YILDIZ TECHNICAL UNIVERSITY

PEN PLOTTER

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MECHATRONICS SYSTEM DESIGN REPORT

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REVISION HISTORY

Date	Rev. No	Definition	Author(s)
23/12/2023	1.0	Report Beginning	Ömer Faruk Bağcı
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SYMBOL LIST

a: $Acceleration$

W: $Weight$

N: $Newton$

$Amps$: $Amper \times Second$

V: $Volt$

A: $Amper$

h: $hour$

W_h: $Watt \times Hour$

π: 3.14

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ABSTRACT

Ink or laser for transferring digital drawings or writings onto a sheet of paper printers are used. In some cases, this information is not stored on paper or in other ways. It must be transferred to the surface. In cartography, technical training is required to draw detailed maps for drawing or drawing electronic circuits on PCBs (Printed Circuit Boards) Ink or laser printers are not useful when necessary. For example, to transfer an electronic circuit drawing onto a PCB, ink or laser It must be printed on wax paper using a printer. Then, the circuit drawing on paper is transferred to the PCB using heat. However, while the drawing is transferred onto the PCB using heat, the ink in some areas may not completely transfer to the PCB or the paper may tear. A pen plotter device can be used to solve the problems in this example. With the pen plotter device, drawings can be made on different surfaces easily and with high precision transferable.

There are two types of plotter machines. One of them is electrostatic plotter another one is pen plotter. We decided to design pen plotter becuase of our project requirements. Raspberry pi zero 2w single board computer will be used in plotter motion control and receiving data that will be plotted. In the motor motion side, Nema 17 step motor and Sg90 servo motor will be used. Our machine will be controlled with mobile or desktop application remotely. For these applications we use JavaScript and TypeScript languages. On the single board computer side we use JavaScript and C languages.

1. PROJECT DESCRIPTION

This project delves into the development and implementation of a Raspberry Pi Zero 2W-controlled Pen Plotter, designed to merge artistic creativity with technological precision. The project incorporates a 2-step motor for bed movement, a servo for pen adjustment, and operates on a 12V power supply. Its control mechanism allows users to interact with the machine effortlessly through a mobile or desktop application via wifi, offering a seamless and user-friendly experience. The mechanical aspect of the plotter employs a belt and pulley system for optimal movement precision.

2. PROJECT OBJECTIVES

The aims of the project can be summarized as follows.

- To transfer data using wireless communication technology
- Designing a simple and understandable interface
- To use current technological opportunities effectively
- Creating high precise plotting machine
- To support various surfaces for plotting
- Creating affordable machine by amateurs

3. PROJECT SCOPE

Pen plotters are technology products that enable drawing with high precission on different surfaces, which are becoming widespread in the market, and are used by businesses in advertising and brochure printing. We aim for amateur-level businesses with wireless use and a quality interface design. Since we aim for amateur users, we aimed for ease at every stage of the product. It can be used in different studies thanks to its easy installation, easy use, affordable maintenance costs and support of different file types.

4. LITERATURE ANALYSIS

The iDraw 2.0 features a working area of 219 mm x 297 mm and supports file formats such as JPEG, PNG, BMP, and SVG. Weighing 5kg, it employs a Cartesian Gantry motion system and is housed in an open case frame.

With a larger working area of 29 7mm x 420 mm, the iDraw A3 also supports JPEG, PNG, BMP, and SVG file formats. Weighing 2.5kg, it shares the Cartesian Gantry motion system and open case frame design with iDraw 2.0.

The AxiDraw V3 offers a working area identical to iDraw 2.0 (219 mm x 297 mm) and exclusively supports SVG files. Weighing 2.2kg, it utilizes a Cartesian Gantry motion system and an open case frame.

Featuring a smaller working area of 60 mm x 90 mm, Line-us supports files through its dedicated app. The weight is undefined, and it stands out with a SCARA motion system within an open case frame.

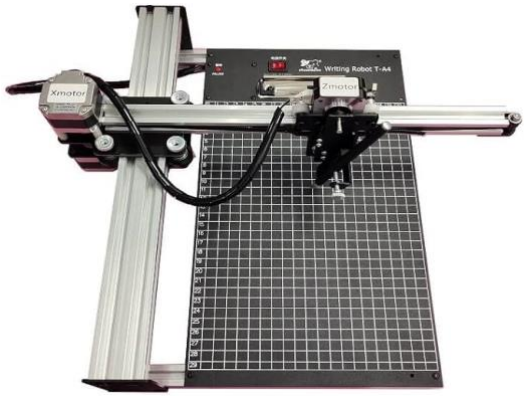

Figure 1 – iDraw 2.0

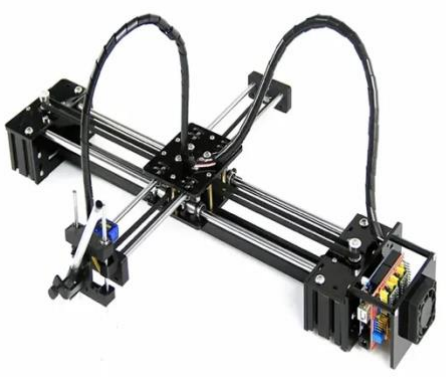

Figure 2 – iDraw A3

Figure 3 – Axi Draw V3

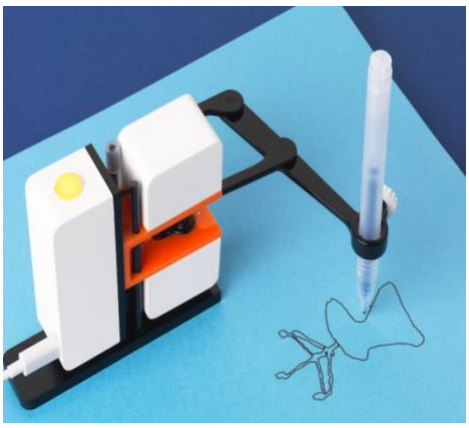

Figure 4 – Line-us

This detailed comparison provides a comprehensive overview of the specifications for each pen plotter, aiding in a nuanced decision based on individual preferences and requirements. The technical specifications of the pen plotters are given in Table 1.

Spec.	iDraw 2.0	iDraw A3	Axi Draw V3	Line - us
Working Area (mm x mm)	219 x 297	297 x 420	219 x 297	60 x 90
File Formats	JPEG,PNG,BMP,SVG	JPEG,PNG,BMP,SVG	SVG	Runs through Line-us app
Weight (kg)	5	2.5	2.2	Undefined
Motion Type	Cartesian Gantry System	Cartesian Gantry System	Cartesian Gantry System	SCARA System
Frame Type	Open Case	Open Case	Open Case	Open Case

Table 1 – Pen Plotter Comparison

5. PROJECT BLACK BOX DIAGRAM

The black box diagram of the system is as follows. The desired plotting part is given as an input to the system. In turn, the part in which the last desired plotting was made is taken as an output by going through the operations in the box.

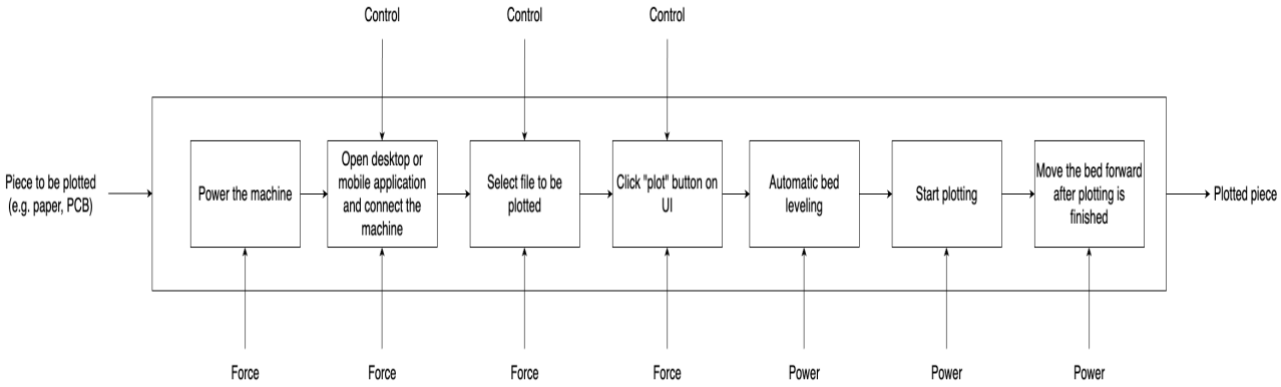

Figure 5 – Black Box Diagram

6. PROJECT NEEDS

While determining the project needs, a study was conducted on what advantages the products have or what problems they have in the literature research. In the fields of architecture, cartography and education, a study was conducted on which features our project can compete with other products in the market. In order for our product to be used in the field of education, our project should be reasonably priced compared to other products in the market. For use in areas such as cartography, architecture, it should be a machine with high precision. Project needs are sorted by their importance. You can see all the project needs below in Table 2.

