Schmalkalden University of Applied Sciences

Master of Mechatronics and Robotics

Project Report

On

XY-Pen Plotter

Under the subject of

Workshop I & II

Submitted by

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Student Declaration

We (Ashay Bengle, Arbaz Basar, Hussain Motiwala, Mahadev Kadam), hereby declare that this project entitled **“XY PEN PLOTTER”** done by us under the guidance of **PROF. DR. STEFAN ROTH AND PROF. DR.-ING. SILVIO BACHMANN** is not copied and submitted anywhere for the award of any degree.

DATE: 30-09-2024
PLACE: SCHMALKALDEN, GERMANY

Acknowledgement

We extend our deepest gratitude to Prof. Dr.-Ing. Silvio Bachmann and Prof. Dr. Stefan Roth for their invaluable guidance and unwavering support throughout this project. Their insightful suggestions, encouragement, and coordination have been pivotal in shaping this dossier and ensuring its success.

We also express our sincere appreciation to our dedicated teachers, whose teachings provided the essential knowledge needed for this endeavour. Furthermore, we are profoundly grateful to the individuals working in the AKT Lab. Their expertise, collaboration, and assistance were crucial to the successful completion of our project.

The valuable contributions from the AKT Lab team, along with the guidance from Prof. Dr.-Ing. Silvio Bachmann and Prof. Dr. Stefan Roth, have greatly enriched our project's outcomes.

We also thank our classmates for their interactions and inquiries, which enhanced our understanding of the subject matter. Their active participation in the learning process has been truly beneficial.

Lastly, we are grateful to the faculty, staff, and management for their assistance and the provision of necessary resources, which enabled us to complete this project. Their support has been instrumental in helping us achieve our goals.

We sincerely appreciate everyone who contributed to making this project a reality.

Schmalkalden University of Applied Sciences

CERTIFICATE

Certified that this Project report titled **"XY PEN PLOTTER"** is the bonafide work of

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who carried out the project under our supervision. Certified further, that to the best of our knowledge the work reported herein does not form part of any other project report or dissertation based on which a degree or award was conferred on an earlier occasion on this or any other candidate.

PROJECT GUIDE

PROF. DR. STEFAN ROTH

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Chapter 1. Introduction

In today's world, where technology and creativity meet, the Pen Plotter project represents this blend perfectly. Using modern engineering, we're able to create detailed drawings of the Nicolaus House, a well-known architectural landmark. The project is not just about copying the building; it is about merging accuracy with artistic creativity.

This project shows the partnership between human skill and technology. With precise algorithms, the Pen Plotter carefully brings the Nicolaus House to life on paper, stroke-by-stroke, blending precision with artistic flair.

The goal is to show how important precision is in engineering while also embracing the artistic potential of technology. By drawing the Nicolaus House with a Pen Plotter, we are taking a journey through history, innovation, and creativity which demonstrating how technology can help us to automate and improve efficiency.

1.1 Objective

Objective of this project was to design and develop a pen plotter capable of creating intricate and precise drawings, with a special focus on reproducing the renowned Nikolaus Haus. This architectural marvel, known for its complex details and cultural significance, posed an exciting challenge. Our primary objective was to build a machine that could faithfully replicate the Nikolaus Haus, balancing accuracy and control over speed.

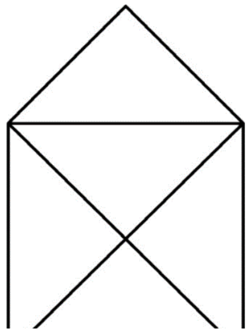


Figure 1- Nicolaus House

1.2. Approach

Unlike traditional pen plotters, we adopted a unique approach by using a lead screw mechanism instead of the conventional belt system. This modification, aimed at enhancing precision, was crucial to achieving the fine detail required for architectural drawings. Additionally, we incorporated a Raspberry Pi to manage the system, adding an extra layer of functionality and versatility to our design.

The design phase of the project involved careful selection of hardware, including motors, sensors, and control mechanisms, to ensure accuracy and smooth operation. On the software side, we first analyzed the project requirements and then developed specific algorithms designed to achieve our goals by ensuring accurate and precise pen movements. This required in-depth exploration of CAD design, motion control, and mechatronics.

Extensive theoretical testing and evaluation were carried out to assess the potential performance of the pen plotter in reproducing the intricate details of the Nikolaus Haus. Through multiple iterations and detailed analysis of software simulations and calculations, we refined the design to achieve maximum accuracy and reliability. The results suggest that the pen plotter is capable of delivering exceptional precision, capturing the essence of the Nikolaus Haus with each stroke.

This report provides a comprehensive overview of the design process, implementation strategies, testing methodologies, and the successful realization of our pen plotter project

1.3. Aim of the Project

The primary aim of this project is to design and a pen plotter capable of accurately replicating the intricate architectural details of the Nikolaus House. By integrating key components such as motors, sensors, and control systems, the project focuses on achieving high precision in plotting complex designs.

Furthermore, the project aims to expand the application of Pen Plotters beyond simple graphics to complex and detailed architectural illustrations, displaying the device's versatility.

By documenting the processes and techniques used, the project aims to provide valuable insights and best practices to the broader field of Pen Plotter art, contributing to its advancement and encouraging further exploration and innovation in this domain. This endeavour also emphasizes the integration of technological precision with creative expression, demonstrating how advanced mechatronic systems can be harnessed for artistic purposes, thus bridging the gap between engineering and art.

