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Parcel Storage and Retrieval System

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Presented in partial fulfillment of the requirements for the Bachelor's degree in Computer Engineering.

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Disclaimer

This report was authored by Oday Yamak and Ahmad Awad, students in the Computer Engi- neering Department at the Faculty of Engineering, An-Najah National University. Aside from editorial adjustments, it has not been altered or corrected as a result of the assessment pro- cess, and it may contain errors in both language and content. The views, conclusions, and recommendations presented in this report are solely those of the authors. An-Najah National University assumes no responsibility or liability for any consequences arising from the use of this report for purposes other than those for which it was intended.

Abstract

Our graduation project presents a smart automated parcel storage and receiving system designed to streamline last-mile delivery. The system consists of six physical lockers arranged in a 2×3 grid (two columns and three rows), each equipped with a motorized door and secured access mechanism. A designated external platform is used for receiving parcels, where a CNC robotic arm picks up each parcel and distributes it into an available locker. The system leverages keypad-based authentication to allow users to retrieve their packages. Upon arrival, the recipient enters a unique code via the keypad. A connected LCD screen displays the entered code in real-time to provide user feedback. If the code is valid, the corresponding locker automatically unlocks. Once the package is collected, the locker door closes automatically, ensuring security and readiness for the next operation.

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Introduction

General Background

With the rapid growth of e-commerce and parcel deliveries, the need for secure and automated storage systems is becoming increasingly important. Traditional last-mile delivery faces challenges such as package theft, delays, and inefficient handling. To address these issues, automated parcel lockers provide a reliable and secure solution for both delivery services and recipients.

Objectives

- Design and implement an automated parcel locker system with a CNC-based robotic arm for package placement.
- Provide secure user authentication using a keypad and RFID payment simulation.
- Enable real-time feedback and control through LCD display and sensors.
- Integrate safety features using flame, gas, and temperature sensors.
- Provide SMS-based notifications to recipients and senders using the SIM800L.
- Integrate Mobile Application for end users

Significance of the Work

The system enhances the efficiency and security of last-mile delivery operations by combining automation, IoT communication, and safety monitoring. It also demonstrates the application of mechatronics, embedded systems, and communication technologies in solving real-world logistics challenges.

Organization of the Report

This report is organized into the following sections:

• Introduction – Background, objectives, and significance.
• Literature Review – Overview of related works and technologies.
• Methodology – Hardware and software design of the system.
• Assembly and System Integration – Step-by-step construction and integration.
• Results and Discussion – Evaluation of system performance.
• Conclusions and Recommendations – Summary and suggestions for future improvements.

Constraints and Earlier Coursewk

Constraints

Hardware Limitations

- **Motor Torque**: NEMA 17 motors were insufficient for vertical motion due to weight constraints, requiring the use of a stronger NEMA 23 motor.
- **Servo Strength**: Low-cost servo motors had limited torque, restricting the locker door size and material thickness.
- **Driver Limitations**: A4988 drivers occasionally overheated under continuous operation, necessitating current-limiting adjustments and cooling measures.

Power and Electronics

- **Power Supply Constraints**: The system depends on a 12V DC power supply and a buck converter for step-down voltages. Any instability in power caused erratic motor or sensor behavior.
- **Heat Management**: Continuous motor operation and electronics required active cooling with a fan, increasing system complexity.

Communication and Control

- **SIM800L GSM Module**: Signal quality and reliability depended heavily on network availability. In areas with poor coverage, SMS notifications were delayed.
- **Arduino Mega Resources**: Although sufficient, the number of peripherals pushed the board near its I/O and memory capacity.

Mechanical Design

- **CNC Mechanism Precision**: Backlash and misalignment in the V-slot rails occasionally caused inaccuracies in parcel placement.
- **Locker Size**: Lockers were limited to six compartments (2×3 grid), restricting the number of parcels that could be stored simultaneously.

Time Constraints

- Development was limited by the academic semester duration, requiring compromises in testing and system optimization.

Earlier Coursework

During our early studies, the Electronics course provided us with the fundamental principles of electronics that proved essential in assembling and troubleshooting the hardware components of the machine, including sensors, motors, valves, and pumps. In addition, the Microcontrollers course, which introduced us to PIC controllers, was especially valuable. The knowledge we gained allowed us to program the onboard computer using Arduino Mega and Uno, an essential step in bringing the machine to life.

We also received training on I^2C and PWM communication, as well as practical skills for connecting various components. This knowledge enabled us to develop the core machine-control code, which was vital to the success of the project.
The Networks course equipped us with an understanding of communication protocols and basic networking skills, which we applied in creating the machine's networking infrastructure. This knowledge was particularly important in enabling remote control of the machine through an application and in integrating the ESP device for user interaction.