No	Need	Importance
1	Lightweight	5
2	Can be controlled remotely without requiring a special device	5
3	Lasts a long time	5
4	Support different size of pens	5
5	High moving precision	5

6	Affordable for amateurs	4
7	Plug and play	4
8	No sharp corners	4
9	Adjustable speed	4
10	Sensitivity adjustment	3
11	Easy to assemble	3
12	Easy to install	3
13	Wide plotting area	3
14	Plot from various files	3
15	Can be easily maintained	2

Table 2 – Project Needs

7. PROJECT REQUIREMENTS

The objective tree for the product has been created according to the project needs. Accordingly, the lens tree is divided into 3 main parts. These are quality, cost-effectiveness, and what needs to be achieved.

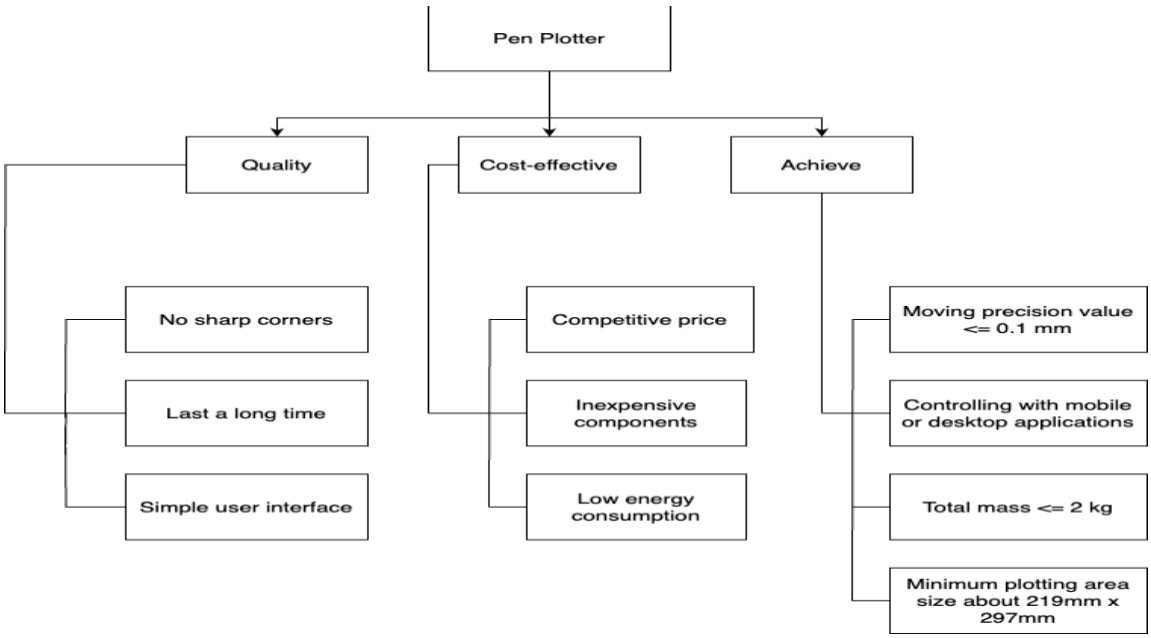

Figure 6 – Objective Tree

Project requirements created according to the project needs and objective tree. The items on the project needs list are not engineering terms so, we have listed the items in the project requirements in a way that complies with engineering terms. You can see the project requirements in Table 3 below.

Metric No.	Need Nos.	Metrics	Importance	Unit
1	1	Total mass	5	kg
2	2	Controlling with mobile and desktop applications	5	List
3	3	MTTF value	5	hr
4	4	Pen gripper diameter	5	mm
5	4	Pen height	5	mm
6	4	Pen diameter	5	mm
7	9, 5	Speed of base plate	4	mm/s
8	9, 5	Step count per full revolution	4	steps/rev
9	6	Unit product cost	4	$
10	7	No complex user interface	4	Subj.
11	7	Power on/off with one mechanical button	4	s
12	8	Buck edge radius	4	mm
13	9, 10	Microstepping range	3	List
14	11, 12, 15	Time to assemble/disassemble	3	s
15	13	Area of plotting base	3	mm^2
16	14	Support common document types	3	List

Table 3 – Project Requirements

8. QUALITY FUNCTION DEPLOYMENT OF THE PROJECT

The quality function diagram of the project is given below. The diagram has been prepared according to the needs and requirements of the project. iDraw 2.0, iDraw A3, axiDraw V3, and line-us have been added as competing products.

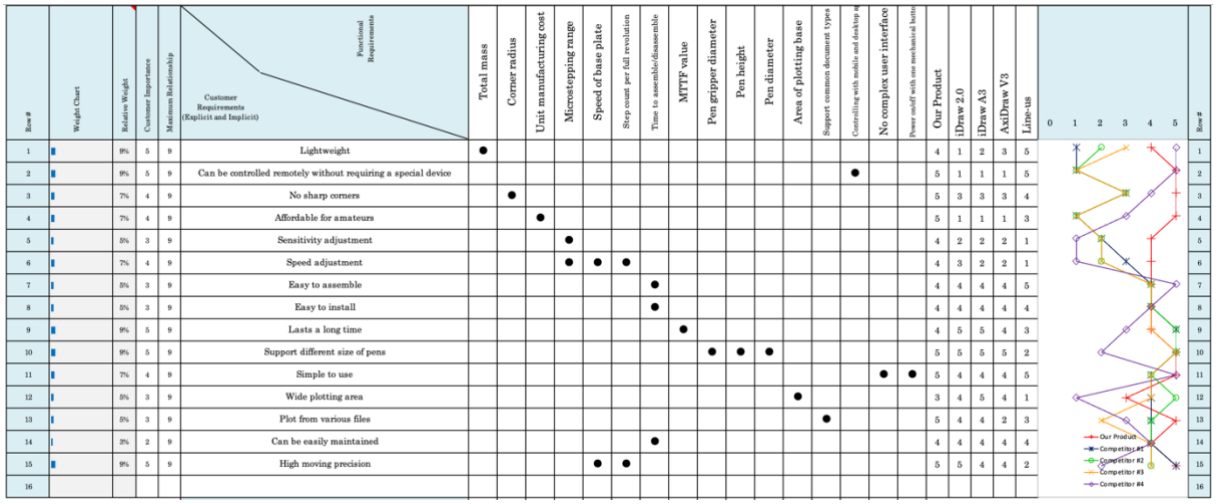

Figure 7 – Quality Function Diagram of The Project

9. PROJECT SPECIFICATIONS

The project requirements were created using engineering terms, but the values of these terms need to be determined. While determining these values, literature research was conducted, and an attempt was made to determine the ideal value. Marginal values were also determined based on ideal values. Some project requirements were left blank because the ideal values of the terms could not be found. You can see all the project specifications below in Table 4.

