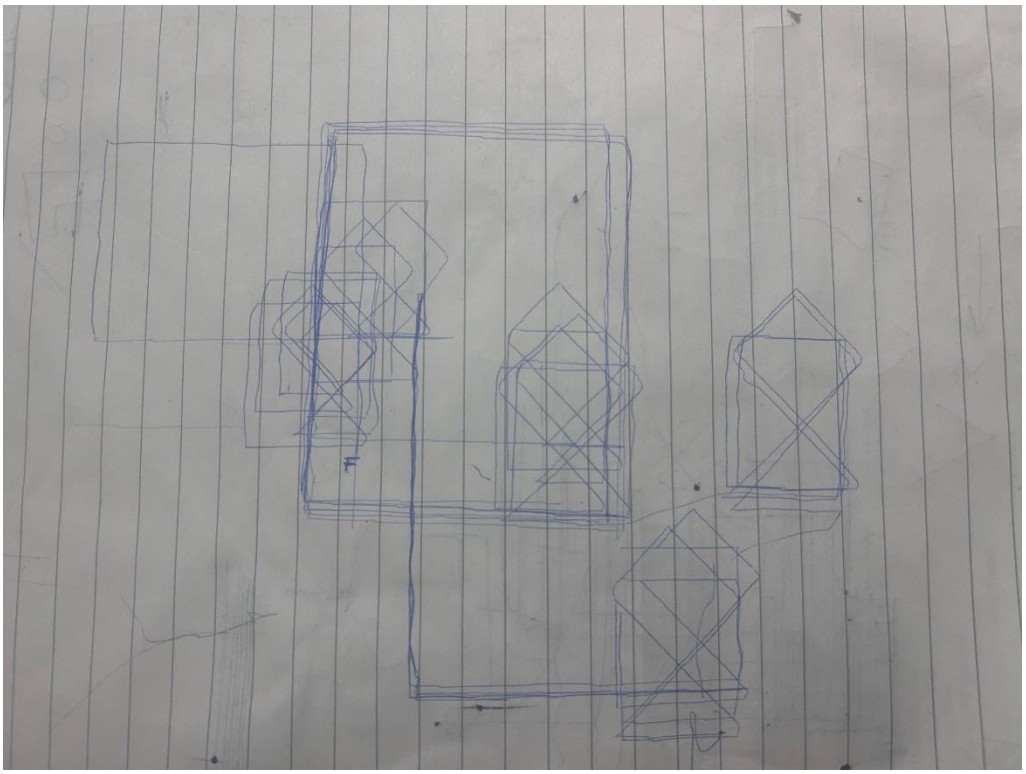


Figure-16: Verification & Validation Procedures

Verification Protocol Number (ValPr.)	Remarks	Criteria (Pass / Fail)
VerPr. 1	Place pen plotter on table with A4 paper, Turn ON Power source, Turn ON electrical circuits	Pass
VerPr. 2	Put pen plotter in box, carried out by focus group, easy to handle	Pass
VerPr. 3	Connect controller with laptop using USB 2.0/Adaptor cable/Power bank	Pass
VerPr. 4	Set-up pen plotter, Start pen plotter by student, Draw Nikolaus' house	Pass
VerPr. 5	Functionality of Limit switch	Pass
VerPr. 6	Press Emergency Stop Button during instance	Pass

Table-1: Verification protocol

4.1 Result of the control program:

Upon executing the above program, the pen plotter assembly is successfully able to draw the required Nikolaus' House of specified dimensions as per the requirements. The course of action that is followed by the system to draw the Nikolaus' is as per the figure mentioned below.