Finally, the Critical Thinking course played a pivotal role in our approach to the project. It helped us develop the ability to analyze problems methodically and reach sound conclusions. These skills allowed us to identify and address potential issues at an early stage, preventing them from becoming costly or difficult to solve. This capability became increasingly valuable as the project advanced, especially when tackling design and power-related challenges.

Literature Review

Introduction

Automated parcel and storage systems have been studied and deployed across logistics and e-commerce industries. Their aim is to provide secure, reliable, and convenient access for both senders and receivers. The integration of mechatronics, IoT, and embedded systems has allowed for innovative solutions to the last-mile delivery challenge.

Automated Storage and Retrieval Systems

Modern systems often include robotic mechanisms that handle the placement and retrieval of packages. These systems improve delivery efficiency, reduce human error, and provide greater security compared to traditional methods.

Sensor Technologies

Different types of sensors are commonly used in automated locker systems:

- IR sensors – for detecting presence of packages.
- Temperature and humidity sensors – for environmental monitoring.
- Gas and flame sensors – for safety detection.
- Limit switches – for detecting axis end-stops in CNC systems.

Actuators

Actuators such as stepper motors, servo motors, and fans are essential components in parcel locker systems. Stepper motors provide precise motion control for CNC arms, while servo motors control locker doors. Fans are used for temperature regulation.

Microcontroller Integration

Arduino boards are widely used for integrating hardware components. They control motors, read sensors, and manage communication between different modules, ensuring smooth system operation.

Communication and IoT

Communication modules like GSM (SIM800L) and ESP systems allow for secure authentication. IoT integration provides advanced functionality such as remote monitoring and automated alerts.

Conclusion

From existing studies, it is clear that a reliable parcel locker system requires the integration of sensors, actuators, microcontrollers, and communication technologies. Our project builds upon these concepts and adds a CNC robotic mechanism for parcel distribution.

Methodology

Overview

The methodology of this project focuses on designing and implementing a smart automated parcel storage and receiving system. The system integrates mechanical, electronic, and software components to achieve efficient operation. The design combines a CNC robotic mechanism, lockers with servo-controlled doors, and a user authentication system, all coordinated by an Arduino Mega.

Mechanical Components

- V-Slot CNC Mechanism: Provides a stable and precise motion structure for the robotic arm.

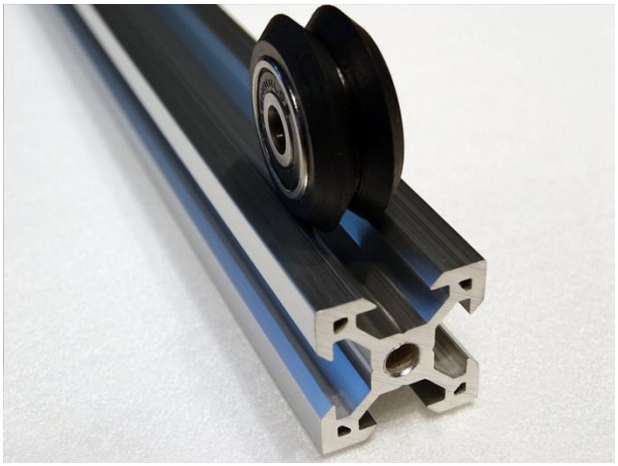

Figure 1 V-SLOT

- Stepper Motors: NEMA 17 motors are used for X and Z axes, while a stronger NEMA 23 motor is used for the Y axis to handle vertical loads.

Figure 2 Nema 17/23 stepper motors

- Limit Switches: Installed at the ends of each axis to ensure safe operation and prevent overtravel.

Figure 3 Limit Switch

- Lockers: Six lockers arranged in a 2x3 grid, each with a servo-controlled door for secure storage.

Figure 4 Servo Motor

Electronic Components

• Arduino Mega: Main controller for the entire system.

Figure 5 Arduino Mega

• Stepper Motor Drivers: A4988 for NEMA 17 motors and DIV268N for the NEMA 23 motor.

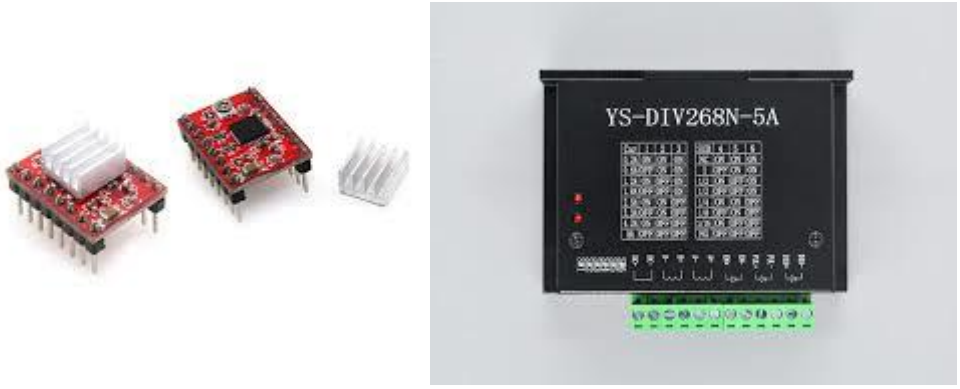

Figure 6 A4988/Div268n stepper drivers

• Keypad: Used for code entry by senders/recipients and interaction with menu.