1.4. Roles and Responsibility

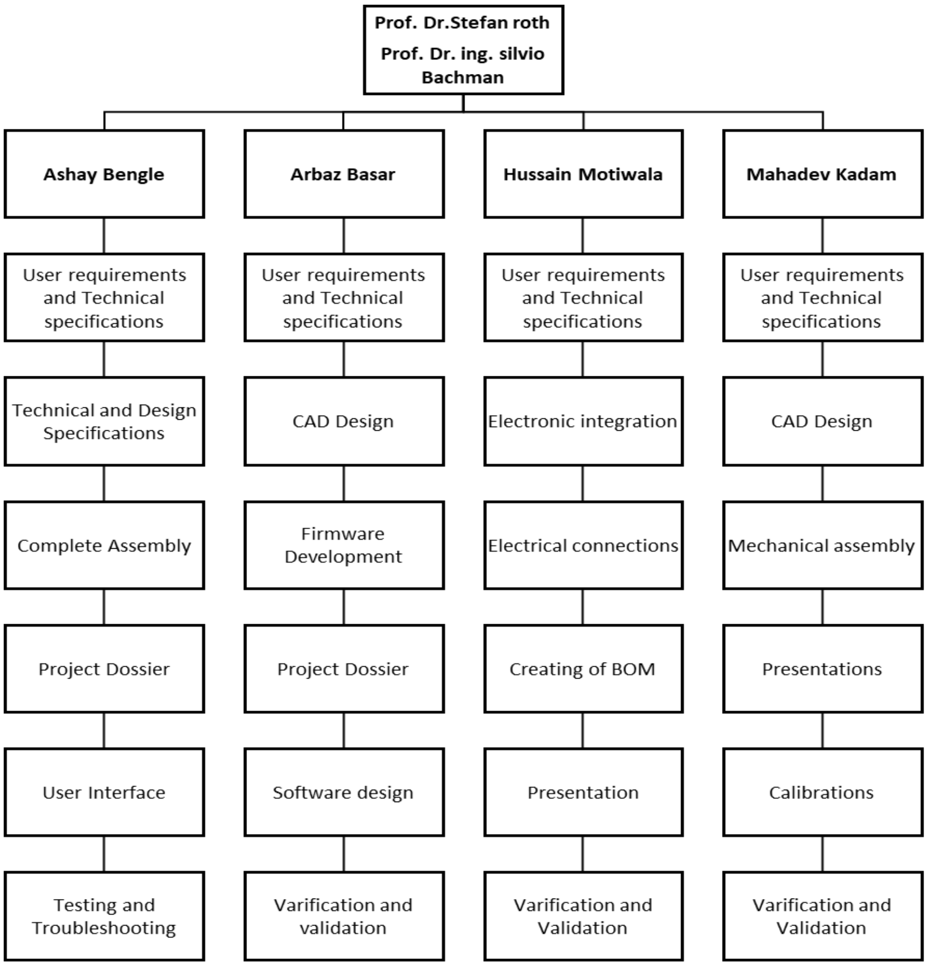


Figure 2 – Roles & Responsibility

Chapter 2. Development Documentation

2.1. V-Model Approach

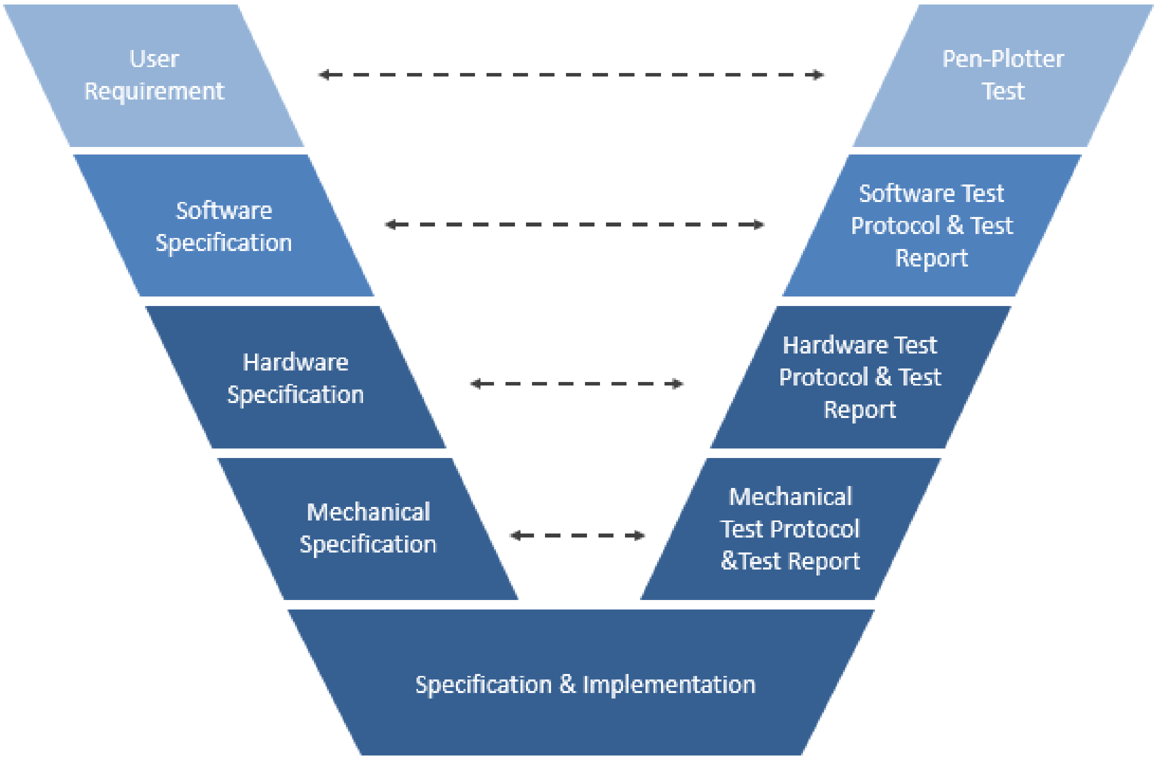


Figure 3 – V-Model

2.1.1 User Requirement

- The pen plotter must precisely replicate complex architectural designs, such as the Nikolaus Haus, with high accuracy.
- The system should prioritize precision over speed, utilizing a lead screw mechanism for X and Y axis movements.

2.1.2 Software Specification

- Develop software capable of drawing complex architectural designs 0with precise pen movements.
- The control interface should provide users with additional information, such as system status and plotting progress, without supporting design uploads.

2.1.3 Hardware Specification

- The plotter uses DC motors paired with lead screws for controlled, precise movements on the X and Y axes.
- The system will include sensors and limit switches to ensure accurate positioning and prevent over-travel.

2.1.3 Mechanical Specification

- The pen plotter's structure must accommodate the lead screw mechanism to ensure smooth and stable movement.
- A rigid frame is essential to reduce vibration, enhancing the precision of the pen's plotting process.

2.1.4 Specification & Implementation

- Integrate mechanical, hardware, and software components to construct the pen plotter, ensuring each subsystem functions cohesively.
- Implement the control system to accurately direct pen movements across paper, maintaining precision.

2.1.5 Mechanical Test Protocol & Test Report

- Test the lead screw's ability to maintain consistent and precise movement across the plotting area.
- Evaluate the mechanical stability of the frame and ensure minimal backlash in the lead screw assembly.

2.1.6 Hardware Test Protocol & Test Report

- Conduct tests on DC motors and sensors to ensure smooth and responsive operation.
- Verify the integration of the hardware components, checking for accurate positional feedback and synchronization.

2.1.7 Software Test Protocol & Test Report

- Test the software’s ability to process input command and control pen movements without error.
- Ensure that the user interface is intuitive and responds accurately to commands, producing precise outputs.

2.1.8 Pen-Plotter Test

- Conduct final tests to evaluate the overall performance of the plotter in recreating the Nikolaus Haus design.

This comprehensive approach ensures the Pen Plotter is fully functional, reliable, and capable of producing high-precision drawings of the Nicolaus House, meeting all user requirements.

2.2 User Requirement

User Requirement						
UR #	**module**	**Title**	**User Requirement**	**Remark**	**Domain (HW/SW/ME/all)**	**Must / Wish**
Application						
UR1	application	intended use	The XY-pen plotter is designed to draw a Nikolaus house after programming and can be used within the laboratory of University by students taking part in Master course MeRo for educational reasons.		all	M
UR2	application	use case	The plotter has to draw a Nikolaus' house		all	M
UR3	application	user environment	The plotter should operate on household power supply			M
General Functions						
UR4	general	portability	XY pen plotter shall be carried by user.	weight up to 3.5kg.	all	M
UR5	general	User Interface	XY Pen Plotter shall be easily operated by the students			
UR6	general	dimensions	XY pen plottter has to fit in small box		all	M
UR7	general	Indicator	XY Pen Plotter shall give a signal when it is turned On and shall give a different signal when it is making Nikolaus house			M
UR8	general	Dustgaurd	XY Pen Plotter shall be designed such that it should avoid collection of dirt and dust from the environment			W
UR9	general	Lifecycle	Pen-Plotter should operate atleast 100 cycle			M
UR10	general	Assembly	All component are easy to assemble.			
Module Function base plate						
UR11	base plate	paper fixation	The paper should stay in place at the corners of the base plate during operation.	Provide grooves to accomodate grippers		
UR12	Base Plate	Quality	The base plate shall be made of good quality material	-		M
UR13	Base Plate	Dimension	Supports multiple different paper sizes	-		M
Module Function - Frame						
UR14	Frame	Structure Layout	The frame must be stable and rigid.			M
Module Function - pen holder						

Module Function - Slider						
UR16	Slider	Movement	The slider must maintain high precision and accuracy in movement to produce detailed and consistent plots.			W
Module Function - Motor Controller						
UR17	Motor Controller	Specifications	Motor controller must provide precise control for accurate pen plotting.			W
UR18	Motor Controller	Motor	A drive system with selectable preset speeds is required.			W
Module Function - Control and Coding						
UR19	Control and Coding	Integration	The plotter should seamlessly integrate with CAD (Computer-Aided Design) and CAM (Computer-Aided Manufacturing) software to enable direct plotting of designs created in these applications.			W
UR20	Control and Coding	Limit Switch	Limit switches shall be used to detect end position.			W
UR21	Control and Coding	Emergency Switch	Provision for emergency stop should be available.			M
Module Function - Wiring						
UR22	Wiring	safety	Standardized wire used, all wires are inside a cable protector.			W
Module Function - Power Supply						
UR23	Power Supply	Requirement	The pen plotter must operate reliably on direct electrical power without the need for batteries.			M
Module Function - Actuator						
UR24	Actuator	Adjutable Pressure	Adjustable actuators allow for customized positioning or movement.			W
Regulatory and Standards						
UR25	Regulatory & standards	conformity to standards	Device has to be designed according corresponding standards, i.e. for safety, valid for the product		all	M

Table- 1

2.3 Technical Specification

Technical Specification							
TS #	**ref. to UR #**	**module**	**Title**	**Technical Requirement**	**Remark**	**Domain (HW/SW/ ME/all)**	**Must / Wish**
Application							
TS1	UR1	application	intended use	The plotter is designed and programed to carry out certain tasks and objectives like drawing the Nikolaus hause.			M
TS2	UR2	application	use case	The Nikolaus house should have dimensions of 100 x 100 mm^2 maximum.		all	M
TS3	UR3	application	user environment	The plotter should operate on 200-240V AC supply and frequency around 50 Hz.			M
General Functions							
TS4	UR4	general	portability	The pen plotter should not exceed the weight of a laptop (3.5 kg)			M
TS5	UR4	general	portability	The pen plotter has to be carried by a single user without difficulty			M
TS6	UR5	general	User Interface	The plotter should be designed for user friendly operation			M
TS7	UR6	general	dimensions	Dimensions less the 56x39x42 cm2			M
TS8	UR7	general	Indicator	An LED light to signal machine operation.			W
TS9	UR8	general	Circuit Protection	3D printed Parts to prevent dust and dirt.			W
TS10	UR9	general	Time	The plotter should be able to draw the Nikolaus house in 50 sec, (with a stopwatch)			M
TS11	UR10	general	Assembly	All components of the pen plotter shall be designed for straightforward assembly			
TS25	UR	General	Condition	Pen plotter should run in ambient conditions			
Module Function base plate							
TS12	UR11	base plate	Paper fixation	The corners of the base plate have to be encapsulated with grippers to hold the paper in proper position w/o movement during drawing cylce			

TS13	UR12	base plate	Quality	the base surface should be smooth, low-maintenance, durable, flexible, and resistant to scratches, impact, water, and moisture.			M
TS14	UR13	base plate	Dimensions	The dimension of base plate should be such that it can hold paper from 10x10 cm upto A4 Size			W
Module Function frame							
TS15	UR14	Frame	Structure Layout	The frame should exhibit stability and rigidity to minimize vibrations, thereby ensuring precise plotting.			M
Module Function Pen Holder							
TS16	UR15	Pen-Holder	Pen Grip	The gripper is designed like a clip which will be able to hold pens of various size.			W
Module Function Slider							
TS17	UR16	Slider	Movement	Top quality linear and normal bearings having high number of revolutions are used for accurate movements.			M
Module Function Motor Controller							
TS18	UR17	Motor Controller	Specification	Operating voltage 10-30V, control motor speed, torque, and position, self-tune to motor parameters, and provide maximum output frequency with electrical isolation.			M
TS19	UR18	Motor Controller	Motor	Use of Stepper motor and servo motor.			M
Module Function Control and coding							
TS20	UR19	Control and Coding	Integration	It shall be compatible with standard file formats such as DXF, DWG, and HPGL.			M
TS21	UR21	Control and Coding	Emergency Switch	Emergency button integrated			W
Module Function Wiring							
TS22	UR22	Wiring	Safety	All wiring must comply with relevant electrical safety standards and regulations to prevent electrical hazards and ensure user safety.			M
Module Function power supply							
TS23	UR23	Power Supply	Connection	The device operates on 12V to 20V adaptor.			M
Module Function Actuator							