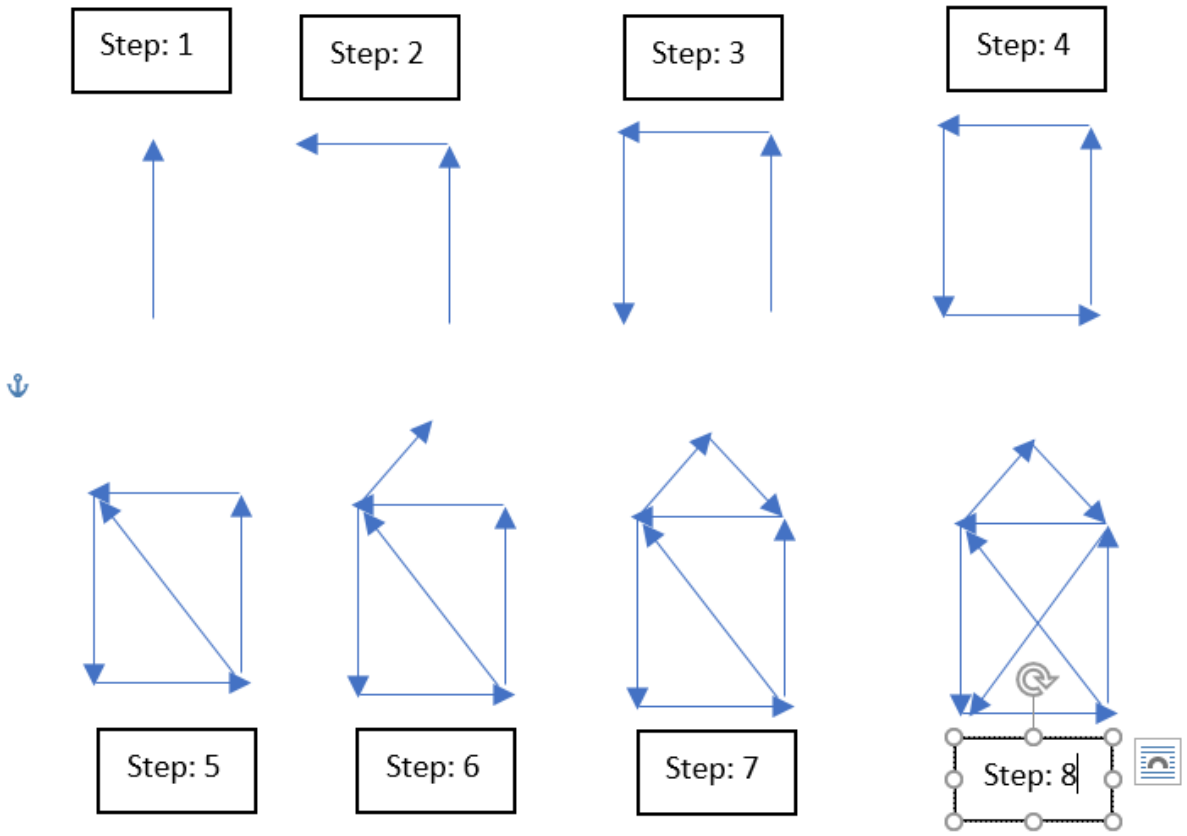


Figure-17: Control program

5. CONCLUSION:

We have finally developed a fully functional XY Pen plotter that is capable of drawing the Nikolaus' House as per the specification mentioned in the user requirements. All the components that were provided for this project have been used apart from the Hall Effect sensor whose functionality was not required for the current design of our pen plotter.

5.1 Retrospective Points:

- The team's skills in coding, 3D modelling, teamwork, and time management were all much enhanced by the process of creating and implementing the XY Pen Plotter.

- During the process of 3D modelling, there were a few flaws that ended up affecting how the pen plotter was put together. For instance, a somewhat correct synchronization was produced via the connection between the drive belt and the pulleys that were 3D printed. This occasionally led to slip conditions between the two components, which caused the Nikolaus home drawing to deviate significantly from the ideal drawing.

- The power output of the Geared motors that were given to us turned out to be inadequate. In a very small number of situations, this led to slip circumstances, which led to distortions in the Nikolaus House's final output drawing. We could have utilized stepper motors instead of the traditional DC servo motors, which would have been significantly more effective in terms of power output and performance.

- In some situations, the Motor Driver Controller caused unequal power distribution to the two motors. This resulted in asymmetrical drawing of the Nikolaus House during few iterations.

- Due to several flaws in the mechanical parts (Ball Bearings, Guide Rods), the entire system cannot be entirely vibration-damped.

5.2 Final model:

The final outlook of our designed model is as shown in the figure below. The resultant XY pen plotter is capable of successfully drawing the Nikolaus' House within the specified limits as per the user requirements with an operating time of roughly 30 seconds for each cycle.