No	Need Nos.	Metrics	Imp.	Unit	Margianal Value	Ideal Value
1	1	Total mass	5	kg	< 2	< 1.5
2	2	Controlling with mobile and desktop applications	5	List	Android, Ios, macOs, Windows	Android, Ios, macOs, Windows
3	3	MTTF value	5	hr	20000 - 100000	25000 - 1300000
4	4	Pen gripper diameter	5	mm	-	-

5	4	Pen height	5	mm	-	-
6	4	Pen diameter	5	mm	8 - 12	6 - 20
7	9, 5	Speed of base plate	4	mm/s	0.1 - 3	0.01 – 5
8	9, 5	Step count per full revolution	4	steps/rev	200 - 3200	64 - 6400
9	6	Unit product cost	4	$	< 100	< 80
10	7	No complex user interface	4	Subj.	-	-
11	7	Power on/off with one mechanical button	4	s	-	-
12	8	Buck edge radius	4	mm	-	-
13	9, 10	Microstepping range	3	List	1, 4, 8, 16	1, 4, 8, 16, 32, 64
14	11, 12, 15	Time to assemble/disassemble	3	s	-	-
15	13	Area of plotting base	3	mm^2	148 x 210	219 x 297
16	14	Support common document types	3	List	JPEG, PNG, SVG	JPEG, PNG, SVG, BMP

Table 4 – Project Specifications

10. SYSTEM ARCHITECTURE

As seen in the below, the pen plotter machine consists of two subsystems. The first of these systems is the plotter machine and the other is the pen plotter machine control application. The file you want to plot is selected using the control application. The selected file is sent to the plotter machine and the drawing process is started on the part placed on the surface of the machine.

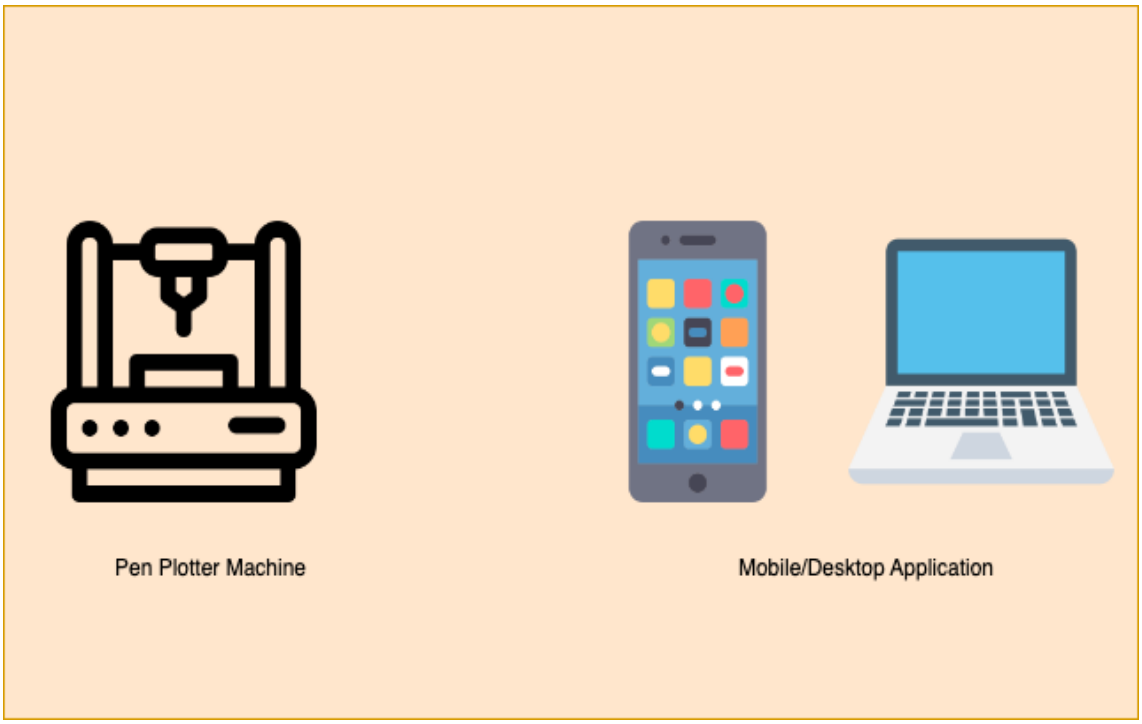

Figure 8 – Pen Plotter Subsystems

Whichever part we want to print on is placed in the device. The file we want to plot is sent via raspberry wifi using the mobile and desktop application. In Raspberry, this file is converted to g-code. After the G-code generation, the necessary signals are sent from the drivers depending on the g-code to the stepper and servo motors. After the G-code processing is completed, the desired file is plotted on the part placed in the machine. You can see the general system architecture in Figure 9.

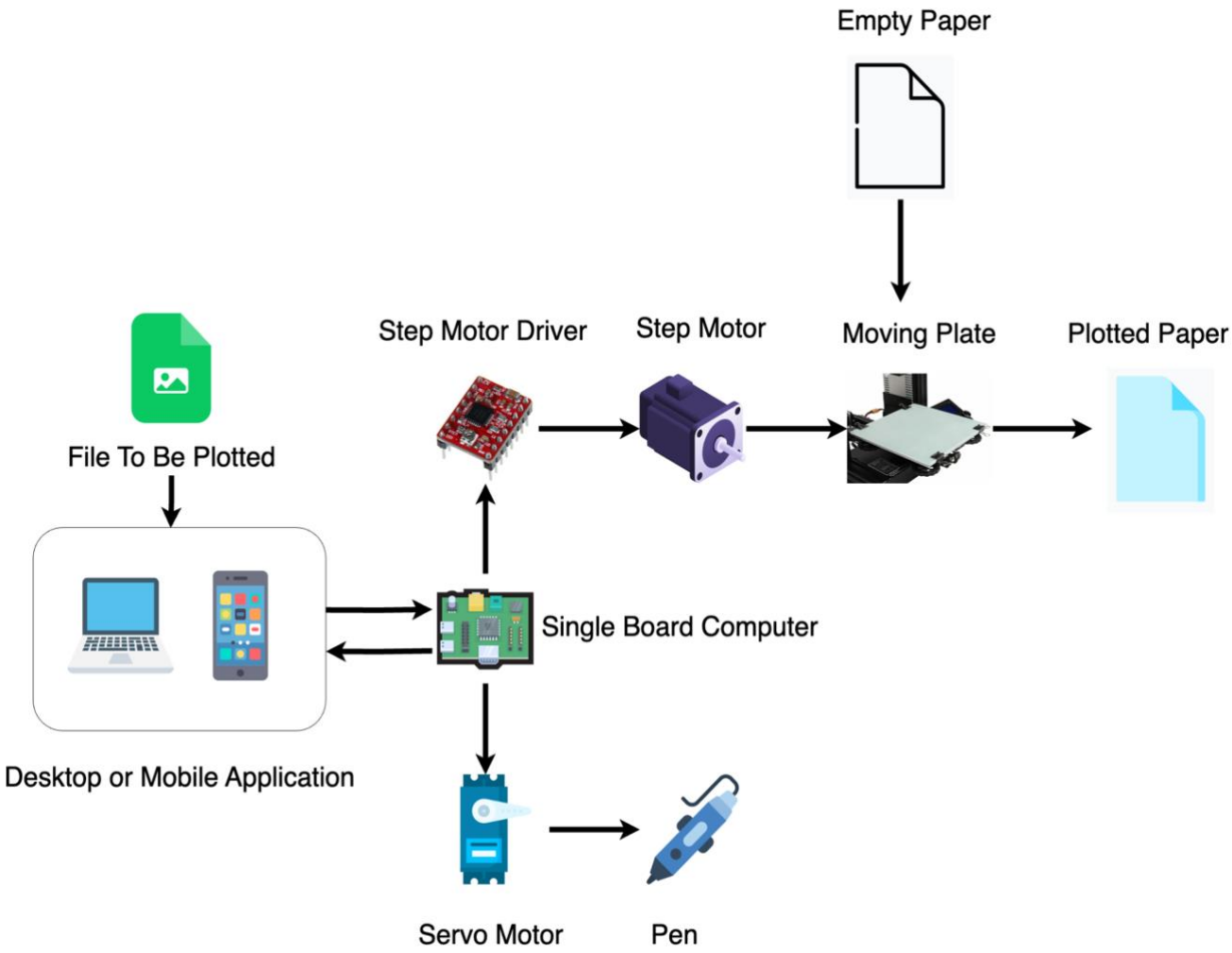

Figure 9 – General System Architecture

11. DESIGN

Pen plotter machine is divided into two subsystems as mobile/desktop application and mechanical part. In the mechanical part, 2 stepper motors were used to move the pen in the desired directions in the x and y directions. The stepper motors are mounted on the bed and pen gripper with a belt system. The belts, on the other hand, receive the movement from the step motor with a pulley. The belts are again supported by a pulley. The pen gripper and the bed both slide on two axles. A servo motor is used to move the pen up and down. Preliminary design can be seen in Figure 10.