TS24	UR24	Actuator		The actuator should allow users to adjust the pen pressure or force applied during plotting to accommodate different types of drawing surfaces and pen types.			M
Regulatory and Standards							
TS25	UR25	Regulatory & standards	conformity to standards	Meet the CE conformity and EN 60335 should be satisfied.			M
TS26	UR25	Regulatory & standards	Quality standards	The pen plotter adhere to the industry's Quality standards			M

Table- 2

2.4 Design Specification

Design Specification					
DS #	**ref. to TS #**	**module**	**Description**	**Remark**	**Domain (HW, SW, ME, all)**
General function					
DS1	TS9	Portability	total weight of parts less than 3 kg, sum of all parts weight		all
DS2	TS9	Dimensions	Plotting board dimensions 400x328x170		all
DS3	TS11	Time	The plotter should be able to draw the Nikolaus house in 50 sec, (with a stopwatch)		
Module Function – Base plate					
DS3	TS16	Material,	Wooden Plate with Formica coating is used to ensure smoothness		ME
		size	size of the table 305mm*305mm*16mm		ME
DS4	TS18	Electronics Casing	Separate Compartment is provided for Packing Electronic components		ME
Module Function - Frame					

DS6	TS20	Dimensions	The frame is designed as a fourpoint support to ensure proper distribution of vibration.		ME
DS7	TS22	material	The frame is made with PLA to ensure high quality		ME
DS8	T20	Guide rail	LMU N6 Linear ball bearing is used to reduce the vibration of shaft which is connected to Pen Holder.	Supplier: Misumi	ME
DS9	T22	bolt & nuts dimensions: https://www.maritimeherald.com/screw- sizes/	Frame has to be assemble by standard bolts, and nuts. (Example M4, M5, M6)	All the bolts and nuts available in the University	ME
Module Function -Pen holder					
DS10	TS 23	multiple pen attachments	Catridge system is given for changing different types of pens	3D Printed part	ME
DS11	TS 24	rigidness	Created a separate slot for holding the pen attachment which constrains the pen's movement from all directions		ME
Module Function Drive Unit					
DS13	TS27	Motor Assembly	Snap fits are provided for motors to ensure ease of assembly and disassembly		ME
DS14	TS28	Part #see Bill of Material	Two 5V high torque Motors are used to drive the leadscrew	DC motors	HW
DS16	TS23	ISO 3740 and ISO 3744	ISO standards for minimizing noise		
Module Function - Coding and Control					
DS17	TS32	refer document "Software"	Propotional control is implemented for achieving accuracy		SW
DS18	TS34	refer App "PenPlotter"	Raspbery Pi is used for controlling the Plotter		SW
Module Function Control Unit					
DS19	TS38	bill of materials (doc.# 01_MERO_BOM)	Sparkfun ESP 32 S2 Wroom module is used for controlling the pen plotter.		HW

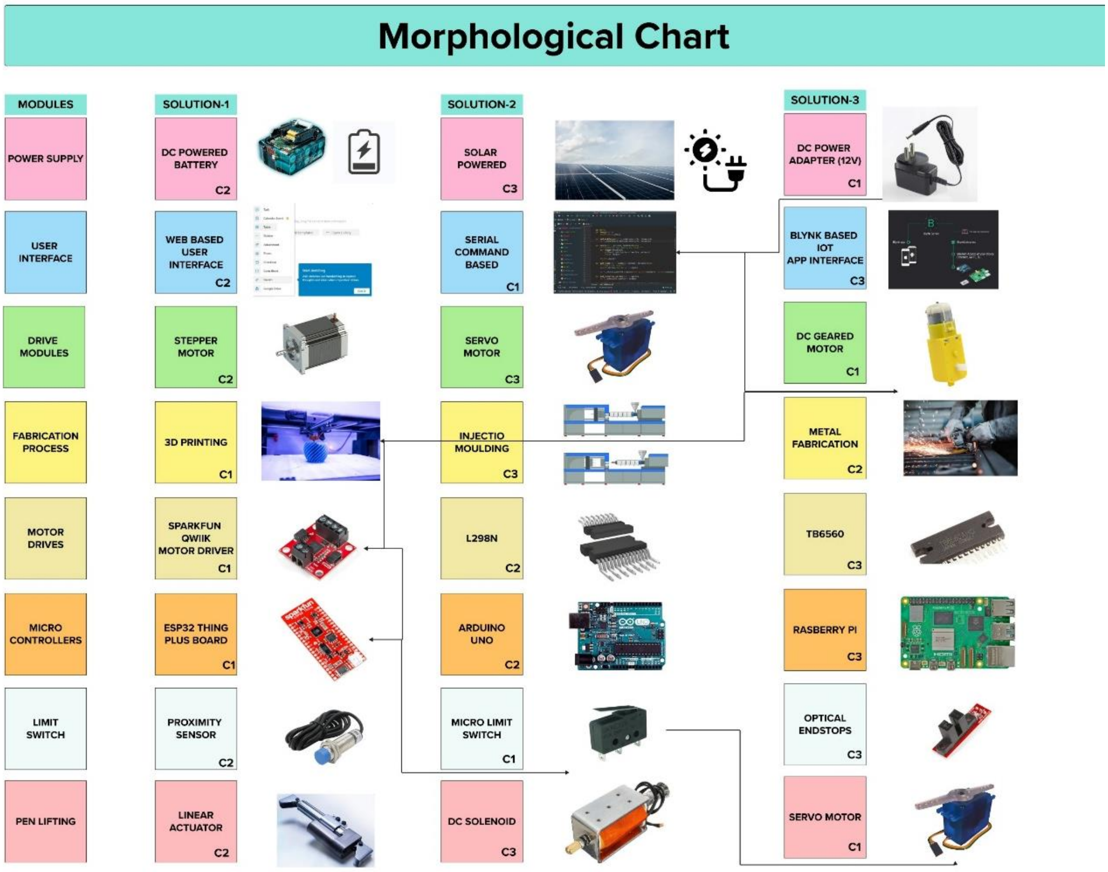
DS20	TS40	Circuit Diagram	The controller is connected through ports and wires with other components to ensure proper connectivity		HW
DS21	TS40	Bread board	MB 102 plug in board 830 pins 60320025 is used which is provide by university		
Module Function Power Supply Unit					
DS_22		bill of materials	Bread board power Supply TS 1171 which is provided by university is used.	Supplier: QITA	HW
Regulatory and Standard					
DS_23	TS_44	IEC 62368-1: https://webstore.iec.ch/publication/69308	Compliance with these standards helps ensure that the pen plotter does not pose a risk of electric shock, fire, or other hazards.		All
DS_24	TS_45	EN 61010-1: https://standards.iteh.ai/catalog/standards /clc/6059fcda-86cb-4d69-ad10- 9c01ce141421/en-61010-1-2010	Compliance with these standards helps ensure that the pen plotter does not pose a risk of electric shock, fire, or other hazards.		All
DS_25	TS_46	EN 55032: https://standards.iteh.ai/catalog/standards /clc/e7e6d805-88c8-4da7-b872- 8bababd41046/en-55032-2015	Compliance with these standards helps ensure that the pen plotter does not interfere with other electronic devices or cause interference.		All

Table- 3

Chapter 3. Concept Analysis

3.1 Morphological Box

The Morphological Box is a structured method employed to explore all potential solutions for the multi-dimensional challenges faced in the Pen Plotter project. This approach allows for the comprehensive analysis of various components and their possible configurations, ensuring the desired functionality is achieved.



MODULES	CONCEPT-1 (C1)	CONCEPT-2 (C2)	CONCEPT-3 (C3)
POWER SUPPLY	DC POWERED ADAPTER	SOLAR POWERED	DC POWERED BATTERY
USER INTERFACE	SERIAL COMMAND BASED	WEB BASED USER INTERFACE	BLYNK BASED IOT APP INTERFACE
DRIVE MODULES	DC GEARED MOTOR	STEPPER MOTOR	SERVO MOTOR
FABRICATION PROCESS	3D PRINTING	METAL FABRICATION	INJECTION MOULDING
MOTOR DRIVES	SPARKFUN QWIIK MOTOR DRIVER	L298N	TB6560
MICRO CONTROLLERS	ESP 32 THING PLUS BOARD	ARDUINO UNO	RASBERRY PI
LIMIT SWITCH	MICRO LIMIT SWITCH	PROXIMITY SENSOR	OPTICAL ENDSTOPS
PEN LIFTING	SERVO MOTOR	LINEAR ACTUATOR	DC SOLENOID

Figure 4 – Morphology Chart

3.2 Decision Matrix

The Decision Matrix method was utilized to evaluate and select the optimal combination of components for the Pen Plotter based on key criteria such as cost, complexity, reliability, and ease of integration. The table below details the evaluation process for the primary components of the Pen Plotter

Pairwise Comparison

As More Important	COST	DRAWING QUALITY	DRAWING SPEED	PORTABILITY	DURABILITY	UI/EASE OF USE	SUM	PERCENTAGE
COST		5	5	3	1	3	17	17.34%
DRAWING QUALITY	3		5	5	5	5	23	23.46%
DRAWING SPEED	3	1		5	3	1	13	13.26%
PORTABILITY	3	1	1		1	1	7	7.14%
DURABILITY	5	3	3	5		3	19	19.38%
UI/EASE OF USE	5	1	3	5	5		19	19.38%
					Check Sum		98	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 point for A