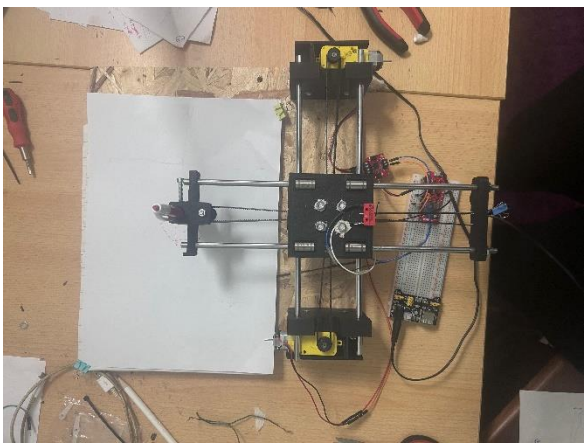
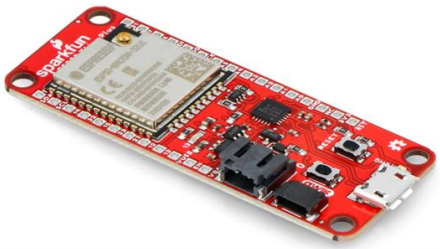
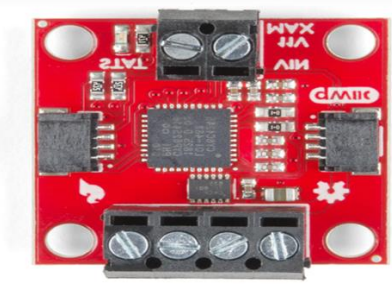
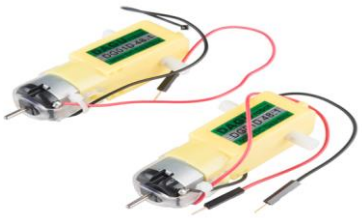


Figure-18: Final Working Model of XY Pen Plotter

6. APPENDIX:

Part Description	Image for Reference
Arduino IDE- Microcontroller ESP32 WROOM system, single-core 32-bit Xtensa LX6 processor with clock rates of up to 240 MHz	
QWIIC Motor Driver 1.5 A peak drive per channel, 1.2 A steady state Operates from 3 to 11 Volts with 12V absolute max 3.3V default VCC and logic Controllable by I2C or TTL UART signals	
DC Motor Suggested Voltage: 4.5VDC No Load Speed: 140RPM No Load Current: 190mA Max. Load Current: 250mA Torque: 800 gf-cm	
Power supply Breadboard Power Supply TS1171	
Push Button 15 0 / length 24 mm	
Limit switch XSS-5GL13 Operating voltage 250V	

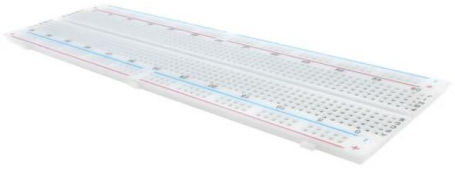
Jumper Cables JST SH 4-Pin Cable QWIIC Compatible, 100mm long	
Transmission belts T2 2mm pitch 6mm wide rubber timing belt	
Guide Rods Misumi Stainless Steel (600 mm)	
Linear Ball Bearing LMU-N6 Stainless Steel	
Breadboard MB-102 Plug-In board 830 pins60320025	

Table-2: Bill of Materials

7. GitHub

For access to the project's Design, code and other elated documents, please refer to our GitHub page:

XY-Pen-Plotter.

8. REFERENCES

1. https://learn.sparkfun.com/tutorials/esp32-thing-plus-hookup-guide/all#arduino-example-esp32-ble
2. https://learn.sparkfun.com/tutorials/esp32-thing-plus-hookup-guide/all#hardware-overview
3. https://learn.sparkfun.com/tutorials/esp32-thing-plus-hookup-guide/all#troubleshooting
4. https://spectrum.ieee.org/the-axidraw-minikit-is-the-modern-xy-plotter-you-didnt-know-you-wanted
5. https://www.creativemechanisms.com/blog/learn-about-polylactic-acid-pla-prototypes
6. https://www.math.kit.edu/didaktik/seite/ws-euler/media/nikolaus
7. https://www.thingiverse.com/thing:1514145