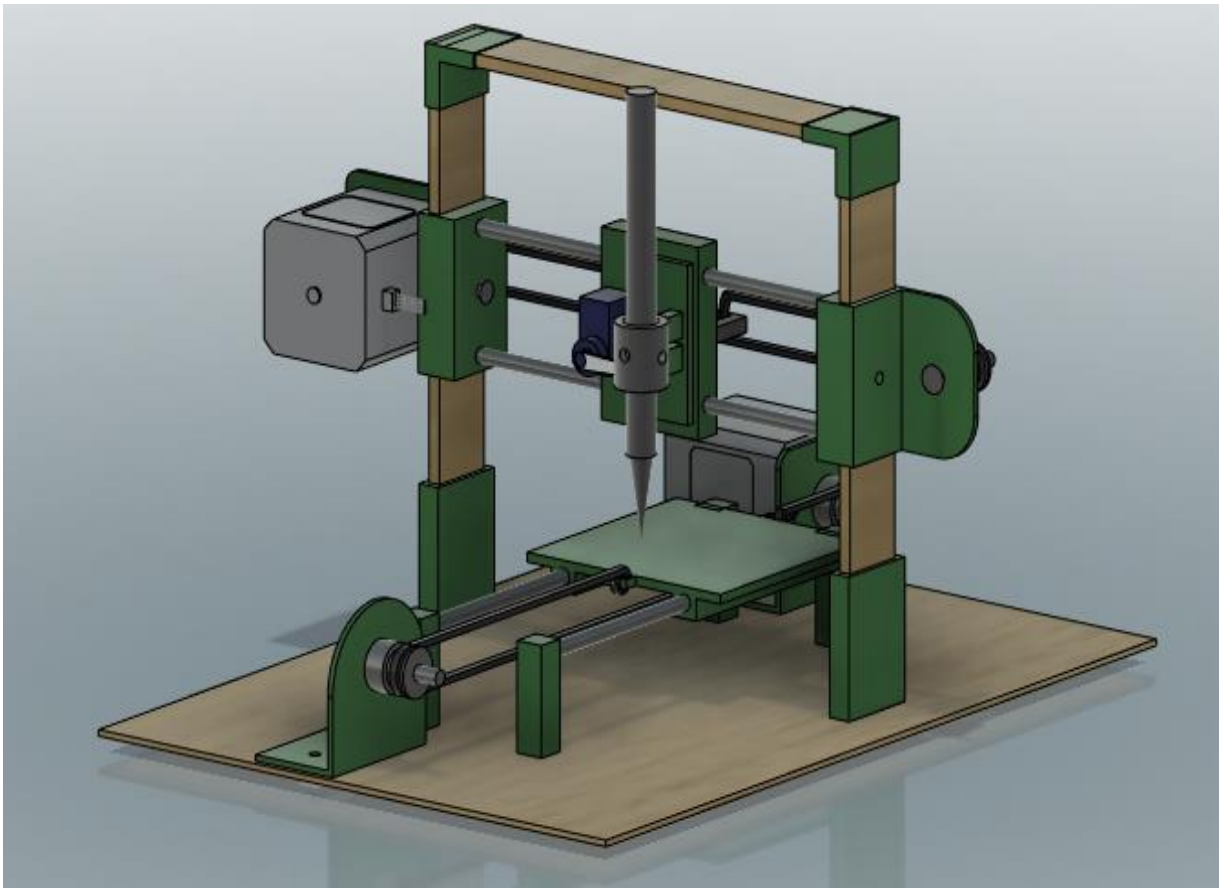

Figure 10 – Preliminary Design

11.1 **Body Design**

There are 3 common type for body design based on motion type. One of them is cartesian gantry system, another one is scara system and the last one is cartesian system. We decided to use cartesian system, so our design for this motion type is open frame.

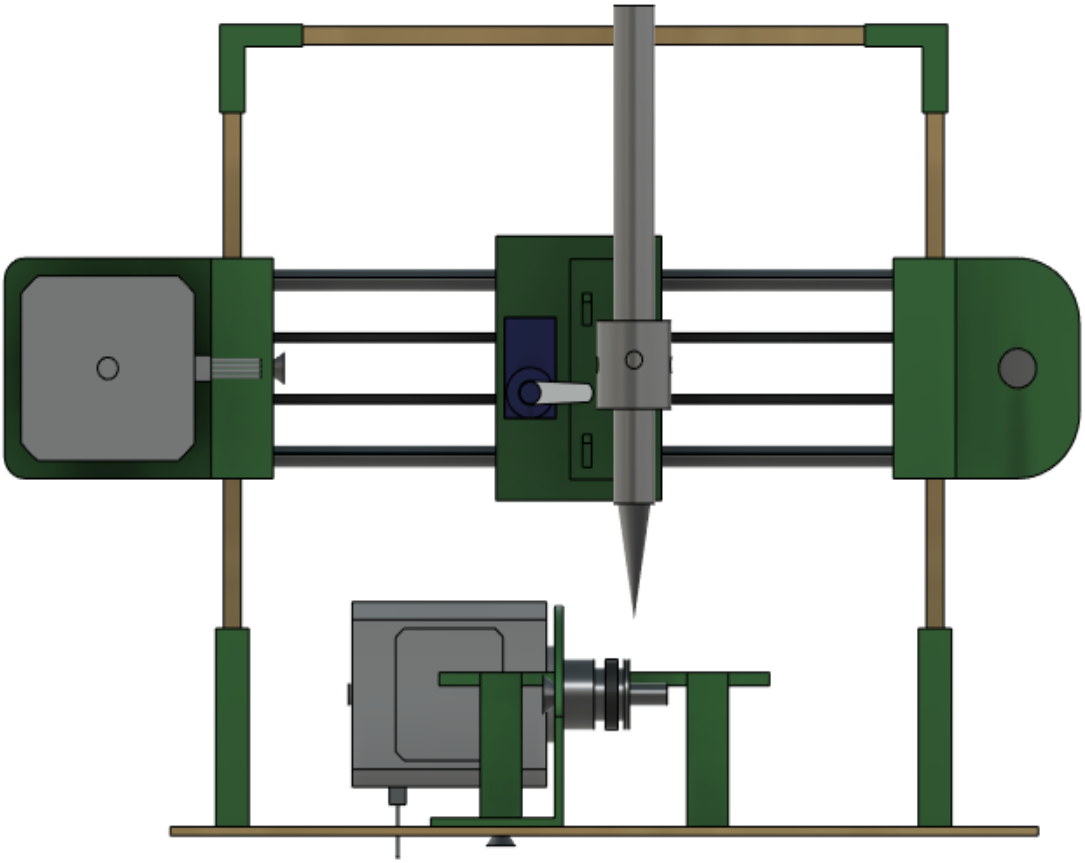

Figure 11 – Cartesian Open Frame Design

11.2 Mechanical Calculations

We determined sensitivity of the plotter machine as 0.01 mm. The operation of the machine with this precision does not depend only on the step motor. Since the machine will move with a belt and pulley system, this sensitivity depends on the pulley, motor angle and microstepping resolution of step driver. When we investigate the stepper motors sold on the market, the step angles range from 0.9° to 5.625°. There are many types of motors on the market for 1.8° step angle. Because of the easy access and stability we selected Nema17 HS4401 step motor. This step motor has 1.8° step angle. We selected the belt that is GT2 timing belt which has width of 6 mm and GT2 16 teeth pulley. Tooth pitch of the pulley is 2 mm.

Specifications	Value
Number of teeth	16
Pitch	2 mm
Circumference	16 x 2 = 32 mm

Table 5 – Pulley Specifications

The belt will move at a distance equivalent to 32 mm per rotation. Motor takes 1.8° per step. One step will move plotter by a distance of (32 mm/360°) x 1.8° = 0.16 mm. For 0.01 mm distance we selected the motor driver which has 1/16 microstepping resolution. Using 1/16 microstepping operation one step will become (1.8°/16) = 0.1125°. One step will move plotter by a distance of 32mm/360° x 0.1125° = 0.01mm.

11.3 Torque Calculation

We have to check torque of the motor is enough for pencil gripper mechanism and bed.

