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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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HOCHSCHULE SCHMALKALDEN
UNIVERSITY OF APPLIED SCIENCES

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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in partial fulfillment for the award of the degree of Master of Engineering in Mechatronics & Robotics during the academic year 2022-23.

Prof. Dr. Stefan Roth
Faculty of Mechanical Engineering

Prof. Dr. Ing- Silvio Bachmann
Faculty of Electrical Engineering

ACKNOWLEDGEMENT

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Additionally, we would like to express our gratitude to all of the teachers whose advice gave us a clear path to follow in order to complete this endeavour. Furthermore, we would like to thank all of our senior colleagues and classmates for helping us and giving us a good working experience. Finally, we would like to thank each and every person who has worked so hard and consistently to make this project a success.

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

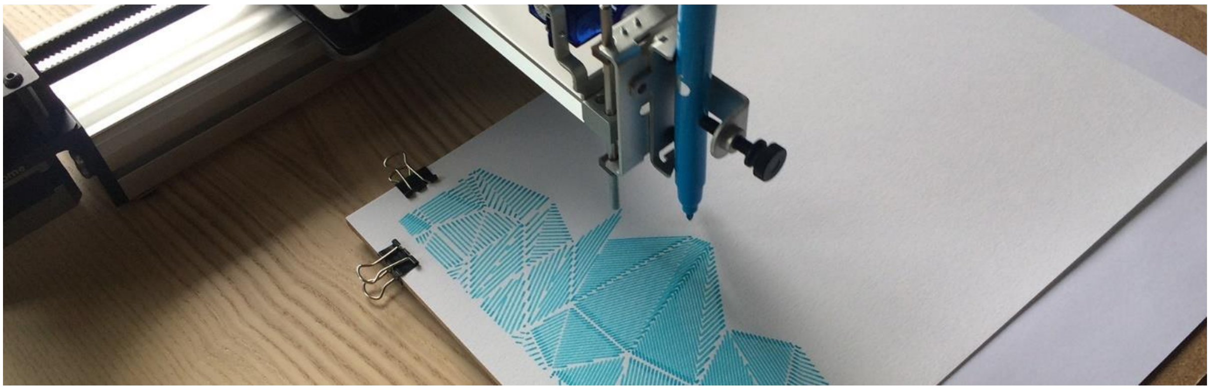


Figure-1: Concept example of XY Pen Plotter

The XY pen plotter is a complex tool that uses a computer-driven software to rapidly, precisely, and accurately write words and graphical artwork. The pen plotter is a prime example of a mechatronic system that functions by synchronized cooperation across the domains of electrical, software, and mechanical engineering, with mechanical engineering being the dominating one.

The analog measurement tools like seismographs provided the initial concepts for pen plotters. Modern computer-driven XY pen plotters have their roots in these historical XY pen plotters.

A system of intricate writing tools that may be dragged over a piece of paper to draw is used to create a text or a picture. In other words, the pen plotter has a two-axis control that enables X and Y axis movement. Additionally, there are intricate pen plotter designs that elevate or descend the pen using a unique writing component. To allow the pen to fit into the system, a hole is supplied at the far end of the assembly. Colored letters or pictures may be created using a variety of pens. Modern pen plotters use SVG (Scalable Vector Graphics) and related files, which let you mix various forms, pathways, text, and graphic components to produce a variety of graphics.

1.1 TASK DESCRIPTION:

The primary goal of this project is to build and construct an XY pen plotter that is capable of accurately drawing the Nikolaus home, a basic eight-line layout of a home, as illustrated in the image below.

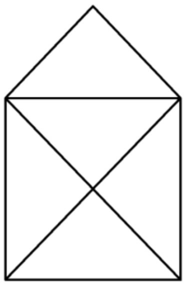


Figure-2: Nikolaus House

- The project requirements also include the realization of the following functions:
- Using 3D printing to create a stiff mechanical system that includes a pen holder.
- Creating a workable IC-layout method to provide the pen-plotter the necessary electrical support.
- Create a functional software program that controls the pen plotter's movement in order to effectively create the Nikolaus House.
- Understanding that synchronous collaboration between all three domains is necessary to successfully sketch the requisite Nikolaus House.

2. PLANNING & CONCEPTUALIZATION

2.1 CONCEPT DESIGN OF PEN PLOTTER:

Prior to conceptualizing the design, our main strategy was reviewing the pre-existing ideas that were already available online and conducting a broad group brainstorming session. We chose to move on with the H-Bot Pen Plotter Mechanism, which is shown in the picture below, out of all the available designs.

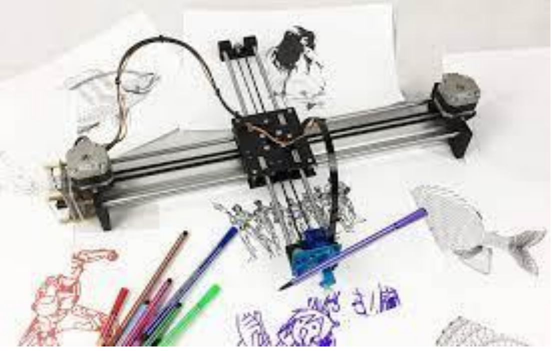


Figure-3: H-Bot Pen Plotter Mechanism

2.2 WORKING MECHANISM OF XY PEN PLOTTER:

The XY plotter's current design reportedly employs two Gear motors to position the penholder. Instead of being positioned along the x and y axes directly, these two motors are placed on the x-axis opposite to one another. Along the x and y axes, a loop of the drive belt is attached to the mobile chassis. Turning on one motor while holding the other stationary, makes it easier for the assembly to move diagonally (at a 45° angle). The penholder is moved down the opposing diagonal by turning the other motor while maintaining steady motion with the first one.