Figure 5 – Decision Matrix

3.3 Concept Evaluation

Based on the decision matrix concept is evaluated as shown in the figure

Concept Evaluation

CRITERIA	RATING RANGE	WEIGHT	SOLUTION 1		SOLUTION 2		SOLUTION 3	
			POINTS	POINTS*WEIGHT	POINTS	POINTS*WEIGHT	POINTS	POINTS*WEIGHT
COST	1 - > 200 euro 3 - 150 - 200 euro 5 - < 150 euro	17.34%	3	0.52	5	0.86	3	0.52
DRAWING QUALITY	1 - ACCURACY>5mm 3 - 1mm<ACCURACY <5mm 5 - ACCURACY<1mm	23.46%	5	1.17	3	0.70	5	1.17
DRAWING SPEED	1 - TIME>2min 3 - 1min<TIME,2min 5 - TIME>1min	13.26%	3	0.39	3	0.39	1	0.13
PORTABILITY	1 - >5KG 3 - 3.5KG TO 5KG 5 - <3.5KG	7.14%	1	0.07	3	0.21	1	0.07
DURABILITY	1 - SIMPLE 3 - Fair 5- Complex	19.38%	5	0.96	3	0.58	3	0.58
UI/EASE OF USE	1 - CODING INTERFACE 3 - HTML WEBUI GUI 5 - IOT INTERFACE	19.38%	5	0.96	1	0.19	3	0.58
			22	4.07	18	2.93	16	2.47
1-3-5 POINT SYSTEM			WINNING CONCEPT					

Figure 6 – Concept Evaluation

Chapter 4. Verification and Validation

4.1 Verification Protocol

Verification Protocol					
VerP #	**ref to TS #**	**test procedure (description of routine)**	**Verification criterion**	**ref. # (i.e., test protocol, etc.)**	**Domain (HW/SW/ME /all)**
Application					
VerP1	TS14	Measure height and width of the Nikolaus Haus by mm Ruler	100 mm × 100 mm, ±4%		All
VerP2	TS_10	The plotter should be able to draw the Nikolaus house in 50 sec, (with a stopwatch)	Cycle time from Program run should be >=50 secs	Measured by a Stopwatch	All
VerP3	TS_25	Pen plotter should run in ambient conditions	measured temperature should be in the range of 15- 30-degree celcius	In the lab	All
General Functions					

VerP5	DS_1	The complete setup with all the necessary assembly should be weighed on a lab scale	Total weight should be less than 3 kg	In the Lab	All
VerP8		Run 20 cycles of Nikolaus House every day for 2 weeks	"20 cycles/ day for 2weeks without any damage / failure"	In the Lab	All
Module Function-Base plate					
VerP9	TS 2 TS 14	Operate the pen plotter with a A4 sheet and below sizes fitted on the base plate and check for any damages on the paper after few cycles	-	Tested in the Lab lively	HW
Module Function Frame					
VerP10		Shaft dimensions are measured with a Ruler	Dimensions are correct/incorrect	In the Lab	HW
VerP12	TS 26	Metric Screws, Bolts, nuts are used	-	-	ME

Module Function- Linear Movement Axis					
VerP13	TS 26	0.5mm Precision maintained	Maintained	Tested in the lab	All
VerP14	TS 26	Belt is used and Motor speed controlled in range 0.1 to 10mm/s	To test Speed of Motor and Tension	Tested in the lab	HW
Module Function -Pen holder					
VerP15	TS 16	Pens and Pencils between 6mm to 20mm are fitting	Pen attachment should accommodate pen shape hexagon and size between 6 to 20 mm	Tested in the lab	HW
Module Function Control Unit					
Module Function Indicator					
VerP19	TS 8	LED should be indicated by green color when the process is going on.	Glows green / not when process is running	In the Lab	HW
Module Function Power Supply Unit					
VerP21	TS 3 TS 18	Use Multimeter to check the peak Voltage and current	Should be within the operating range of motor and motor drives	In lab by multimeter	HW
Regulatory and Standard					

VerP23	TS 25, TS 26	CE conformity assessment to be carried out with respect to machinery device directive 2006/42/EC	CE assessment done	CE-assessment doc# 05_MERO_CE	All

Table- 4

4.2 Verification Report

Verification Report						
VerR #	**ref. to VerP #**	**Test function (to be copied from verification protocol)**	**nominal criterion, target value**	**actual value**	**criterion passed / failed**	**remark**
Application						
VerR1	VerP1	Measure height and width of the Nikolaus Haus by cm Ruler	50 mm × 50 mm, ±4%	-	Passed	
VerR2	VerP2	The plotter should be able to draw the Nikolaus house in 50 sec	<=50 Seconds	45 Seconds	Passed	
VerR3	VerP3	Pen plotter should run in ambient conditions	-	-	Passed	
VerR4	VerP4	Focus group (5 members) should manage to run Nikolaus' house drawing cycle after max 10 min oral introduction to plotter	3 runs	6 runs	Passed	
General Functions						
VerR5	VerP5	The complete setup with all the necessary assembly should be weighed on a lab scale	Weight <3kg	2.2Kg	Passed	
VerR6	VerP6	Store total pen plotter into the storage box 18	Must fit in box with lid closed	Fit n box	Passed	
VerR7	VerP7	Parts of Pen plotter is 3D Printed using PLA plastic, except Base, Rods and Fasteners	Six 3D printed parts		Passed	

VerR8	VerP8	Run 20 cycles of Nikolaus House every day for 2 weeks	20 Cycles/day	30Cycles/day	Passed	
Module Function-Base plate						
VerR9	VerP9	Operate the pen plotter with a A4 sheet and below sizes fitted on the base plate and check for any damages on the paper after few cycles	Passed		Passed	
VerR10	VerP10	Reduced vibrations of the pen plotter by providing supports at corners of Base plate	Passed		Passed	
Module Function Frame						
VerR11	VerP11	Shaft dimensions are measured with a Ruler	Dimensions are Correct		Passed	
VerR12	VerP12	The 3D-printed components should have an infill 50%	50% filled		Passed	
VerR13	VerP13	Metric Screws, Bolts, nuts are used	Using Metric fasteners		Passed	

Module Function- Linear Movement Axis						
VerR14	VerP14	Precision maintained	0.5mm		Passed	
VerR15	VerP15	Leadscrew is used and Motor speed controlled	Range 0.1 to 10mm/s		Passed	
Module Function -Pen holder						
VerR16	VerP16	Pens and Pencils between 8mm to 20mm are fitting	Passed		Passed	
VerR17	VerP17	Vibrations/wobbling movements while pen plotter is running	Preventing Vibrations		Passed	
Module Function Control Unit						
VerR19	VerP19	ESP 32 board should communicate with hardware within 1 second.	communicate with in 1 second		Passed	
Module Function Indicator						

VerP21	VerP21	To Power off the pen plotter when slider reaches end point in its path.	Power OFF			
Module Function Power Supply Unit						
VerR22	VerP22	Use Multimeter to check the peak Voltage and current	5V DC		Passed	
Regulatory and Standard						
VerR23	VerP23	CE conformity assessment to be carried out with respect to machinery device directive 2006/42/EC	CE-conformity	CE conformity not necessary	passed	For lab use no CE necessary

Table- 5

4.3 Validation Protocol

Validation Protocol			
ValP #	**ref. to UR #**	**validation procedure (description of routine)**	**validation criteria**
ValP1	UR 25	Place pen plotter on table with A4 paper, Insert Euro plug in 220V AC or 5V DC power source, turn on circuit, motor running smoothly	LED on controller circuit should glow
ValP2	UR 23	Connect controller with laptop using USB cable	Establish serial communication
ValP3	UR 1, UR 2, UR 3, UR 4, UR 5	Set-up pen plotter at University's lab, start pen plotter by student, draw Nikolaus' house Nikolaus house plotted in one run	Nikolaus house plotted in one run
ValP5	UR 4, UR 5	Put pen plotter in the box, carried out by focus group, easy to handle	Single student can handle box with pen plotter
ValP6	UR 25	Standard Fasteners	Assemble and dis-assemble finished with in 4mins each.
ValP7	UR14	Easy to assemble and dis-assemble	Assemble and dis-assemble finished with in 4mins each.