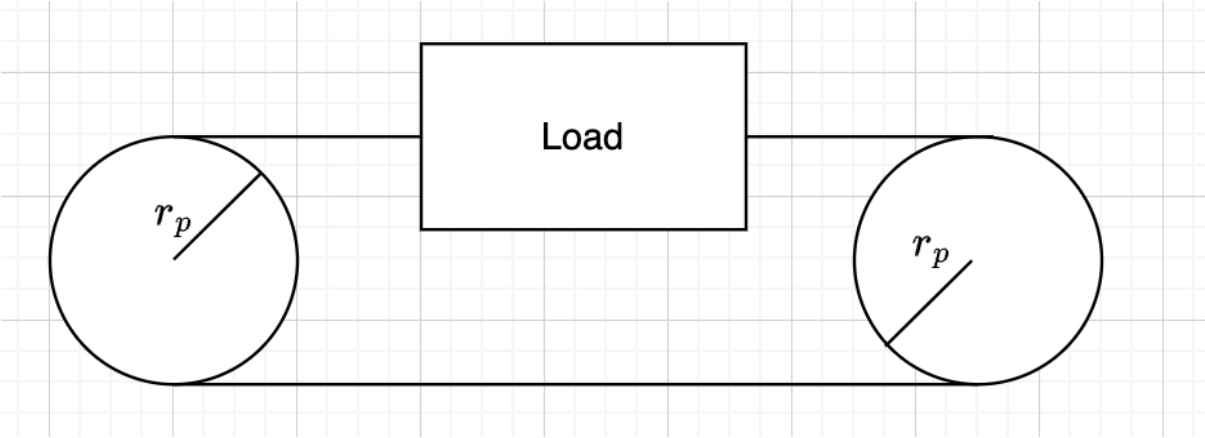

Figure 12 – Pulley and Load

Required information are listed Table 6 below.

Specification	Value
Load weight (m_l)	$300g = 300x10^{-3}kg$
Belt weight (m_b)	$12g = 12x10^{-3}kg$
Pulley weight (m_p)	$5g = 5x10^{-3}kg$
Inertia of the motor (J_m)	$54gcm^2 = 5.4x10^{-6}kgm^2$
Outer diameter of the pulley (r_o)	$12mm = 12x10^{-3}m$
Inner diameter of the pulley (r_i)	$5mm = 5x10^{-3}m$

Table 6 – Mechanical Component Specifications

First calculate the inertia of the pulley.

$$J_p = \frac{1}{2} m_p (r_o^2 + r_i^2) \qquad \text{(Eq. 11.1)}$$

where,

$J_p \gg Inertia\ of\ the\ pulley$

$m_p \gg Weight\ of\ the\ pulley$

$r_o \gg Outer\ diameter\ of\ the\ pulley$

$r_i \gg Inner\ diameter\ of\ the\ pulley$

$$J_p = \frac{1}{2} x(5x10^{-3})(12^2 + 5^2)x10^{-6} = 0.423\ x10^{-6}\ kgm^2 \qquad \text{(Eq. 11.2)}$$

For load calculation there are two load for two belt system pen gripper section and bed. Because of the weight of the bed is higher than pen gripper, we selected load as weight of the bed. Also extra weight is included that is weight of the belt.

$$J_l = (m_b + m_l)x(r_o^2) \qquad \text{(Eq. 11.3)}$$

where,

$J_l \gg Inertia\ of\ the\ load$

$m_b \gg Weight\ of\ the\ belt$

$m_l \gg Weight\ of\ the\ load$

$r_o \gg Outer\ diameter\ of\ the\ pulley$

$$J_l = (12x10^{-3} + 300x10^{-3})x(12^2)x10^{-6} = 44.928x10^{-6}\ kgm^2 \qquad \text{(Eq. 11.4)}$$

Now, we can calculate total inertia of the system. Total inertia of the system summation of the inertia of the motor, inertia of the pulleys and inertia of the load.

$$J_t = J_m + J_{p1} + J_{p2} + J_l \quad \text{(Eq. 11.5)}$$

where,

$J_t \gg Total\ inertia\ of\ the\ system$

$J_m \gg Inertia\ of\ the\ motor$

$J_{p1} \gg Inertia\ of\ the\ pulley\ 1$

$J_{p2} \gg Inertia\ of\ the\ pulley\ 2$

$J_l \gg Inertia\ of\ the\ load$

$$J_t = (5.4 + 0.423 + 0.423 + 44.928)x10^{-6} = 51.174x10^{-6} kgm^2 \quad \text{(Eq. 11.6)}$$

We can calculate the required torque with total inertia and angular acceleration of the motor. Low angular acceleration is enough for this machine. So, it is selected $0.1\frac{rad}{s^2}$. Using equation below we can calculate the torque value.

$$T_{acc} = J_t\, x\, \alpha \quad \text{(Eq. 11.7)}$$

where,

$T_{acc} \gg Acceleration\ torque$

$J_t \gg Total\ inertia\ of\ the\ system$

$\alpha \gg Angular\ acceleration\ of\ the\ motor$

$$T_{acc} = (51.174x10^{-6})x0.1 = 5.1174x10^{-6}\ Nm \quad \text{(Eq. 11.8)}$$

The detent torque (acceleration torque) of the motor is given that 2.2 N.cm as maximum. Which is equal to $22x10^{-3}\ Nm$. Our calculated torque value is so smaller than the maximum torque of the motor, so this motor can be used in this project.

12. MOTOR SELECTION

Nema17 HS4401 step motor specifications required for our project are listed in the Table 7 below.

Specification	Value	Image
Step Angle (θ_s)	200	
Maximum Current (I_{max})	1.7 A	
Inductance (L)	2.8 mH	
Inertia of the motor (J_m)	$54gcm^2$	

Table 7 – Nema17 HS4401 Specifications

13. ELECTRICAL SYSTEM DESIGN

The electrical drive system of the plotter will consist of three main systems. These are DC step motor, step motor driver and power supply respectively. The step motor configuration of the machine will be selected in such a way that it can move the base plate with determined speed that specified in the technical requirements. The step motor driver will be selected according to the technical specifications of the step motor.

In the circuit below, there are two step motors, two step motors driver, two limit switches, tow pull-down resistors, one signel board computer and one servo motor. Step motor drivers are powered by 5 volts and its motor voltage input is powered by 12 volts. Servo motor and raspberry pi is powered by 5 volts.

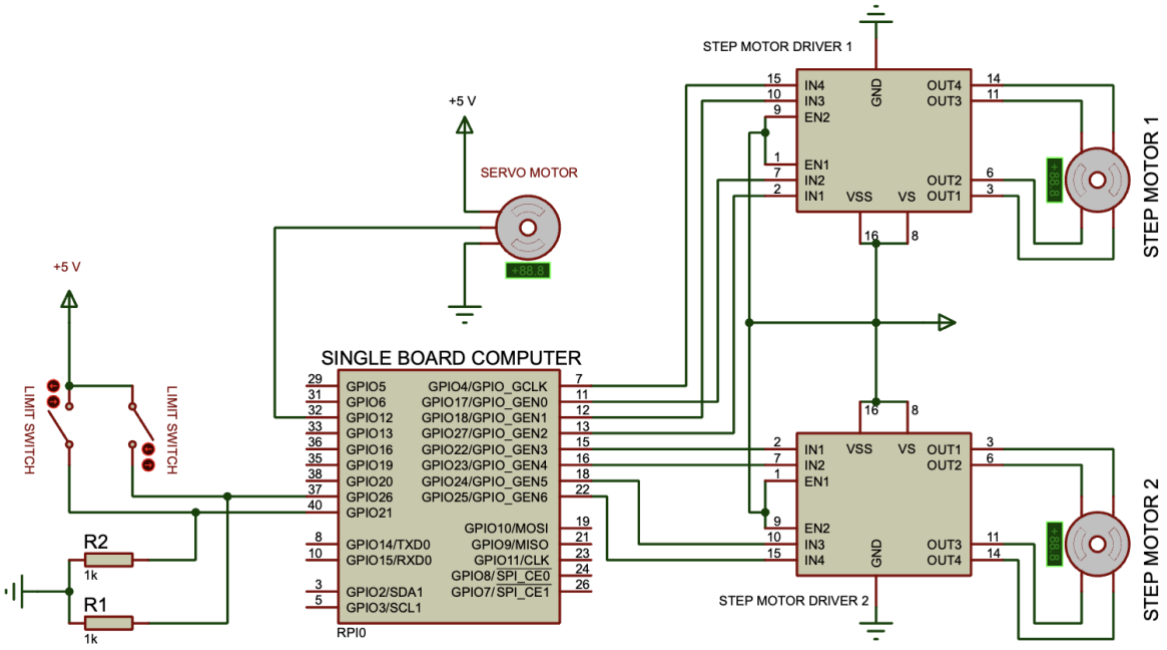

Figure 13 – Electrical Circuit of The Plotter Machine

14. POWER CALCULATION

It is important to know how much power the entire system consumes. Because in the electrical circuit design part, it is necessary to make a power supply system and a power distribution system that can provide these powers. The main consumer in the power system is the step motors.