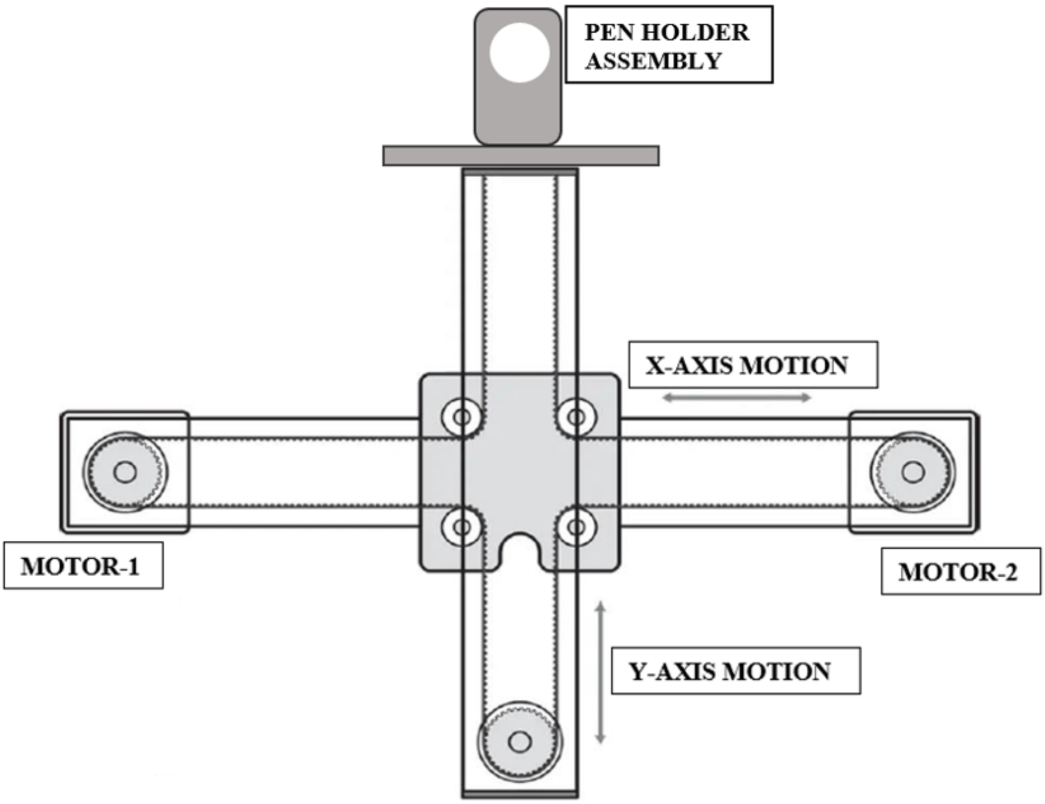


Figure-4: Working model of the H-Bot Mechanism XY Pen Plotter

2.3 DEVELOPMENT OF V-MODEL:

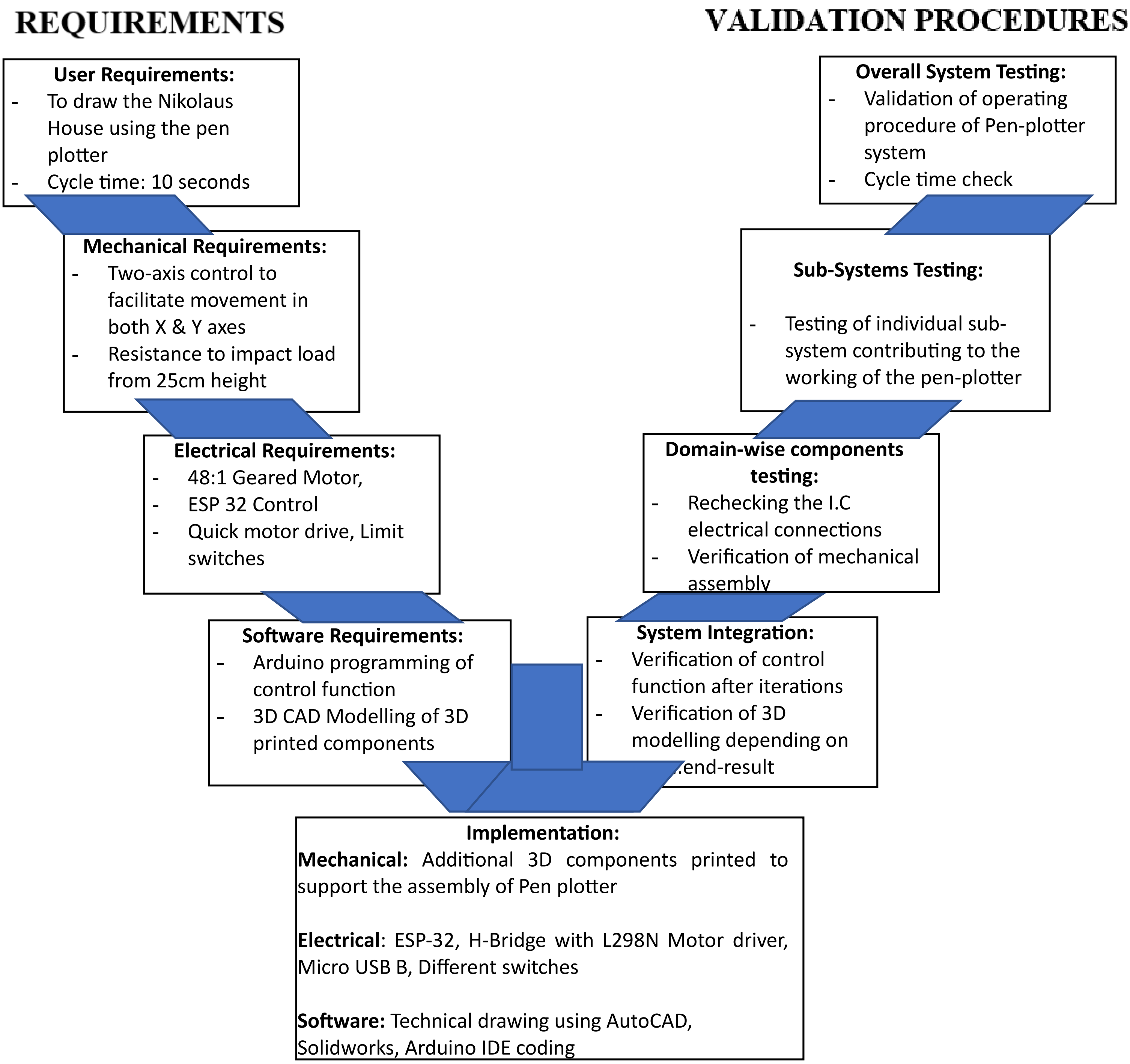


Figure-5: V-Model

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.
- This pen plotter should have a maximum lifespan of at least 4-5 cycles before failing.
- The cost of the pen-plotter must be around 140-160 €.

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 belts**: Drive belts are 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 cost of the pen-plotter is around 140 €.
- 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 made a list of all the secondary and tertiary sub-components that were necessary for the construction of the full system based on our examination of the design of an H-bot XY pen plotter. Following thorough calculation and analysis of the necessary criteria, we used Solidworks to design each of these sub-components. We next converted the 3D drawing to the STL file format for additive manufacturing (third-party 3D printing). In this exercise, we learned about the three major types of materials used in 3D printing: ABS (Acrylonitrile butadiene), Nylon, and Polylactic Acid (PLA). PLA is a material with exceptional thermoplastic characteristics that is warp- and low-melting-temperature resistant. Since PLA material has more rigidity and strength than Nylon and ABS, we chose to utilize it to print our sub-components.

The following represents the sub-components that have been 3D printed specifically as a part of the mechanical sub-components required for assembly. The detailed 3D part drawing is depicted in the appendix section of this report.

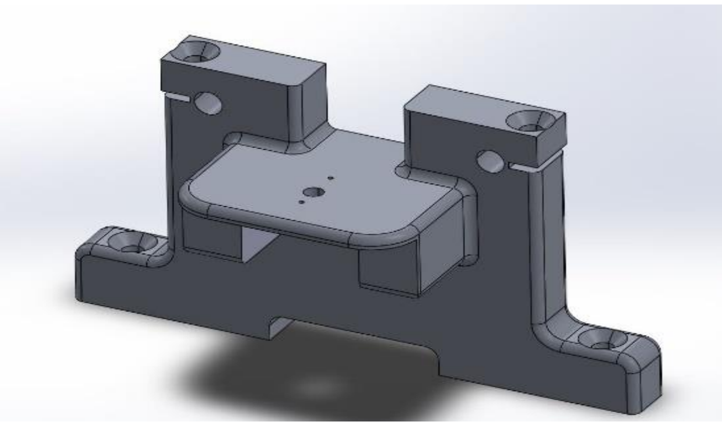


Figure-6: X-Axis Support Bracket (LHS & RHS)