Table- 6

4.4 Validation Report

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

Table- 7

Chapter 5. Technical Solution Representation

5.1 Design Overview

The pen plotter design encompasses a meticulous CAD model that delineates the mechanical and electronic components, ensuring precise and efficient plotting capabilities. The design focuses on three primary axes: X, Y, and Z, each with specific configurations and functionalities to enable accurate movement and plotting. Below is an in-depth explanation of the design features and considerations:

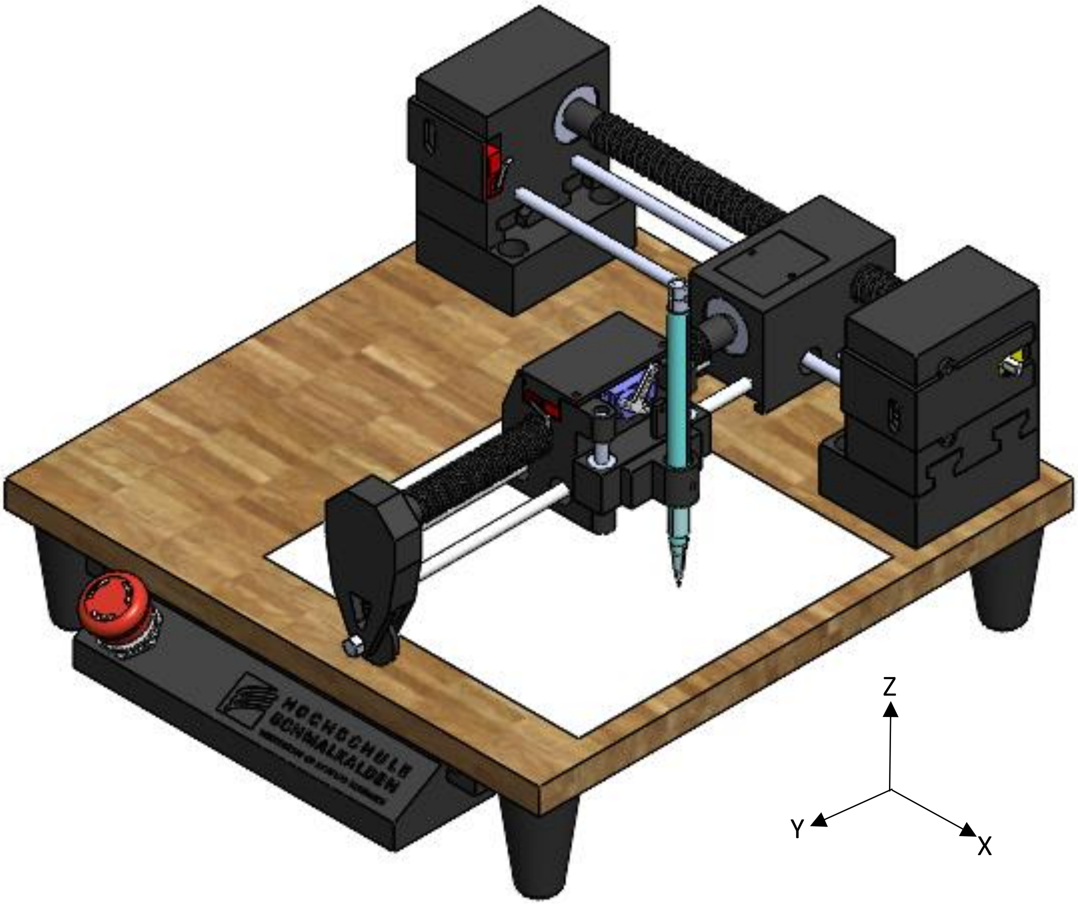


Figure 6 – Final Assemblly

The X-axis features leadscrew mechanisms, which are connected to a DC motor and supported by roller bearings on both sides. The bearing housings are secured to the base using a slots and key arrangement. A nut, which has a motor casing and a support, is responsible for movement along the X-axis and facilitate movement along Y-axis.

Along the Y-axis there is leadscrew which is supported by x-axis nut and a free roller. Roller act as a sliding supports while the X-axis nut act as a fixed support. On the Y-axis nut, pen is mounted and the servomotor, which is incorporated in the Y-axis nut, carries the movement of the pen along the Z-axis. The movement of X and Y-axis nut enables the pen to draw stretches and have precise control on the motion.

5.2 Programming and Operational Overview

The ESP32 microcontroller manages all operations, and the Raspberry Pi provides a user interface and facilitates interaction with the system through a touch screen display. Below is a more detailed breakdown of how the components work together:

1. Initialization and Setup:

- Raspberry Pi powers on, and the touch screen display loads the user interface (UI). This interface allows users to input various parameters such as the size of the plot, speed, and any design or image to be plotted.
- The ESP32 initializes all GPIO pins and sets up communication with the motors, sensors (limit switches), and indicators (RGB LED).
- The ESP32 connects to the QWIIC motor driver, the servo motor, and the limit switches to prepare for motion control.

2. Plotting Process:

- User Input via Touch Screen: The user can input commands (e.g., starting the plot) and parameters through the Raspberry Pi's touch screen interface. Once the plot starts, the Raspberry Pi sends the data (design, motion commands) to the ESP32 via USB serial communication, Wi-Fi, or Bluetooth.
- Pen Movement: The DC motors (for X and Y axes) drive the pen carriage. The ESP32 sends PWM signals to the QWIIC motor driver, which adjusts motor speed and direction based on the current position and target coordinates.
- X and Y axis: The DC motors control the X and Y axis movements. The plotter uses these motors to position the pen at the correct coordinates. The ESP32 continuously calculates the necessary position using algorithms that map out the plotter's grid.
- Pen Lifting: The servo motor (SG90) lifts and lowers the pen. It lowers when the plotter needs to draw a line and raises when the pen needs to move between points without drawing.
- Real-time Feedback: The limit switches installed at the ends of the X and Y axes act as boundary detectors. If the pen carriage reaches the end of an axis, the ESP32 reads the switch state (via GPIO) and stops the motor in that direction to avoid mechanical damage.

3. Status Monitoring and Indications:

- The RGB LED provides real-time feedback on the system's status:
  - Green: System ready and running normally.
  - Red: Emergency stop triggered or error encountered.
- The ESP32 controls the RGB LED using PWM signals to adjust colors, responding to various system states (set through the program).

4. Emergency Stop:

- Round Pushbutton (EMG Stop): If the user presses the emergency stop button, the ESP32 immediately interrupts all ongoing processes, stopping the motors and raising the pen. This ensures the plotter halts safely, preventing mechanical or electronic damage.

- The ESP32 monitors the EMG button's state constantly through its GPIO pins, and if it detects a button press, it triggers an interrupt to safely stop the machine.

5. Power Management:

- Breadboard Power Supply: This module supplies 3.3V and 5V DC to the ESP32, the motors, and other components like the RGB LED. The power supply ensures stable voltage for the ESP32's logic and motor control circuits.
- Resistors: Resistors are used to protect sensitive components like the RGB LED from overcurrent and ensure safe operation of other elements like the EMG button.

6. Communication between Raspberry Pi and ESP32:

- The Raspberry Pi and ESP32 communicate either over Wi-Fi or Bluetooth. The Raspberry Pi, acting as the user interface, sends commands and parameters to the ESP32. For instance, the user can select designs, start/stop the plotter, and view real-time updates on the touch screen display.
- The Raspberry Pi can also update the ESP32's firmware over-the-air (OTA) if needed, eliminating the need for direct USB connection.

7. Completion of Plotting:

- As the plotter completes the drawing, the ESP32 continuously monitors the X and Y positions, adjusting the motor speeds and ensuring the plot is accurate.
- Once the drawing is finished, the ESP32 raises the pen using the servo motor, and the motors stop moving. The RGB LED might flash green to signal successful completion.

8. User Controls via the Touch Screen:

- Through the touch screen on the Raspberry Pi, the user can:
- Start/stop the plotter.
- Set the design to be plotted.
- Monitor the position of the pen in real-time (via step-counting method and limit switches).

5.3 Circuit Design

Our device's electronic circuit is designed with two DC motors controlled by a QWIIC motor controller, powered by a charging adapter supplying both 5V and 3.3V. The circuit incorporates four limit switches arranged in parallel to monitor end-of-travel positions, thereby preventing mechanical damage. For enhanced precision, the system includes a servo motor for controlling the pen's vertical movements. An emergency button is strategically placed in series with the main power source to ensure safety. The entire system is managed by an ESP32 Thing Plus, utilizing VS Code as the development platform, which facilitates efficient and precise control.