We will drive our stepper motors with 12 volts and the total power to be consumed in the system is calculated as 44.3 watts. A device with a 12-volt 4 ampere can be selected as the power supply, but a power supply with a 12-volt 5 ampere specification will be selected so that there are no glitches in the system.

No	Component	Voltage	Ampere (A)	Power (W)
1	Raspberry pi zero 2w	5	0,120	0,7
2	Nema17 HS4401 - 1	12	1.7	20,4
3	Nema17 HS4401 - 2	12	1.7	20,4
4	Sg90	5	0,550	2,75
5	Step motor driver	5	0,008	0,04
	Total			44,3

Table 8 – Power Consumption of The Components

15. STEP MOTOR DRIVER SELECTION

According to mechanical calculation section, microstepping resolution of the driver must be minimum 1/16. In market we found a4988 step motor driver. This step motor driver can supply 2A output. Nema17 HS4401 stepper motor has maximum 1.7A and this driver can be work at 8-35 voltage range. Also we can use this driver with 1/16 microstepping resolution.

Figure 14 – A4988 Step Motor Driver

16. SENSORS

The sensors to be used in the project were selected in line with the literature research and the technical requirements of the project. Accordingly, only one sensor is need for our project that is limit switch. We use limit switch for determining that the base plat is collide with boundiries.

Figure 15 – Limit Switch

17. COMMUNICATION SYSTEM

In this project the pen plotter machine will communicate via wifi. Wifi module is embedded in raspberry pi zero 2w.

Wireless communication will be made between the machine and the remote-control device with the help of the wifi. Image transfer and other datas will be transferred in this way. Thus, with the interface designed for the machine on the computer or mobile application, it will be possible to follow the progress of the machine such as time, speed, coordinates, and pen status.

18. CONTROL SYSTEM

Raspberry pi zero 2w single board computer will be used as a basis for plotter motion control and data acquisition from sensors. Wireless data transfer to the remote-control device will be carried out with the help of the wi-fi module. Also, file will be converted to g-code using raspberry.

Figure 16 – Raspberry Pi Zero 2w

19. SOFTWARE DESIGN

Three Different software is required for the pen plotter project. These softwares are mobile application software, desktop application software and embedded system software. Control applications will be written for mobile and desktop that will send the necessary data to the machine and receive the necessary information from there. On the embedded system application side, software will be developed that will send the data from mobile or desktop applications to the workplace and the necessary signals to the electronic parts connected to the raspberry pi.

19.1 Mobile Application

You can see flow chart of mobile and desktop application below. First user starts the application then connect to wifi hotspot of the plotter machine. If connection is not successful application can not go further. After connection, user can select the file for plotting. Selected file will send from mobile/desktop application to the plotter via wifi. If there is an error while transferring file to the plotter or file process error, then user will be notified what is the error. If there is no error user can start the plotting by pressing the start button.

Figure 17 – Flow Chart of The Mobile and Desktop Applications

19.2 Mobile Application User Flow

Only user flow diagrams are shown in the application section. The final codes will be added in the B.Ç section. All the steps of mobile application can be seen in Figure 18.

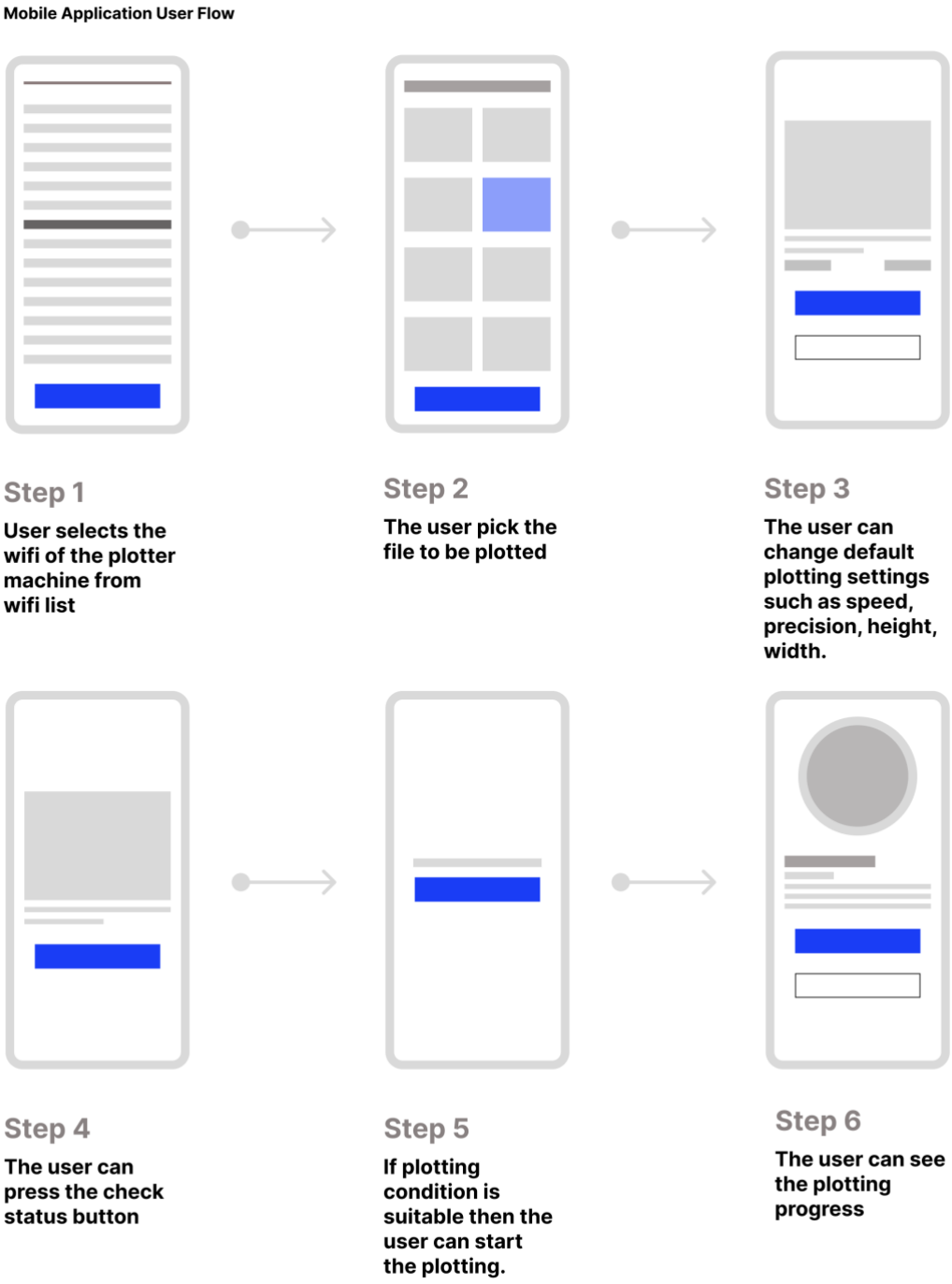

Figure 18 – User Flow of The Mobile Application

19.3 Desktop Application User Flow

Only user flow diagrams are shown in the application section. The final codes will be added in the B.Ç section. All the steps of dektop application can be seen in Figure 19.