Figure-7: Y-Axis Brackets

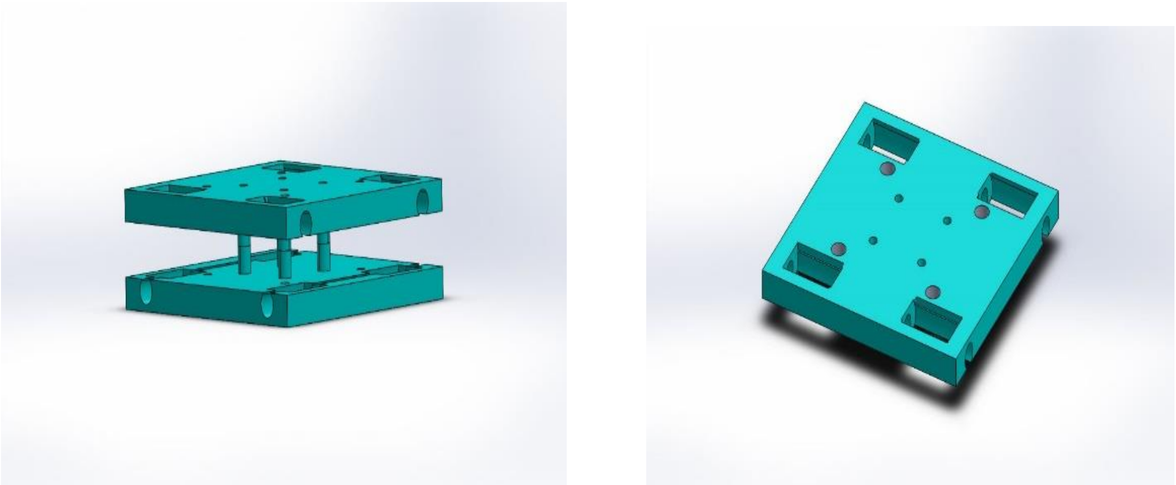


Figure-8: Middle Support Brackets for Bearing Mounting

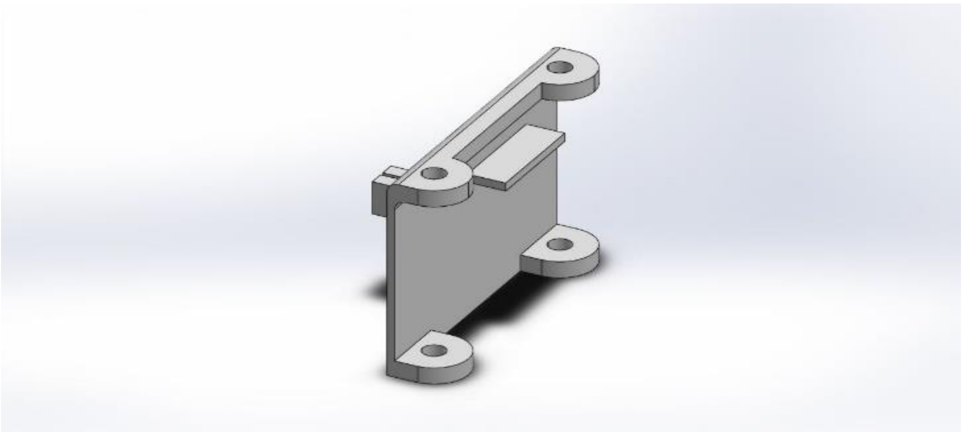


Figure-9: Pen Holder Bracket

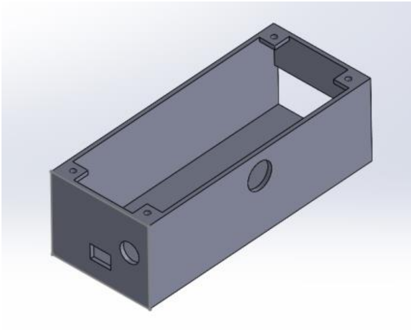


Figure-10: Cover Box

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.

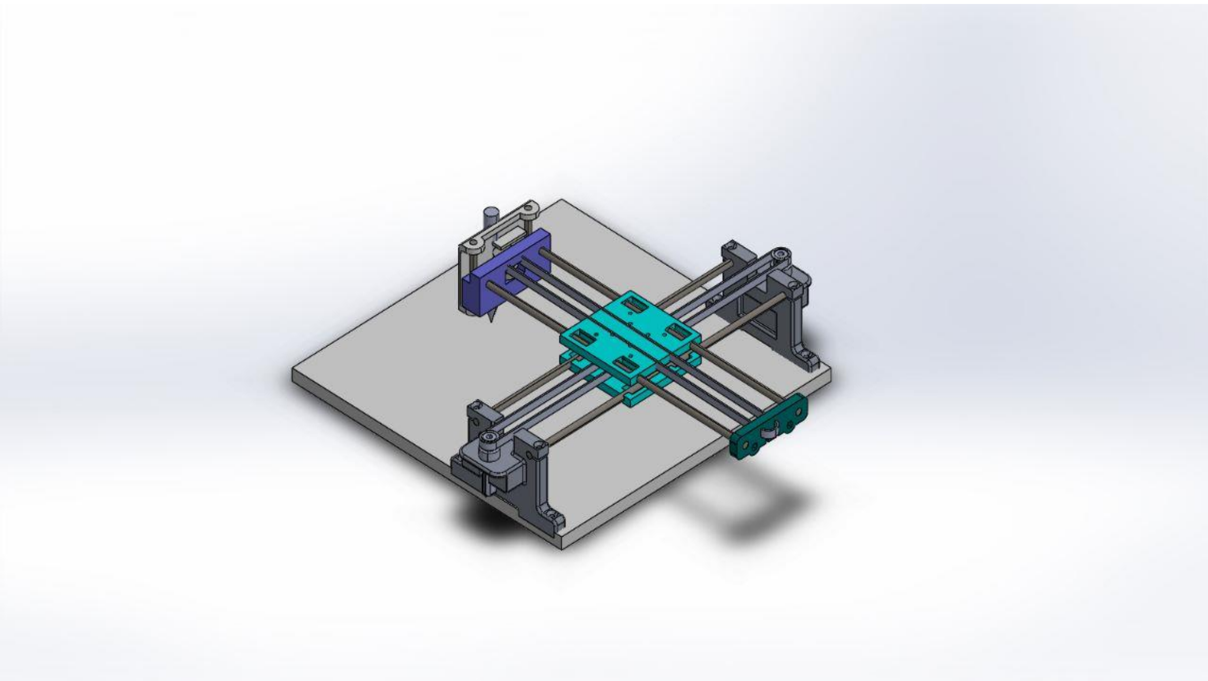


Figure-11: 3D Printed Support Structure Assembly of XY Pen Plotter

3.2 ELECTRONICS HARWARE DESIGN

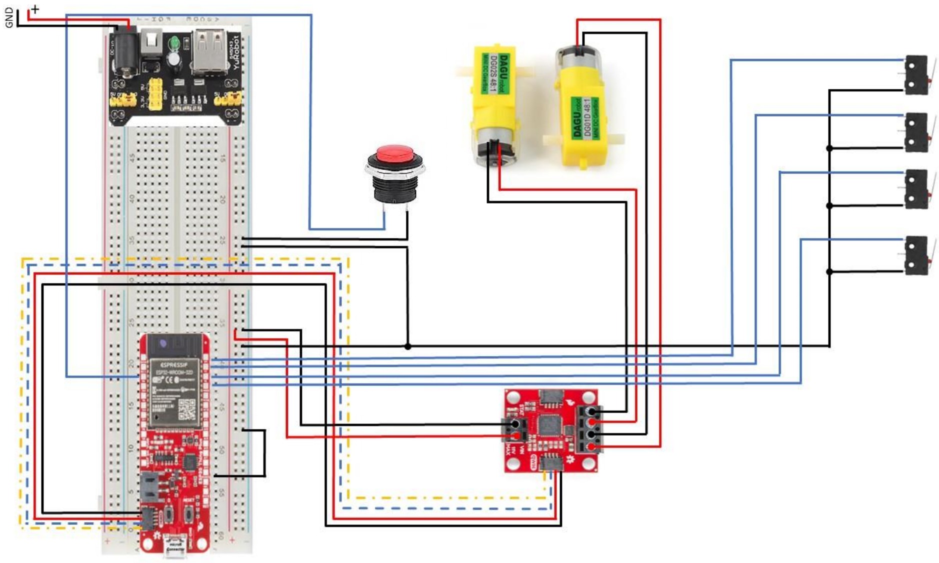


Figure-12: Electronic Circuit Layout

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

Serial Communication: A standard CE certified Breadboard component

Microcontroller: ESP-32

Motor Driver Controller: L298N H-Bridge Motor Controller

Motors: 2 x 1:48 Geared Motors

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 capacity powers both of these controllers. The two controllers' secondary and tertiary connections are 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