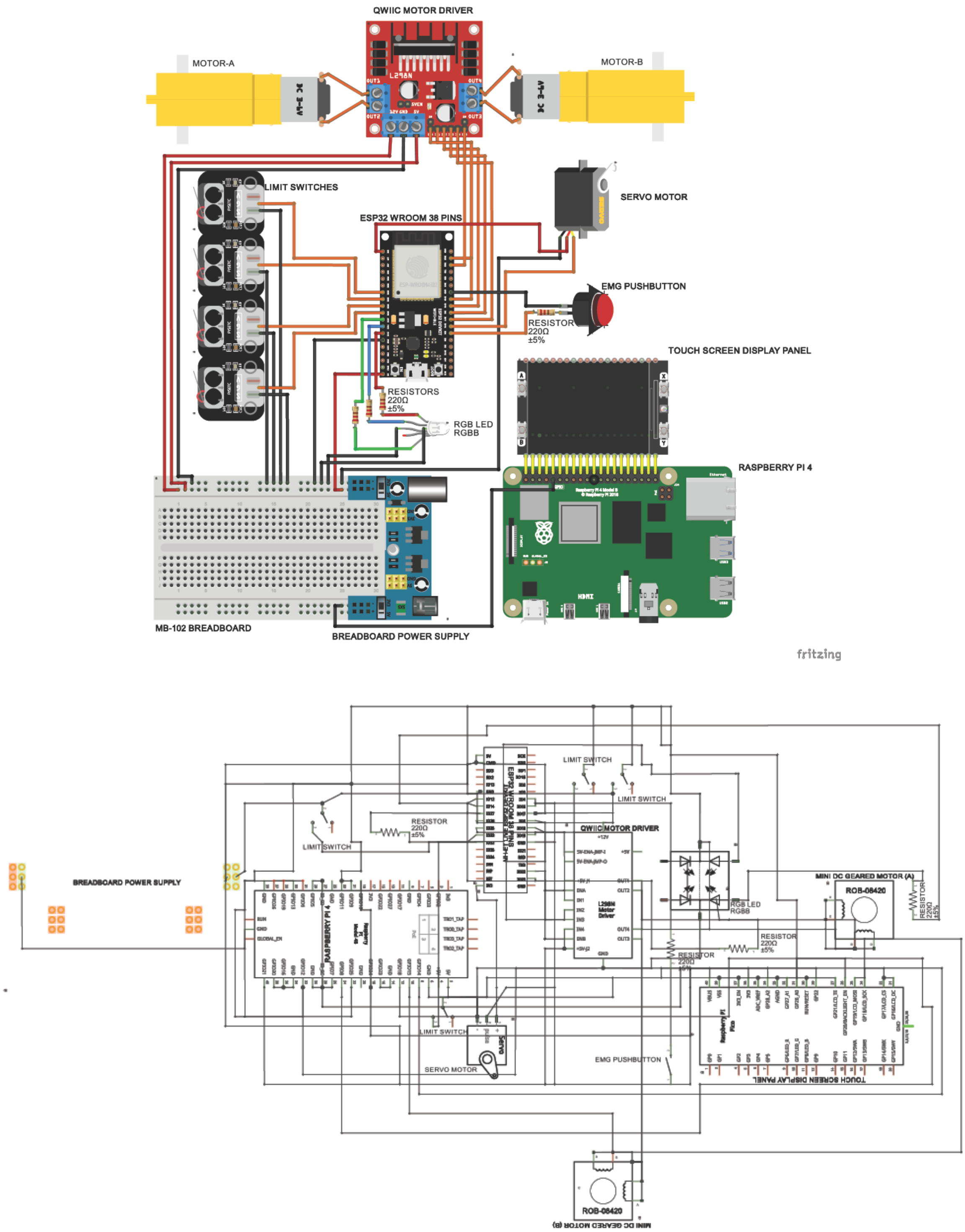


Figure 7 – Circuit Diagram

5.4 Software Design

Understanding the Operation of a Pen Plotter

To fully appreciate our pen plotter project, it’s crucial to understand how a pen plotter functions. Similar to a 3D printer, a pen plotter moves with precision using XY coordinates, though it lacks the Z-axis for vertical movement. This design enables pen plotters to mimic hand drawing, producing consistent, high-quality prints. Depending on the chosen writing instrument, they can draw on various flat materials such as cardboard, plastic, and sheet steel. Unlike traditional printers, pen plotters utilize a unique printing method.

Pen plotters offer a high degree of customization. Users can modify the speed and pressure of the writing device to achieve specific effects and even develop custom drawing software to generate intricate designs

Programming the XY Pen Plotter for the Nikolaus House

The following is the sample code , which is used to draw Nikolaus house by the pen plotter

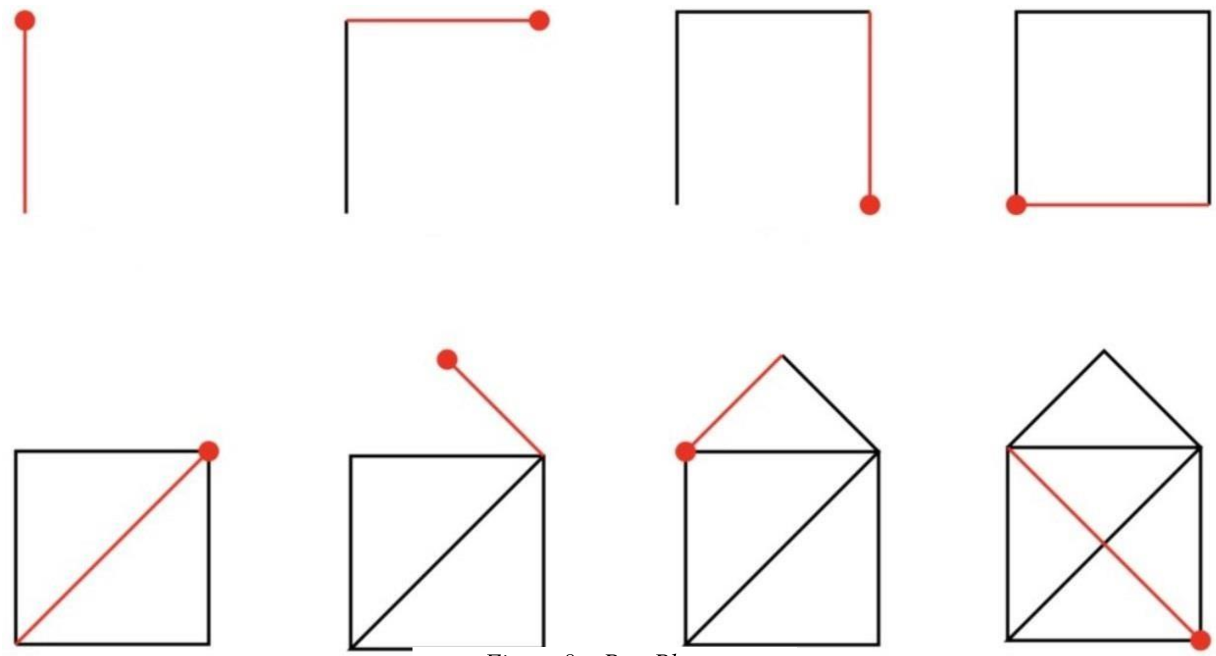


Figure 8 – Pen-Plotter

Bluetooth Code Pen-Plotter

```
#include <SCMD.h>
#include <SCMD_config.h>
#include <Wire.h>
#include <BluetoothSerial.h>
#include <Servo.h>

SCMD myMotorDriver;
BluetoothSerial serialBT;

Servo penServo;

// Motor constants
#define X_MOTOR 0
#define Y_MOTOR 1
```

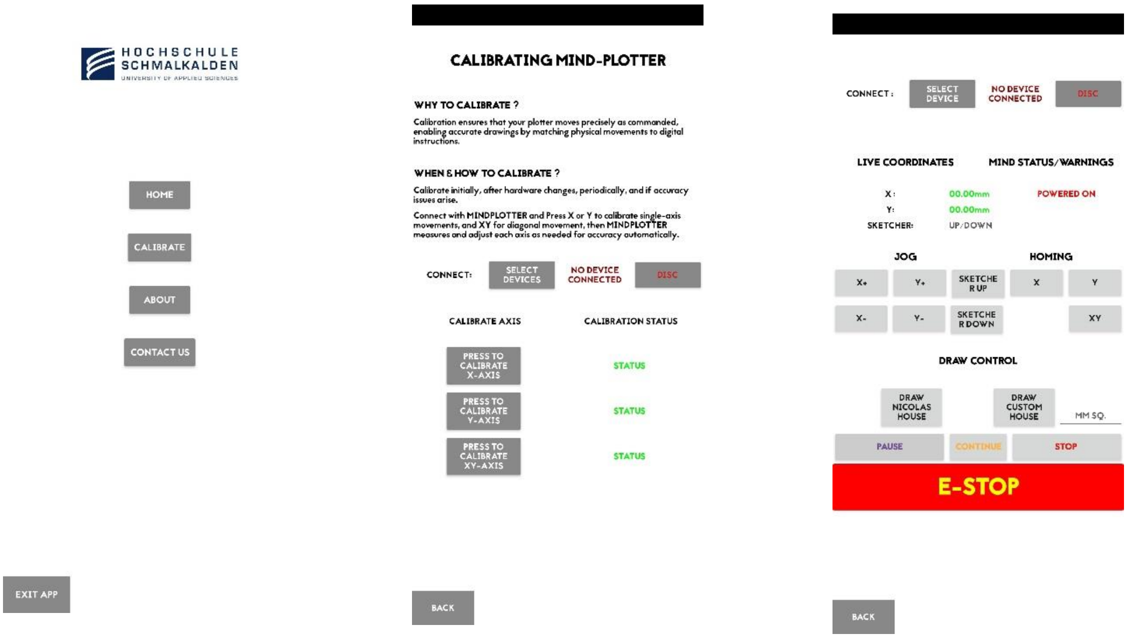
Code Pen-Plotter

```
// Pin constants
#define EMERGENCY_PIN 8
#define X_LIMIT_SWITCH_MIN 9
#define X_LIMIT_SWITCH_MAX 14
#define Y_LIMIT_SWITCH_MIN 11
#define Y_LIMIT_SWITCH_MAX 12
#define SERVO_PIN 13

// Lead screw parameters
const float pitch = 4.0;
const float stepsPerRev = 200;
const float stepsPerMm = stepsPerRev / pitch;

// Machine dimensions
const float maxX = 100.0;
const float maxY = 100.0;

// Coordinates for the pen's current position
float currentX = 0;
float currentY = 0;

// Pen servo positions
const int PEN_UP_ANGLE = 90;
const int PEN_DOWN_ANGLE = 10;

void setup() {

  Serial.begin(9600);

  // Setup motor driver
  myMotorDriver.settings.commInterface = I2C_MODE;
  myMotorDriver.settings.I2CAddress = 0x5D;
  myMotorDriver.settings.chipSelectPin = 10;

  // Wait for motor driver to initialize
  while (myMotorDriver.begin() != 0xA9) {
    Serial.println("Motor driver ID mismatch, retrying...");
    delay(500);
  }

  // Configure limit switches and emergency stop
  pinMode(X_LIMIT_SWITCH_MIN, INPUT_PULLUP);
  pinMode(X_LIMIT_SWITCH_MAX, INPUT_PULLUP);
  pinMode(Y_LIMIT_SWITCH_MIN, INPUT_PULLUP);
  pinMode(Y_LIMIT_SWITCH_MAX, INPUT_PULLUP);
  pinMode(EMERGENCY_PIN, INPUT_PULLUP);
```

Please note the above is just a part of the code and not the entire programme.