Figure 7 Keypad

• LCD 20×4 (I2C): Provides real-time feedback and instructions.

*Figure 8 I2C 20*4 lcd*

• RFID Module: Simulates payment and provides admin override.

Figure 9 RFID

• SIM800L GSM Module: Sends SMS codes to senders and receivers.

Figure 10 SIM800L

• IR Sensors: Detect presence of parcels.

Figure 11 IR sensor

•DHT Sensor: Monitors temperature and controls cooling fan via H-bridge.

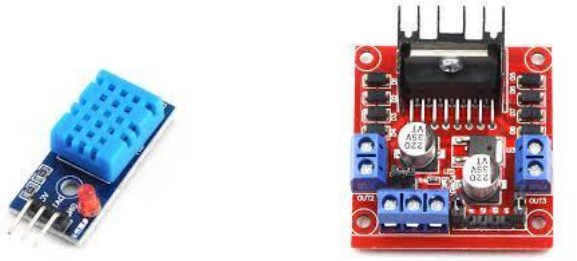

Figure 12 dht/h-bridge

• MQ2 Gas Sensor and Flame Sensor: Trigger alarms and buzzer when hazards are detected.

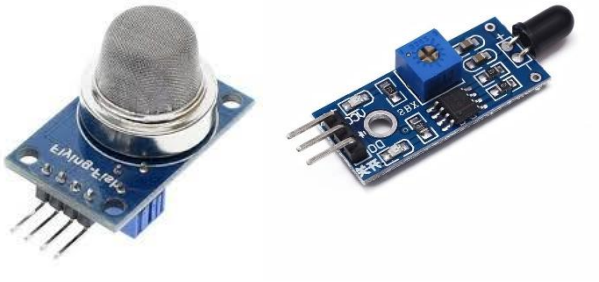

Figure 13 mq2/flame sensors

• Buzzer: Alerts users of emergency conditions.

Figure 14 Buzzer

• ESP8266 for communication with mobile application

Figure 15 ESP8266

• Power Supply: 12V base supply with DC-DC buck converter for voltage regulation.

Figure 16 Buck Converter

Software Implementation

The system software was implemented using Arduino IDE and written in C/C++ for the Arduino Mega/ESP8266. The CNC control logic manages parcel pickup and placement into lockers. The authentication system verifies codes entered by the recipient via keypad. The LCD provides interactive feedback. GSM module communication sends SMS notifications, while sensors continuously monitor system state for safety and automation.

The mobile application is written in flutter it interacts with esp8266 and its interact with Arduino mega through serial.

Assembly and System Integration

The assembly of the smart parcel locker system followed a structured process:

1. Mechanical Structure Assembly:
   - V-slot CNC frame was built with rails for X, Y, and Z motion.
   - Stepper motors were mounted with couplings and pulleys.
   - Limit switches were installed at axis endpoints.

2. Locker Integration:
   - Six lockers were arranged in a 2x3 grid.
   - Servo motors were fixed to each door for automated control.

3. Electronics Setup:
   - Arduino Mega was connected to all system components and connected with esp8266 through serial.
   - Drivers (A4988, DIV268N) connected to respective motors.
   - Keypad and LCD were mounted externally for user interaction.
   - GSM connected with Arduino mega for sending SMS to end users

4. Safety Components:
   - DHT sensor installed inside the system.
   - Fan mounted with H-bridge for cooling control.
   - MQ2 and flame sensors installed for hazard detection.
   - Buzzer connected for alarm alerts.

5. Power Management:
   - A 12V DC supply powers the system.
   - A buck converter steps down voltages for 5V and 4.3V(sim800l) components.