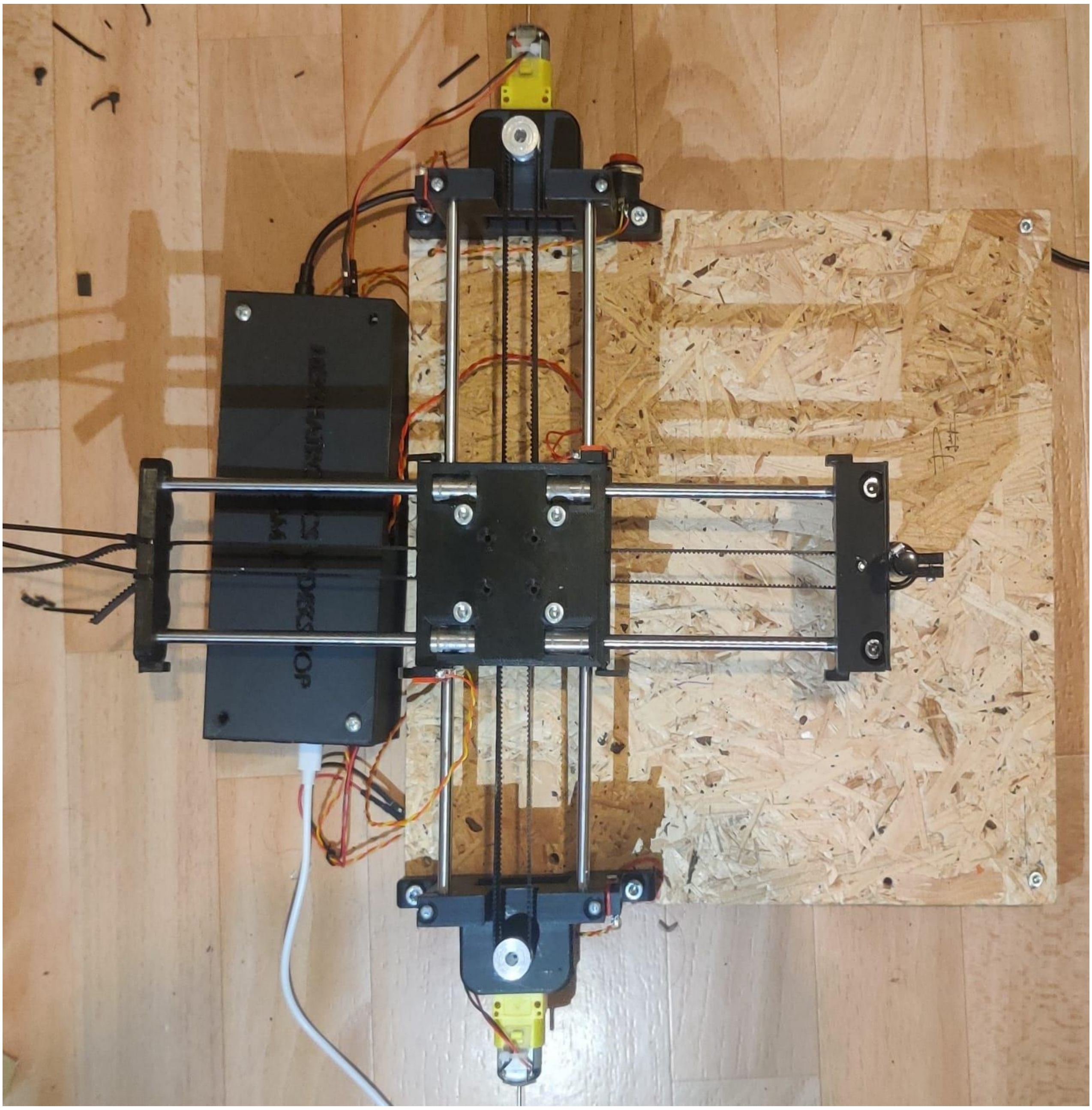


Figure-13: Assembly of Integrated Mechanical components and Electrical Circuit Layout

3.4 SOFTWARE DESIGN

One of the most important and time-consuming jobs, the control function of the pen plotter demands significant programming expertise in the necessary disciplines. As previously said, we created a control function program using the ESP-32 and its complimentary programming tools that can direct the action of the pen plotter assembly to draw the necessary Nikolaus House.

The following program is the outcome of a iterative process:

wifi3 | Arduino IDE 2.1.0

File Edit Sketch Tools Help

SparkFun ESP32 Thing ...

wifi3.ino

```
#include <WiFi.h>
//#include <esp_system.h>
#include <Arduino.h>
#include <stdint.h>
#include "SCMD.h"
#include "SCMD_config.h" //Contains #defines for common SCMD register names and values.
#include "Wire.h"

SCMD myMotorDriver; //This creates the main object of one motor driver and connected peripherals.
const char* ssid     = "Abc";
const char* password = "12345678";


WiFiServer server(80); // Port 80

void comb1();
void comb2();
void comb3();
void comb4();
void comb5();
void speeds();
void timings();
int randomNumberArray[5];
int i=0;
int indexx=0;
int randomIndex;
int emerg=0;
bool notfound = true;
bool c= true;
bool d=false;
void (*combArray[])() = {comb1, comb2, comb3, comb4, comb5};
String state = "Pen plotter is ready";
String b;
String coordinates;
int speed;
String x, y;
```

Output Serial Monitor ×

Message (Enter to send message to 'SparkFun ESP32 Thing Plus' on 'COM4') wifi3 | Arduino IDE 2.1.0

File Edit Sketch Tools Help

SparkFun ESP32 Thing ...

wifi3.ino

```
// comb definitions
void comb1() //com1
{
  pos_x();delay(3000);stp(); delay(1000);pos_y();delay(3000);stp();delay(1000);neg_x();delay(3000);stp();delay(1000);neg_y();delay(3000);stp();delay(1000);
  ne();delay(3000);stp();delay(1000);nw();delay(3000);stp();delay(1000);sw();delay(3000);stp();delay(1000);se();delay(3000);stp();delay(1000);
}

void comb2()  //com2
{
  pos_x();delay(3000);stp();delay(1000);pos_y();delay(3000);stp();delay(1000);sw();delay(3000);stp();delay(1000);pos_y();delay(3000);stp();delay(1000);
  pos_x();delay(3000);stp();delay(1000);nw();delay(3000);stp();delay(1000);sw();delay(3000);stp();delay(1000);se();delay(3000);stp();delay(1000);
}

void comb3()  //com3
{
  pos_x();delay(3000);stp();delay(1000);pos_y();delay(3000);stp();delay(1000);nw();delay(3000);stp();delay(1000);sw();delay(3000);stp();delay(1000);
  pos_x();delay(3000);stp();delay(1000);sw();delay(3000);stp();delay(1000);pos_y();delay(3000);stp();delay(1000);se();delay(3000);stp();delay(1000);
}

void comb4()  //com4
{
  pos_x();delay(3000);stp();delay(1000);nw();delay(3000);stp();delay(1000);ne();delay(3000);stp();delay(1000);se();delay(3000);stp();delay(1000);
  sw();delay(3000);stp();  delay(1000);pos_y();delay(3000);stp();delay(1000);pos_x();delay(3000);stp();delay(1000);neg_y();delay(3000);stp();delay(1000);
}

void comb5()  //com5
{
  ne();delay(3000);stp();delay(1000);neg_y();delay(3000);stp();delay(1000);nw();delay(3000);stp();delay(1000);ne();delay(3000);stp();delay(1000);
  se();delay(3000);stp();delay(1000);neg_x();delay(3000);stp();delay(1000);neg_y();delay(3000);stp();delay(1000);pos_x();delay(3000);stp();delay(1000);
}

void sw() {
  // Perform the motor actions
  myMotorDriver.setDrive( LEFT_MOTOR, 0, 250);//nw dir
  myMotorDriver.setDrive( RIGHT_MOTOR, 1, 0);
```

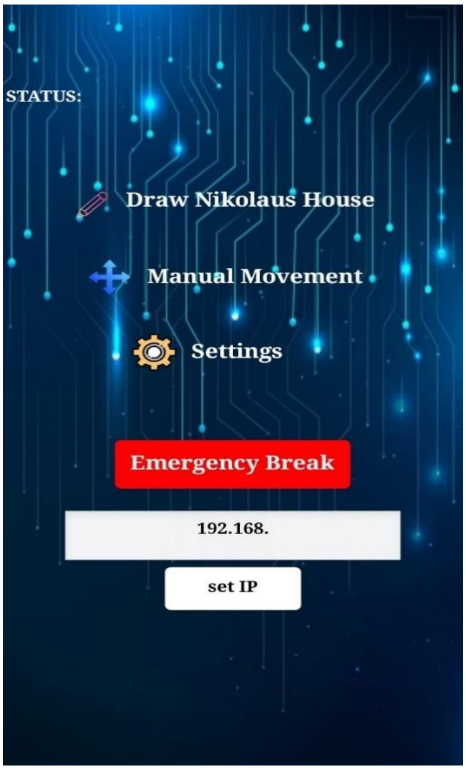
Output Serial Monitor

Message (Enter to send message to 'SparkFun ESP32 Thing Plus' on 'COM4')