5.5 User Interface

To operate the pen-plotter an application is developed through which the communication can be performed. Bluetooth protocol is used for communication between user and the pen-plotter. The reason for using Bluetooth as a communication protocol is that it is available in every smart phones, consumes less power, reliable and have low latency.



The code which were used to create connection between ESP32 and Smart phones are as follow:

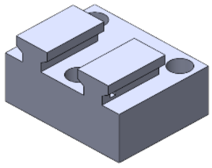
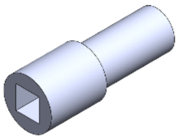
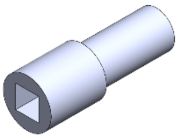
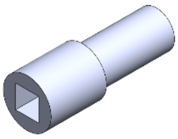
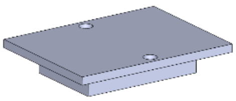
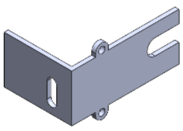
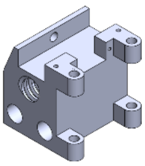
Bluetooth Code Pen-Plotter

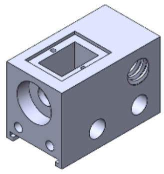
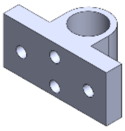
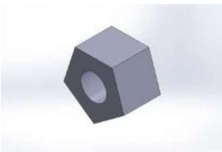
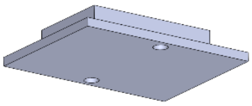
```
#include "BluetoothSerial.h" // Include Bluetooth library

BluetoothSerial SerialBT; // Create BluetoothSerial object

void setup() {
  Serial.begin(115200);               // Initialize Serial Monitor
  SerialBT.begin("ESP32_Simulator"); // Name your Bluetooth device
  Serial.println("Bluetooth device is ready to pair.");
}

void loop() {
  if (SerialBT.available()) {                  // Check if data is received
    String incoming = SerialBT.readString(); // Read the incoming data
    Serial.print("Received: ");
    Serial.println(incoming);                  // Print received data to Serial Monitor

    // Check for the specific message "X00"
    if (incoming == "X00") {
      Serial.println("Signal received!");     // Print confirmation message
    }
  }

  delay(20); // Small delay to improve Bluetooth stability
}
```

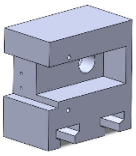
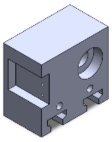
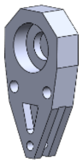
Chapter 6. APPENDIX

6.1 Bill of Material

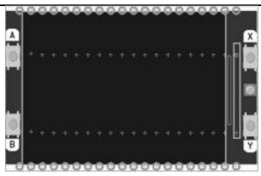
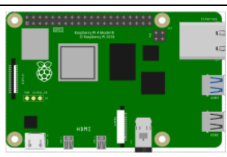
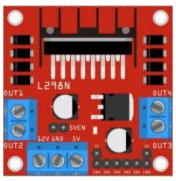
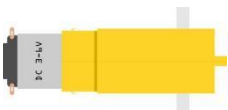
6.1.1 Mechanical BOM

No.	Component	Dimension (mm)	Part No.	Name	Description	Make	Quantity
1		70 x 55 x 39.74	BP-001	Base Plate	Base structure for mounting components.	3D Printed	2
2		26 x 13 x 13	CO-002	Coupling	Coupling component for mechanical connection.	3D Printed	1
3		35 x 13 x 13	CO-003	Coupling	First coupling for shaft alignment.	3D Printed	2
4		26 x 13 x 13	CO-004	Coupling	Second coupling for shaft alignment.	3D Printed	1
5		37.5 x 28 x 6.8	CV-005	Cover	General protective cover.	3D Printed	1
6		42.5 x 69.92 x 41.98	CVM-006	Cover Plate (Motor)	Cover plate for motor protection.	3D Printed	2
7		75 x 42 x 50	NT-007	Y-Nut	Nut for securing leadscrew or rods	3D Printed	1
8		200 x 16 x 16	NLS-007	Leadscrew	Updated leadscrew for linear motion.	3D Printed	1

9		200 x 16 x 16	NLS-008	Leadscrew	Updated leadscrew for linear motion.	3D Printed	1
10		75 x 42 x 50	NT-008	Nut	Nut for securing leadscrew or rods.	3D Printed	1
11		21 x 40 x 18	PH2-009	Pen Holder	Enhanced pen holding mechanism version 2.0.	3D Printed	1
12		16 x 62.17 x 35.5	PH1-010	Pen Holder	Initial version of pen holding mechanism.	3D Printed	1
13		23.53 x 5 x 5	PN-011	Key	Pin for securing components.	3D Printed	1
14		230 x 6 x 6	RP-012	Rod	Rod component for structural support.	3D Printed	4
15		50 x 6 x 6	RPZ-013	Rod	Z-axis rod for vertical movement.	3D Printed	2
16		8.23 x 5 x 7.83	SB-014	Shaft Block	Block for securing the shaft.	3D Printed	1
17		57 x 32.65 x 8.1	TC-018	Top Cover	Protective top cover for the system.	3D Printed	1

18		70 x 40 x 66	XAS2-021	Support	X-axis Support	3D Printed	1
19		70 x 40 x 70	XAS2-022	Support	X-axis Support	3D Printed	1
20		39.25 x 15 x 77.48	YS-024	Roller	Y-axis Roller	3D Printed	1

6.1.2 Electronic BOM

No.	Part Picture	Dimensions (mm)	Part No.	Part Type	Description	Make	Quantity
1		23 x 11.5 x 24	SG90	Servo Motor	Servo Motor: 1.5 kg/cm torque, 4.8V, 0.3 sec/60° speed, 20cm cable length with servo connector.	AMAZON	1
2		8.6 x 5.0	LF-5WAEMBG MBW	RGB LED	RGB LED: 5 mm, wired, 6-pin, with 30 mcd brightness and 60° beam angle.	AMAZON	1
3		212 x 149 x 52	BA001	Touch Screen Display Panel	7-Inch IPS LCD Display: Capacitive touchscreen, 1024 x 600 resolution, HDMI monitor for Raspberry Pi.	AMAZON	1
4		100 x 70 x 30	RAS-4-4G	Raspberry Pi 4	Raspberry Pi 4: 4 GB RAM, 1.5 GHz ARM Cortex-A72, Bluetooth 5, WLAN, LAN, 4 USB ports, 2 micro-HDMI.	AMAZON	1
5		43 x 43 x 27	MOD-L298N	QWIIC Motor Driver	Motor Driver (L298N): Controls two DC motors, 5V-35V, 2A current, max 25W power, 43 x 43 x 27 mm size.	SPARKFUN	1
6		40 x 60 x 10	DAGU - DG01D	Mini Dc Geared Motor	DC Gear Motor: 200RPM, 3-6V, 0.4-0.8 kg.cm stall torque, 1:48 gear ratio, 70 x 22 x 18 mm.	SPARKFUN	1