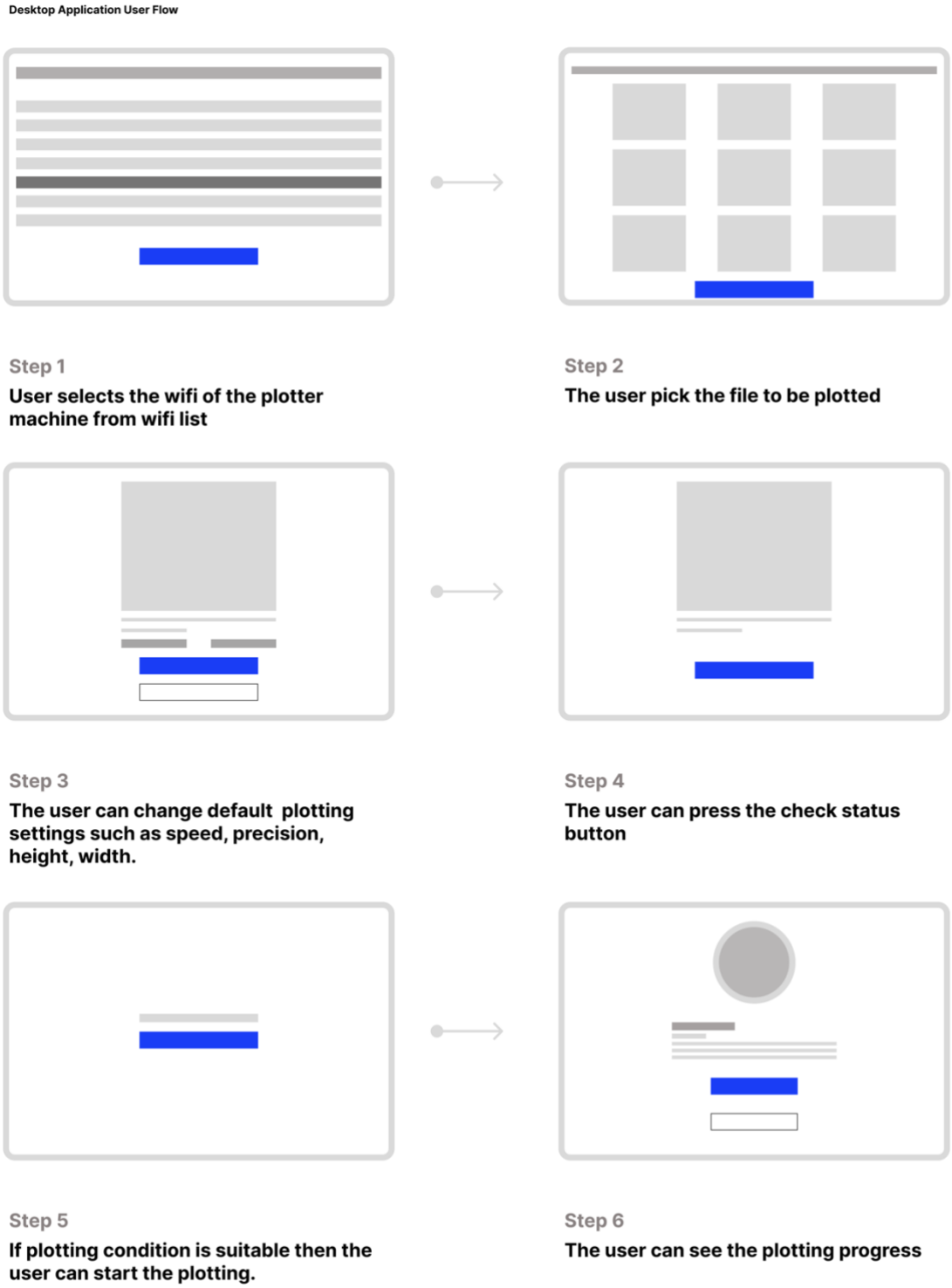

Figure 19 – User Flow of The Desktop Application

19.4 **Plotter Software**

In plotter machine side, user first start the plotter then operating system automatically activate hotspot after the controller booted up. Also, our server software is started when controller booted up. Server waits for mobile/desktop application connection. After device connected to the plotter, then it will get the file from mobile/desktop application. If file type is true, then file will be converted to g-code. If error occurred while generation of g-code, user will be informed. Otherwise, plotter wait for start drawing command. If plotting is started machine will plot the data to the surface. Flow chart of the plotter can be seen in below.

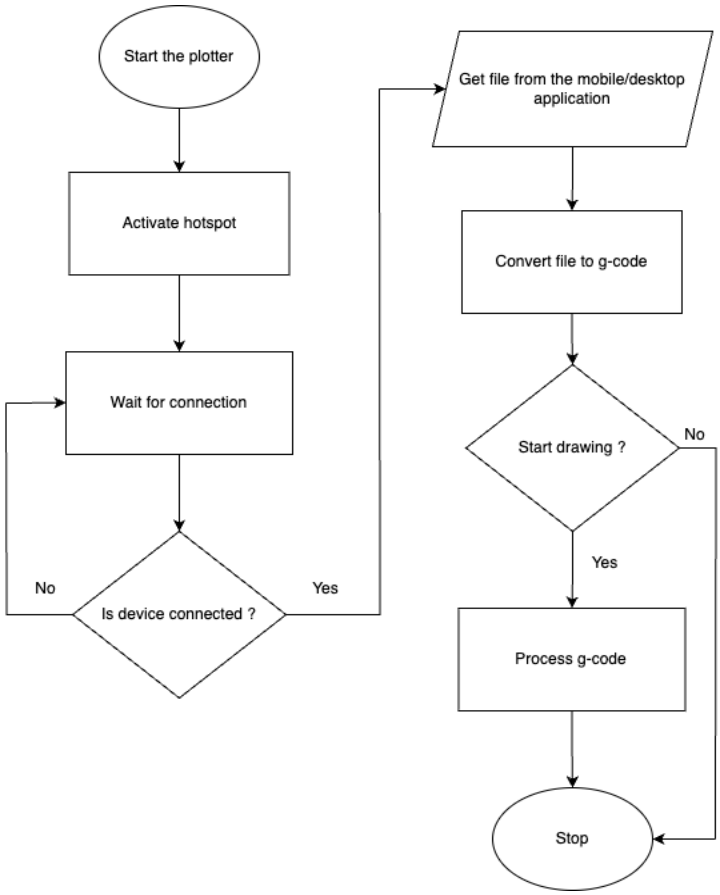

Figure 20 – Flow Chart of The Pen Plotter Machine

20. PROJECT MANAGEMENT

Our work schedule in the project is as follows. Responsibilities of the project team members have been determined so that the project will be completed on time. It is aimed that the project members make up for each other's deficiencies at the missing points in the work schedule.

No	Name and Targets of Business Packages	By Who(s) It Will Be Performed	Time Interval (10/23 – 1/2024) (4 Months)
1	Preliminary Design: -Determining the dimensions of the pen plotter -Making mechanical analysis -Positioning of electronic equipment and motors	Ömer Faruk Bağcı	2023 October – 2024 January
2	Remote Control Application and Hardware Control Software Design: -Designing remote-control mobile and desktop application of pen plotter. -Designing server, images process and generating g-codes from given images for pen plotter	Ömer Faruk Bağcı	2023 November – 2024 January
3	Final Design and System Modeling: -Equipment selection in accordance with the preliminary design	Ömer Faruk Bağcı	2023 December – 2024 January

Table 9 – Work Schedule

21. RISK MANAGEMENT

Some risks have been foreseen for the project. These risks and the precautions that can be taken against these risks are shown in Table 10 below.

No	Highest Risks	Risk Management (Plan B)
1	Mechanical failure	Conduct routine preventive maintenance. Have a service contract with a reliable maintenance provider for quick repairs. Keep a spare pen plotter on standby if possible.
2	Data loss or corruption	Implement a robust data backup system with regular automated backups. Store backups off-site and regularly test data restoration processes.
3	Pen malfuction	Maintain a stock of backup pens. Regularly test and replace pens and have a manual pen replacement process in case of immediate issues.
4	Power outages	Install uninterruptible power supplies (UPS) to provide temporary power during outages. Have a backup power generator for longer outages.

Table 10 – Risk Management

22. PROJECT BUDGET

The budget request is created for five main materials and other materials. It is seen in the Table 11 below.