Ln 200, Col 46 SparkFun

SCAN ME

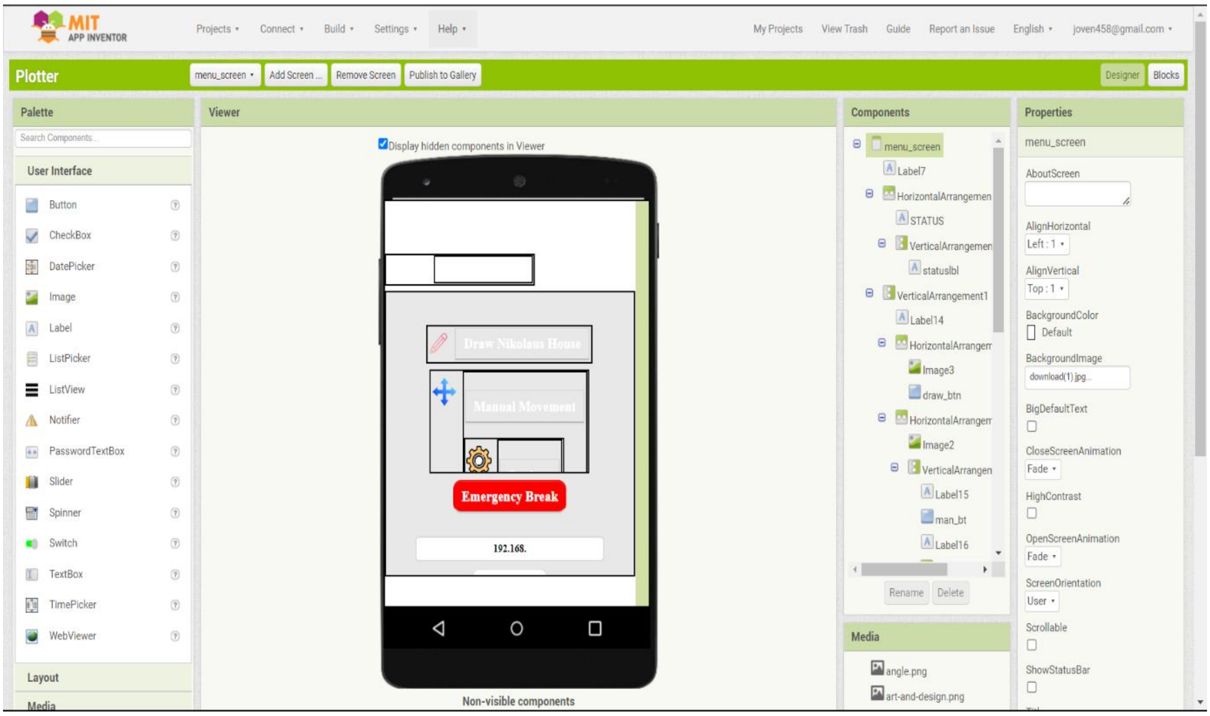
3.5 GUI DEVELOPMENT

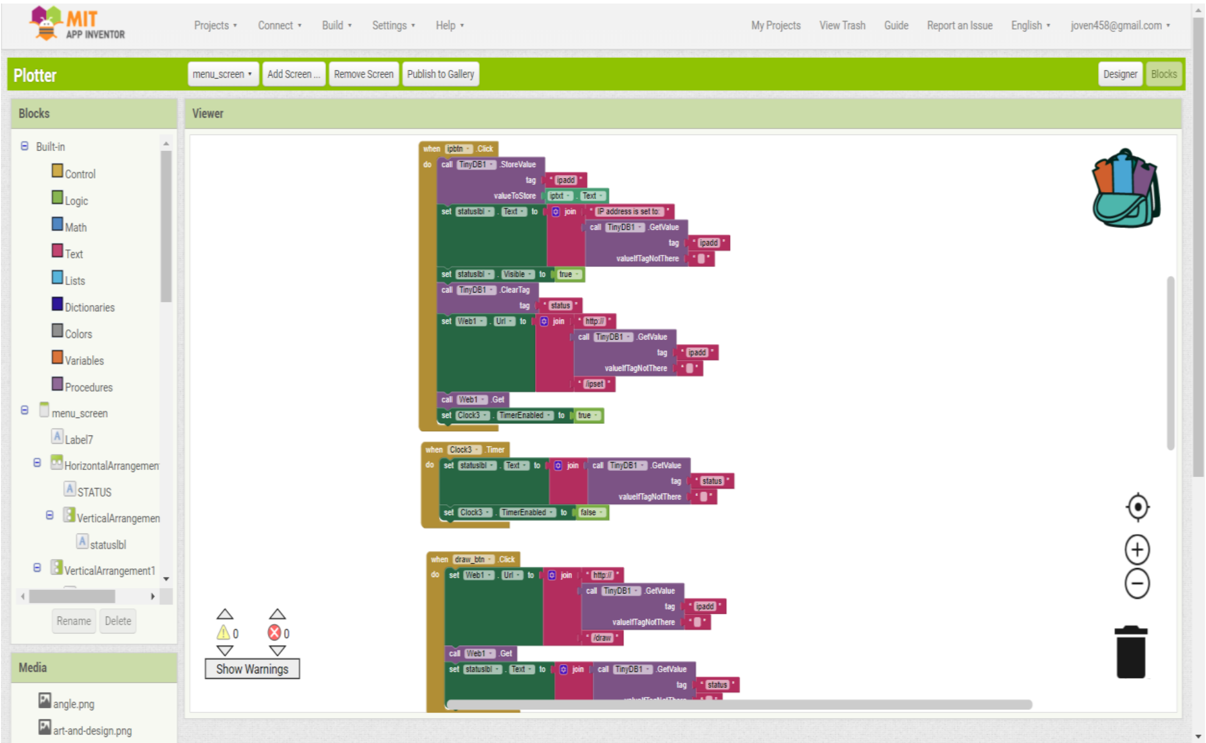


Functions:

This window shows the functions which are used to operate the pen plotter.

- Status of the Pen Plotter
- To draw Nicholas House
- Manual Movement
- Emergency Break
- Set Coordinates
- Set speed


MIT APP INVENTOR
Projects
Connect
Build
Settings
Help
My Projects
View Trash
Guide
Report an Issue
English
joven458@gmail.com
Plotter
menu_screen
Add Screen ...
Remove Screen
Publish to Gallery
Designer
Blocks
Palette
User Interface
Button
CheckBox
DatePicker
Image
Label
ListPicker
ListView
Notifier
PasswordTextBox
Slider
Spinner
Switch
TextBox
TimePicker
WebViewer
Layout
Viewer
Display hidden components in Viewer
Draw Nikolaus House
Manual Movement
Emergency Break
192.168.
Non-visible components
Components
menu_screen
Label7
STATUS
statuslbl
VerticalArrangement1
Label14
Image3
draw_btn
Image2
Label15
man_bt
Label16
Rename
Delete
Media
angle.png
art-and-design.png
Properties
AboutScreen
AlignHorizontal
Left : 1
AlignVertical
Top : 1
BackgroundColor
Default
BackgroundImage
BigDefaultText
CloseScreenAnimation
Fade
HighContrast
OpenScreenAnimation
Fade
ScreenOrientation
User
Scrollable
ShowStatusBar


MIT APP INVENTOR
Plotter
menu_screen
Add Screen ...
Remove Screen
Publish to Gallery
Designer
Blocks
Viewer
Built-in
Control
Logic
Math
Text
Lists
Dictionaries
Colors
Variables
Procedures
menu_screen
Label7
STATUS
statuslbl
VerticalArrangement1
Rename
Delete
Media
angle.png
art-and-design.png
Show Warnings

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's desired output as intended.

We were able to reduce the mistakes found in the Nikolaus House's 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.