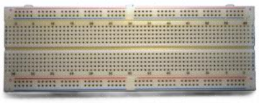
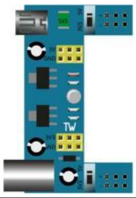
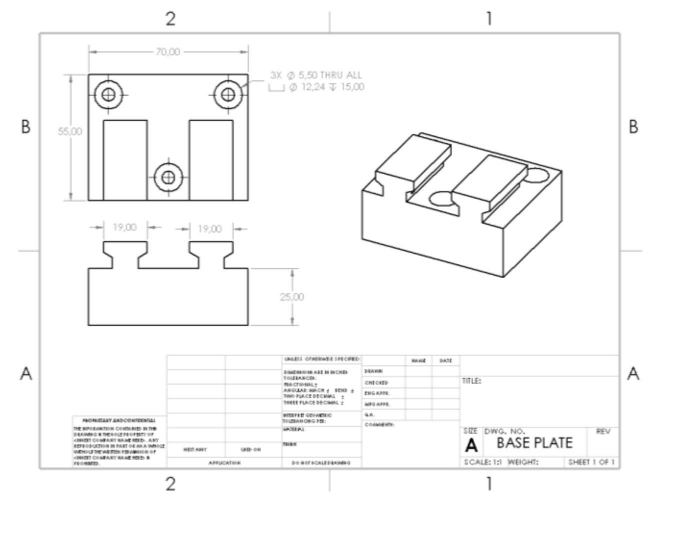
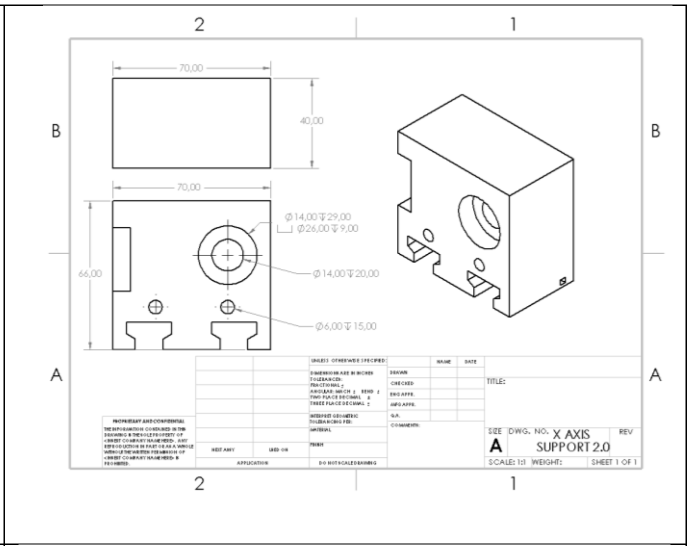
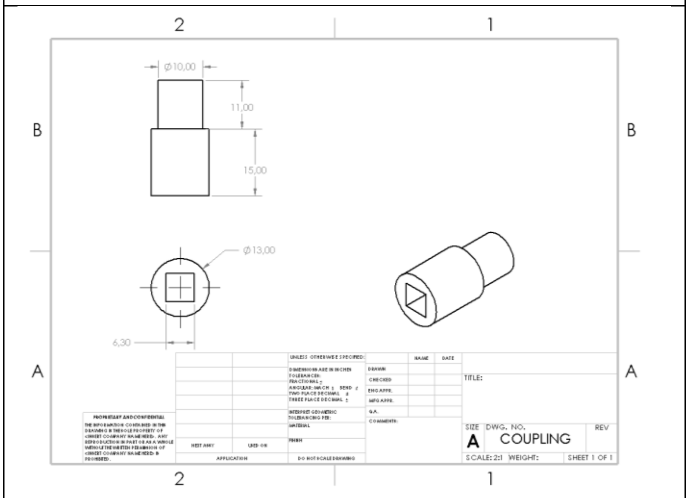
7		33.7 x 12 x 4	DAGU - DG02D	Mini Geared Motor	DC Gear Motor: 6V permanent magnet, full metal gear, speed of 200 RPM.	V-TEC	1
8		9 x 3	22201000	Resistor	Resistor: 220 Ohm, 1W, 5% tolerance, carbon film type.	E-PROJECTS	4
9		120 x 60 x 45	XSS-5GL13	Limit Switch	Limit Switch: Crank-type actuator, SPDT 1NO 1NC, 3A/250VAC or 5A/125VAC.	AMAZON	4
10		15 x 24	RB-SC	ROUND PUSH BUTTON	Push Button Switch: Momentary SPST, 250VAC 3A, red button, 15mm thread, 21g weight.	AMAZON	1
11		225 x 103 x 51	MB-102 BREADBOARD	Mb-102 Bread Board	MB-102 Breadboard: 830 contacts for prototyping electronic circuits.	ECKSTEIN KOMPONENTE	1
12		50.8 x 25.4 x 25.4	WRL-17381	Thing Plus Esp32 Wroom 38 Pins	ESP32: Dual-core, 240MHz, 16MB flash, 21 GPIO, Wi-Fi, Bluetooth, low power	SPARKFUN	1
13		100.08 x 18.03 x 100.08	ED-DP_L20	Jumper Cables	Jumper Wires: 2.54mm DuPont connectors, brass-nickel plated terminals for electrical conductivity.	AMAZON	24
14		55 x 35 x 15	AMS1117	Bread Board Power Supply	Breadboard Power Supply: 7-12V input, 3.3V/5V output, micro USB interface, fits MB-102.	QITA	1

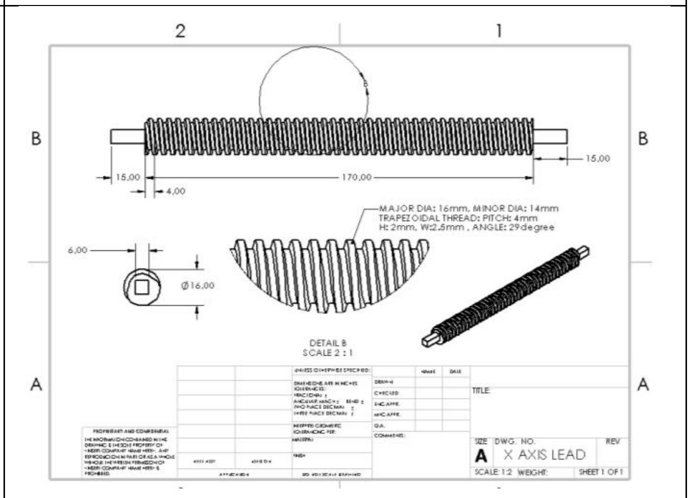
Table- 8

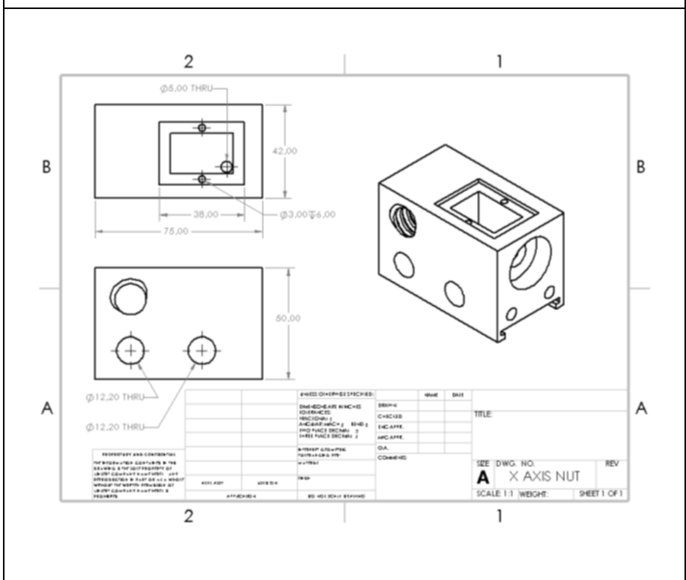
6.2 Engineering Drawing

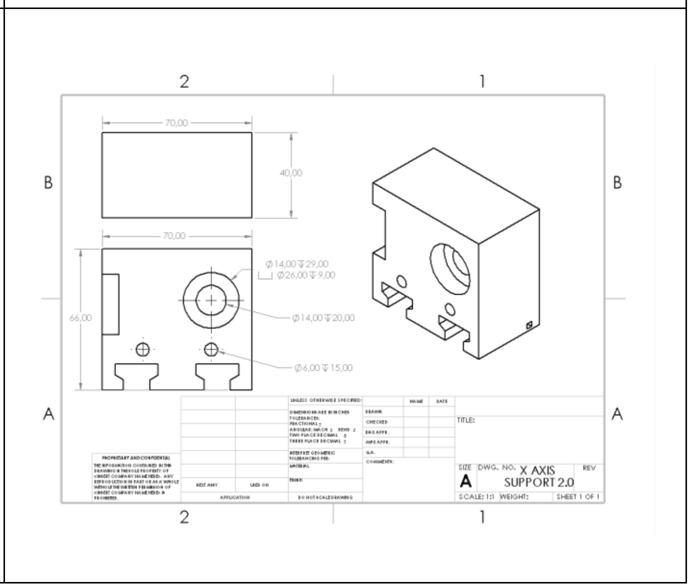


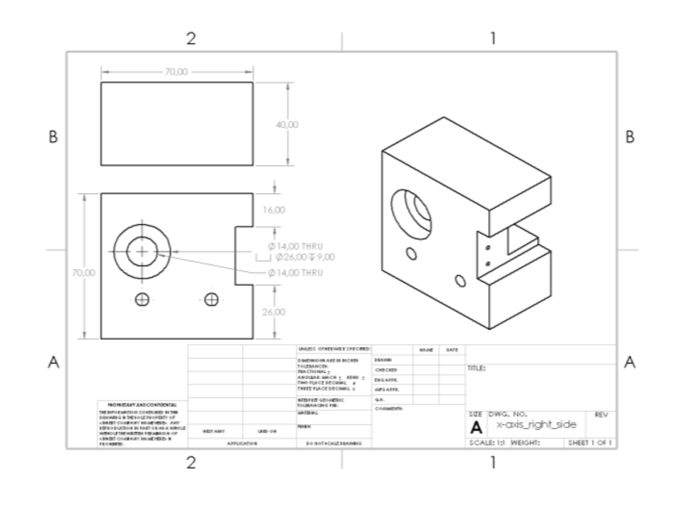











70,00
40,00
16,00
Ø14,00 THRU
Ø26,00 ↧9,00
Ø14,00 THRU
70,00
26,00
TITLE:
x-axis_right_side
SIZE DWG. NO.
A
REV
SCALE: 1:1 WEIGHT: SHEET 1 OF 1

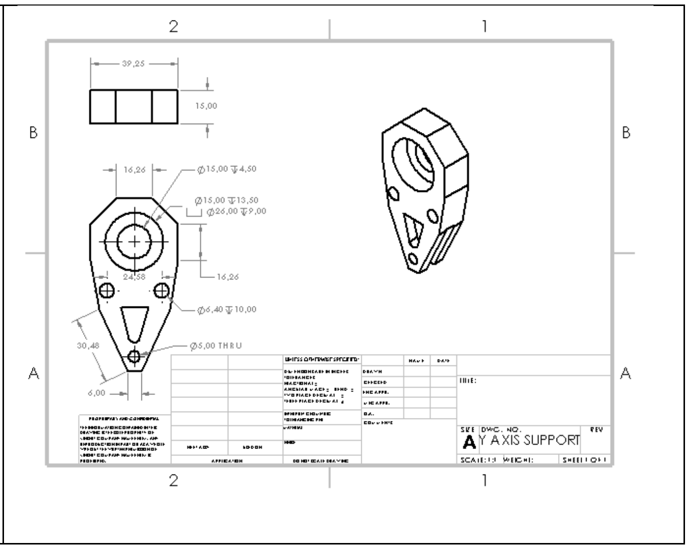

39,25
15,00
16,26
Ø15,00 ↧4,50
Ø15,00 ↧13,50
Ø26,00 ↧9,00
24,58
16,26
Ø6,40 ↧10,00
30,48
Ø5,00 THRU
6,00
Y AXIS SUPPORT

Table- 9