Components	Quantity	Unit Cost (TL)	Total Cost (TL)
Nema17 HS4401	2	250	500
Sg90 servo motor	1	50	50
Raspberry pi zero 2w	1	850	850
A4988 step motor driver	2	40	80
Power supply	1	200	200
Other parts	-	-	1000
Total	-	-	2680

Table 11 – Project Budget

SUMMARY AND CONCLUSIONS

Since initiating our project, significant progress has been made in delineating the framework of our pen plotter machine. This involved defining the fundamental operational principles and identifying the specific requirements of the pen plotter based on these determinations.
We decided what the basic working logic of our pen plotter would be. And in line with these decisions, we determined the needs of our pen plotter.

Within the mechanical design domain, our focus extended to establishing the overall structural geometry of the pen plotter machine. Consequently, we opted for an open frame and Cartesian-type configuration. Further, we pinpointed the approximate dimensions of the machine's body in alignment with our prototype, culminating in the creation of a three-dimensional design for our pen plotter.

Concerning the electrical components, meticulous consideration was given to selecting elements that align with the functionalities required by our plotter machine. The choice of a Raspberry Pi Zero 2W as our processor, along with the identification of servo motors and step motor drivers, exemplifies our efforts in this realm. Additionally, comprehensive decisions were made regarding power supply configurations.

In the software arena, our initiatives commenced with the conceptualization of user flows for both mobile and desktop applications. Simultaneously, we undertook the task of generating G-code from input files, a pivotal aspect in our project's functionality. These collective efforts represent crucial milestones in the development of our pen plotter machine.

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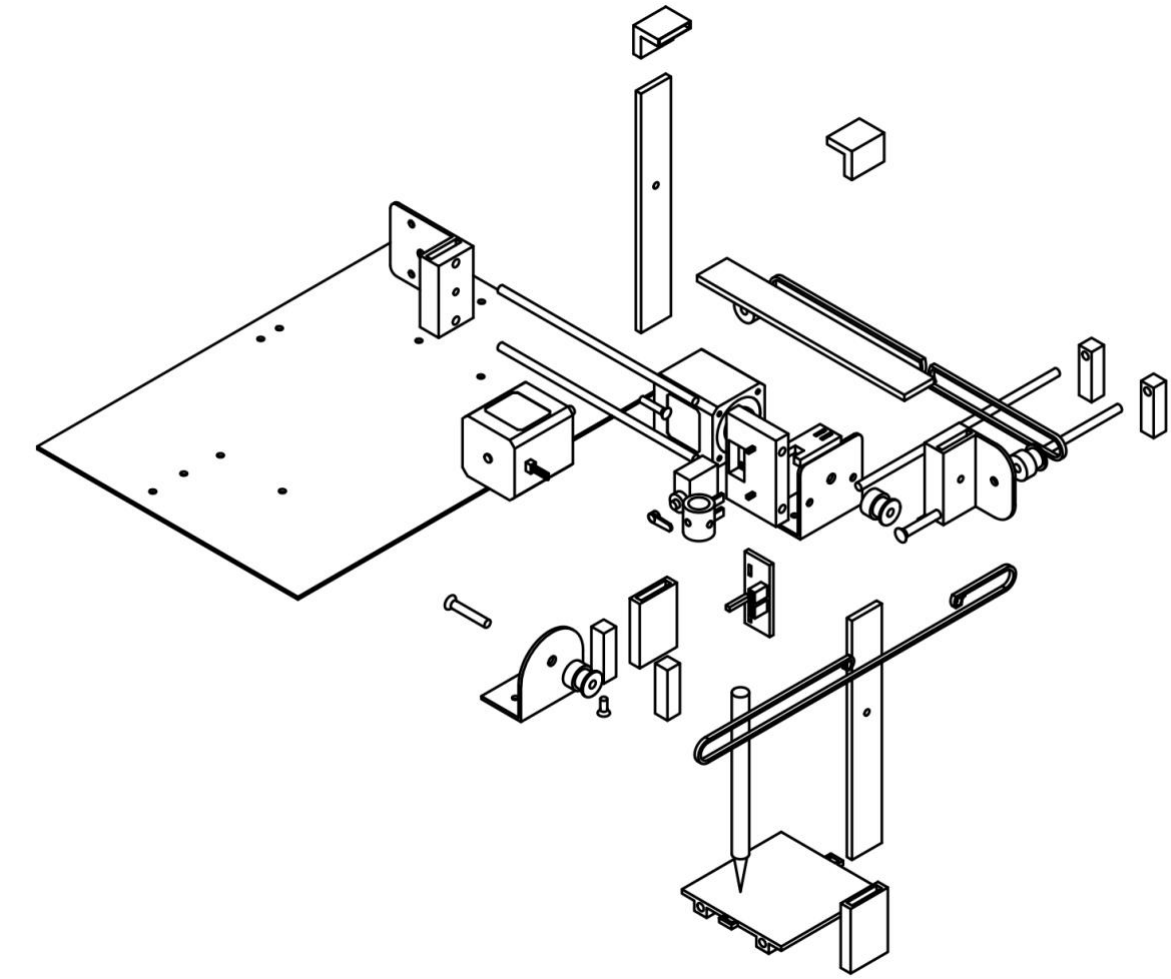
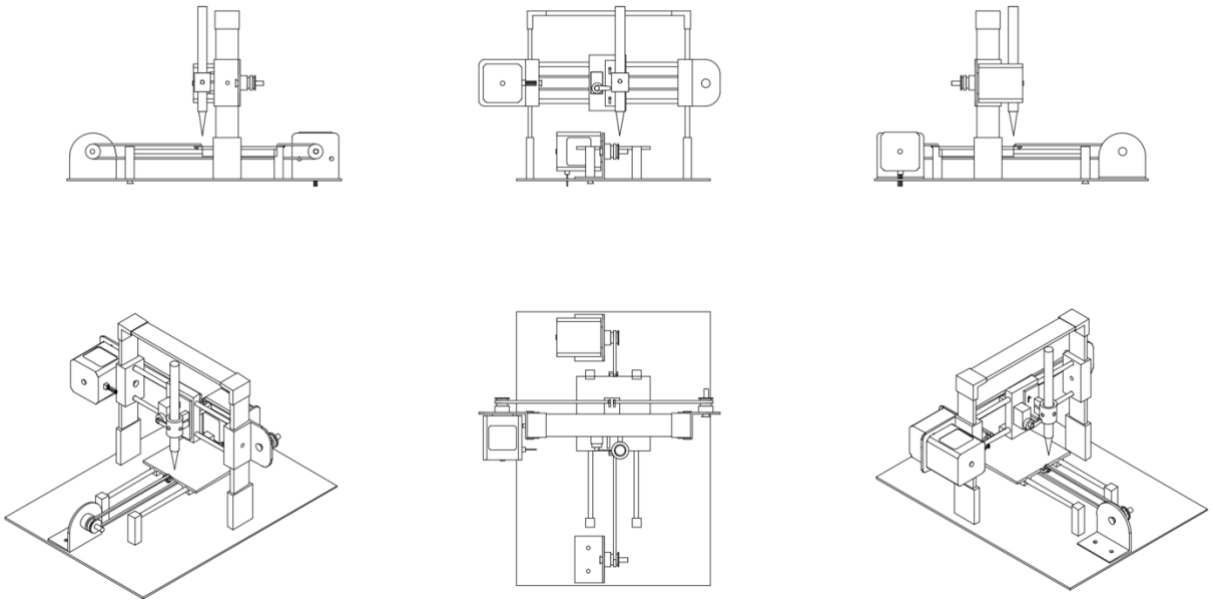
Appendix

Exploded view



Overall technical drawings



Work breakdown structure (WBS)

1.0 Project Management
- 1.1 Project Planning
- 1.2 Project Scheduling
- 1.3 Resource Allocation
- 1.4 Risk Management

2.0 Hardware Design
- 2.1 Mechanical Design
  - 2.1.1 Frame Design
  - 2.1.2 Carriage Design
  - 2.1.3 Pen Mechanism
- 2.2 Electrical Design
  - 2.2.1 Motor Control
  - 2.2.2 Sensor Integration
  - 2.2.3 Power Supply

3.0 Software Development
- 3.1 Firmware Development
- 3.2 User Interface Development
  - 3.2.1 Mobile Application Development
  - 3.2.2 Desktop Application Development

4.0 Testing
- 4.1 Hardware Testing
- 4.2 Software Testing
- 4.3 Integration Testing