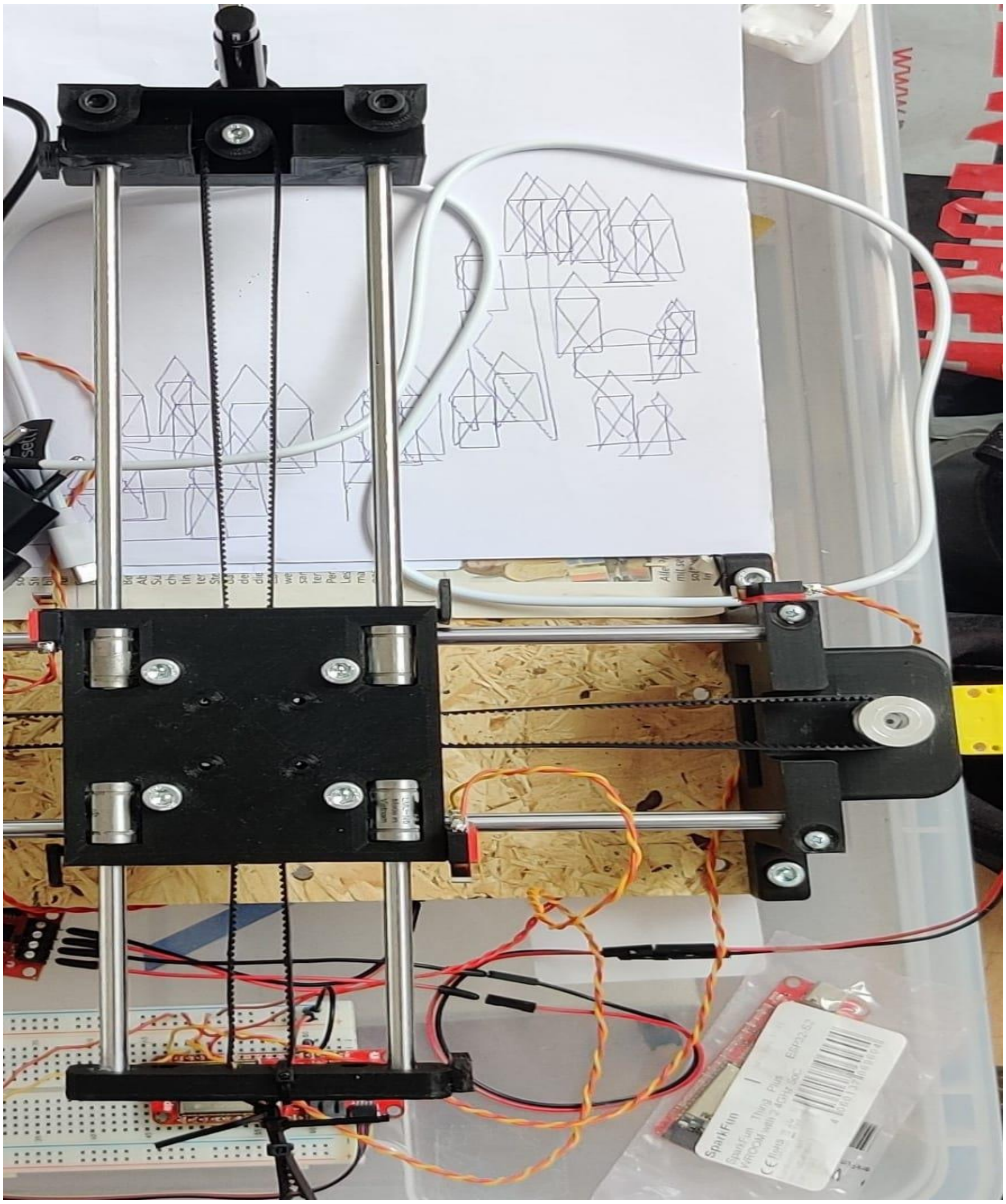
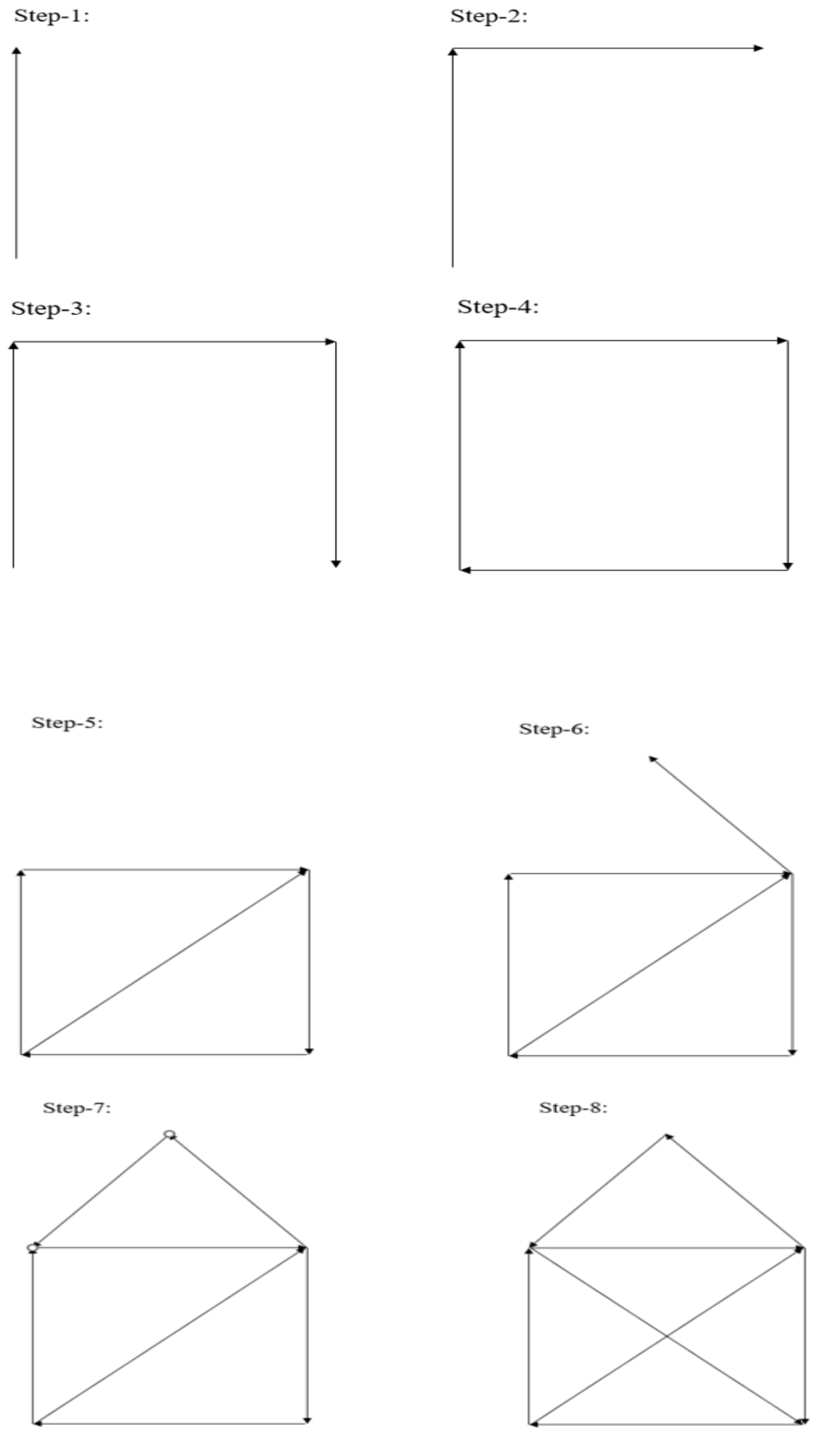


Figure-14: Verification & Validation Procedures

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 cable	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

4.1 RESULT OF THE CONTROL PROGRAM:

The pen plotter assembly successfully draws the needed Nikolaus House with the stated dimensions after running the software program in accordance with the specifications. Following the steps shown in the image below, the system draws the Nikolaus in the manner described.



5. CONCLUSION

Finally, we have developed an XY Pen plotter that can design the Nikolaus House according to the specifications specified in the user requirements. With the exception of the Hall effect sensor, whose functionality was unnecessary for our pen plotter's present design, all of the project's components have been employed.

5.1 RETROSPECTIVE POINTS:

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

- During the process of 3D modeling, 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 following figure illustrates the final appearance of our proposed model. With an operating duration of around 30 seconds for each cycle, the resulting XY pen plotter is capable of sketching the Nikolaus House successfully inside the prescribed bounds as per the user requirements.

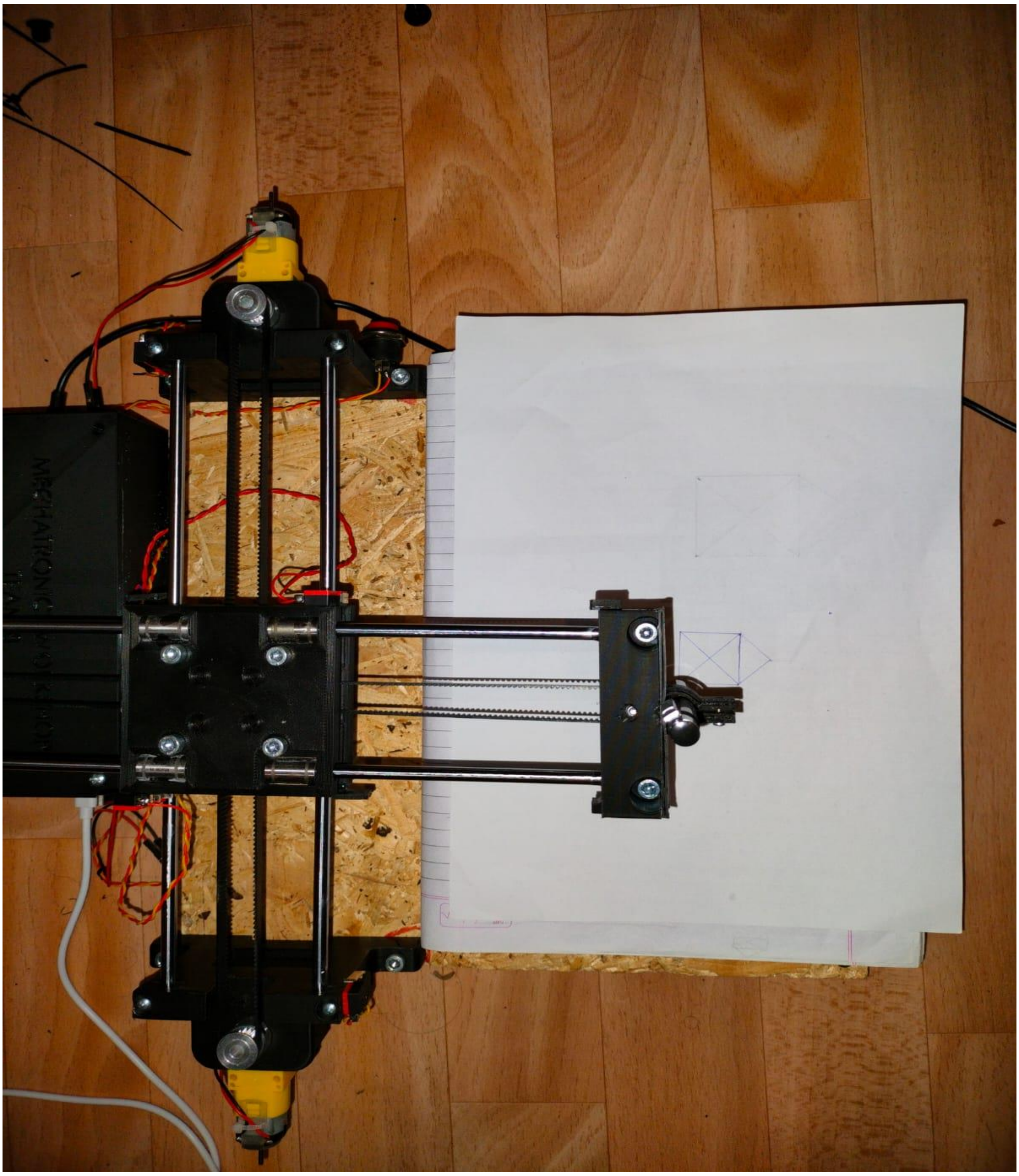
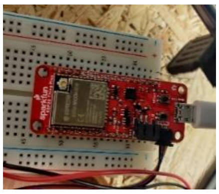
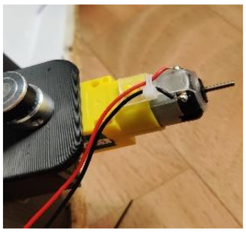
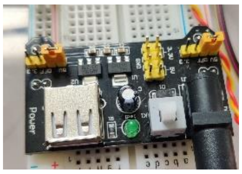
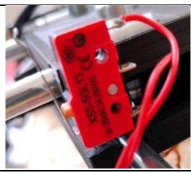


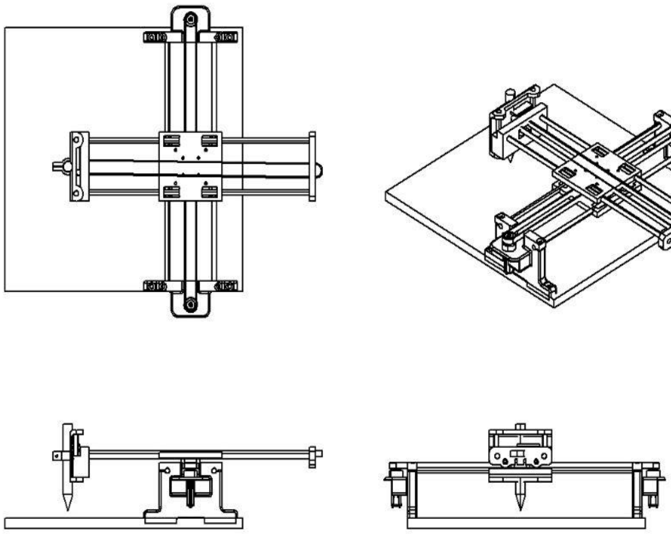
Figure-15: Final Working Model of XY Pen Plotter

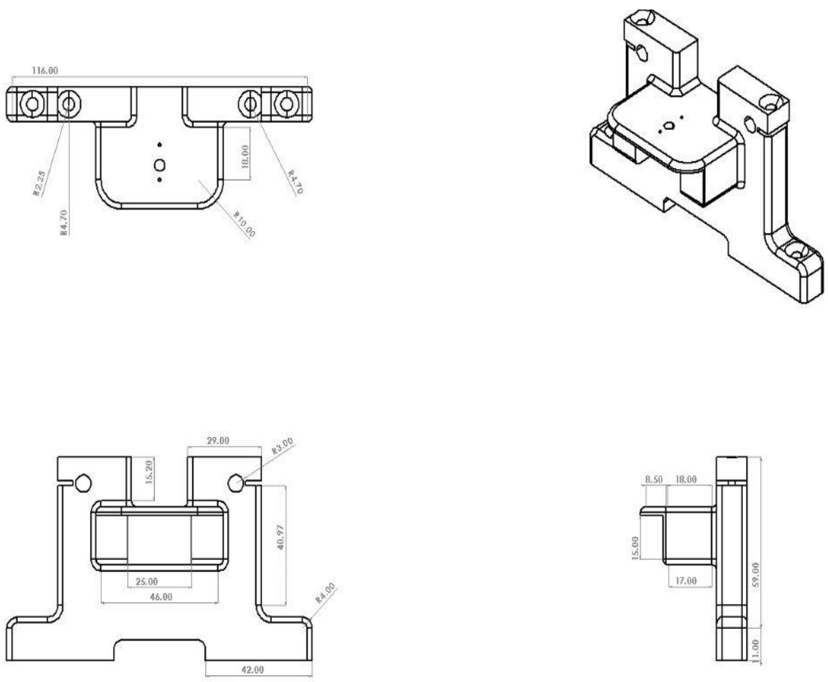
6. APPENDIX

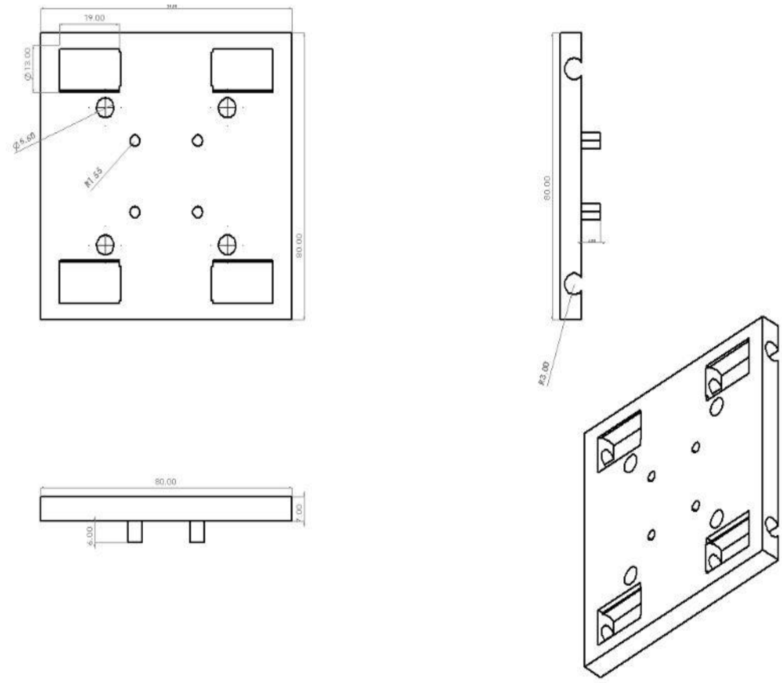
Part Description	Image for Reference
Thing Plus ESP-32 WROOM WRL 17381 Microcontroller	
Qwiic Motor Driver	
DAGU – DG01D 48:1 Mini DC GearBox	
Power Supply TS1171 Breadboard Power Supply Module	
Emergency Push Button Switch ON / OFF condition	
Limit switch (D2F-FL Omron) Snap Action Limit Switch with Level	

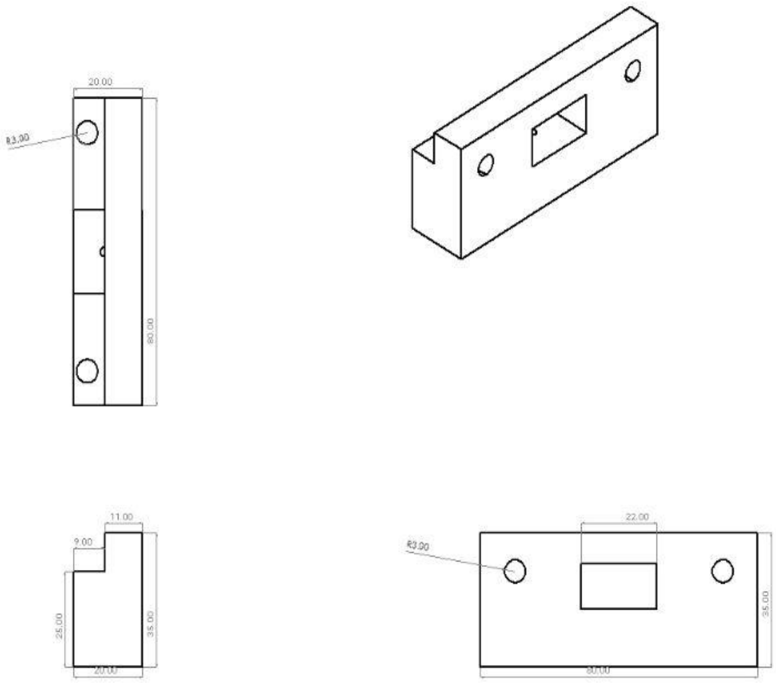
Jumper Cables JST SH 4-Pin Cable QWIIC Compatible, 100mm long	
Drive Pulleys	
Transmission belts Belt Height: 2 mm; Belt Width: 6 mm. Material: Plastic; Length: 500 mm.	
Guide Rods Misumi Stainless Steel (600 mm)	
Linear Ball Bearing LMU-N6 Stainless Steel	
Breadboard	

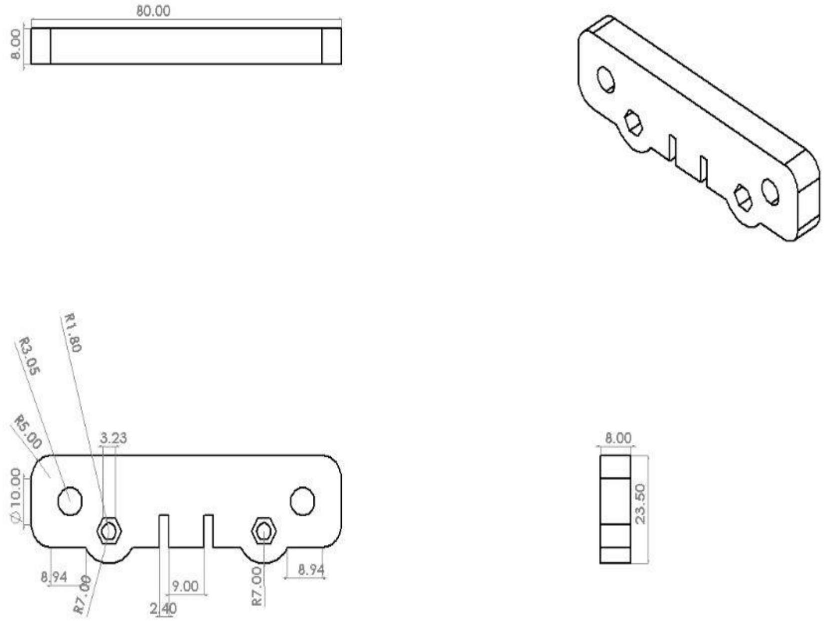
The 3D CAD drawings of the various printed parts are depicted for reference.

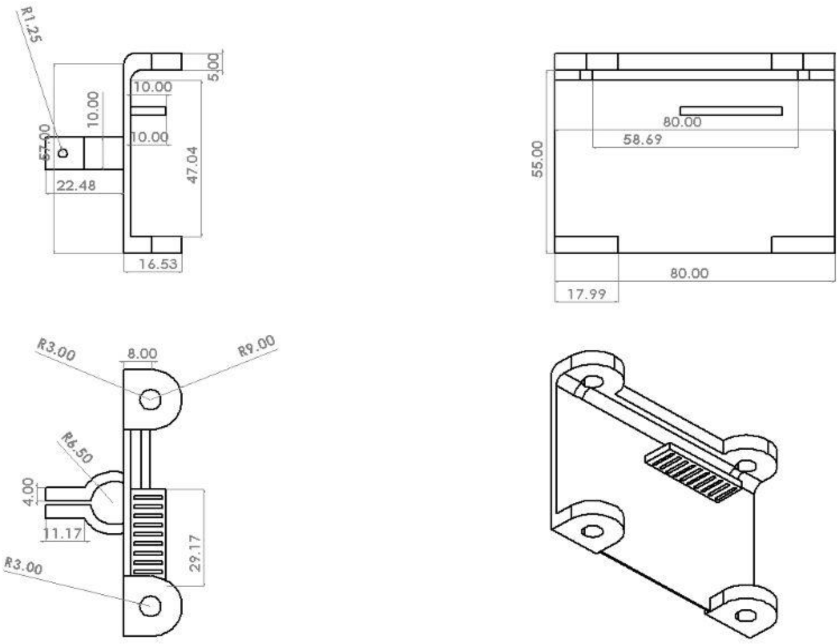





19.00
80.00
7.00


20.00
R3.00
80.00
11.00
9.00
25.00
35.00
20.00
22.00
R3.00
35.00
80.00


80.00
8.00
R1.80
R3.05
R5.00
3.23
∅10.00
8.94
R7.00
9.00
2.40
R7.00
8.94
8.00
23.50


R1.25
5.00
10.00
10.00
10.00
7.00
22.48
47.04
16.53
80.00
58.69
55.00
80.00
17.99
R3.00
8.00
R9.00
R6.50
4.00
11.17
29.17
R3.00

7. REFERENCES

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