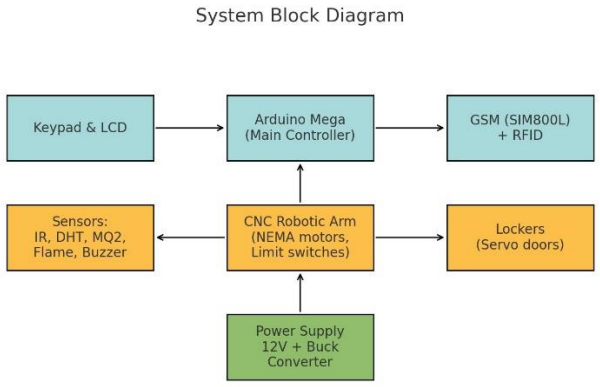

Figure 17 System Block Diagram

Results and Discussion

The smart parcel storage and receiving system was successfully built and tested. The CNC robotic arm was able to pick up parcels from the receiving point and place them into empty lockers. The keypad and LCD interface worked effectively for sender/recipient authentication. RFID functionality allowed admin access to all lockers and simulate payment, while the GSM module successfully sent SMS codes to both sender and receiver in addition to the success of mobile application to add control.

Environmental monitoring features worked as expected: when the temperature exceeded a threshold, the fan was activated automatically. Gas and flame detection triggered the buzzer alert system.

System performance tests confirmed reliable operation of all modules. The robotic end was precise in placing parcels, and locker security was maintained. Safety mechanisms enhanced system robustness.

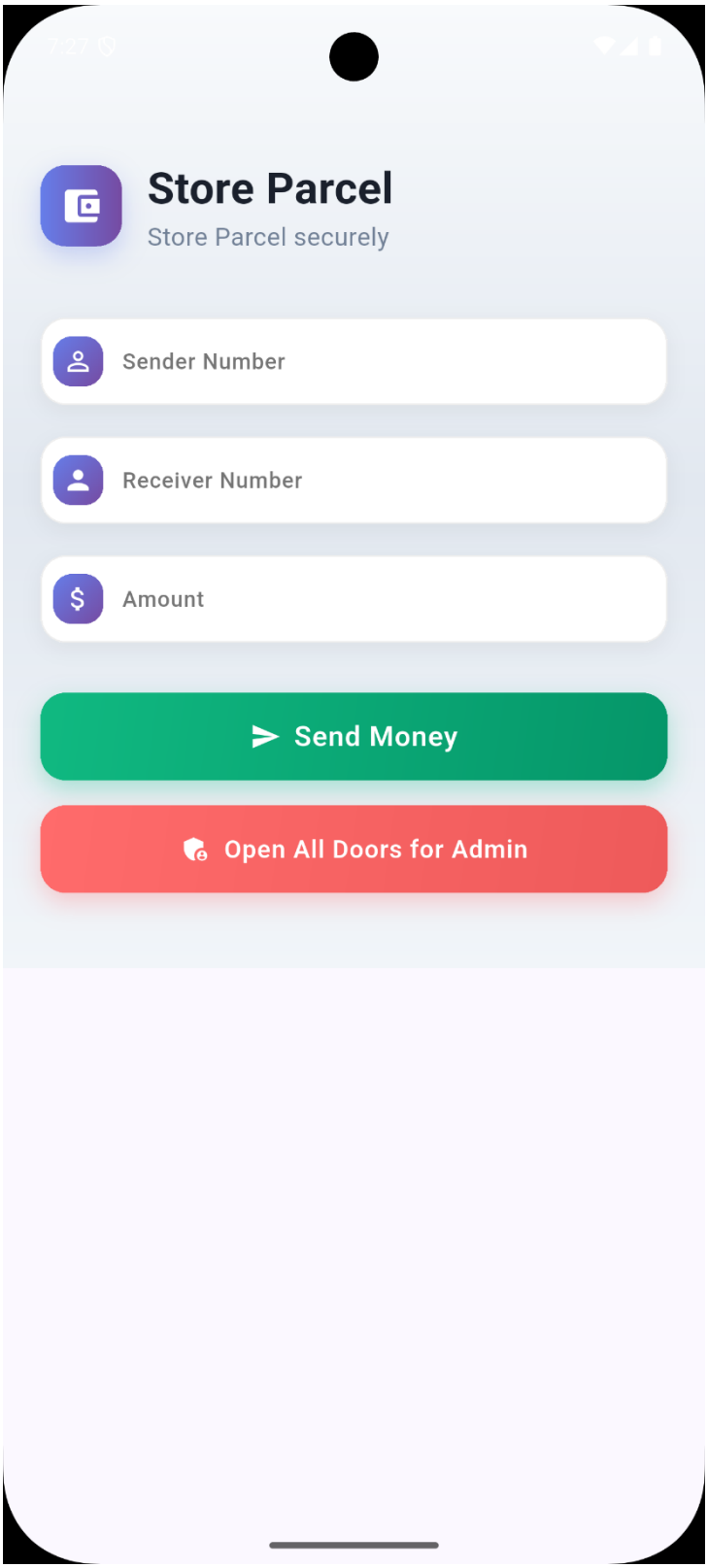

Figure 18 Mobile App

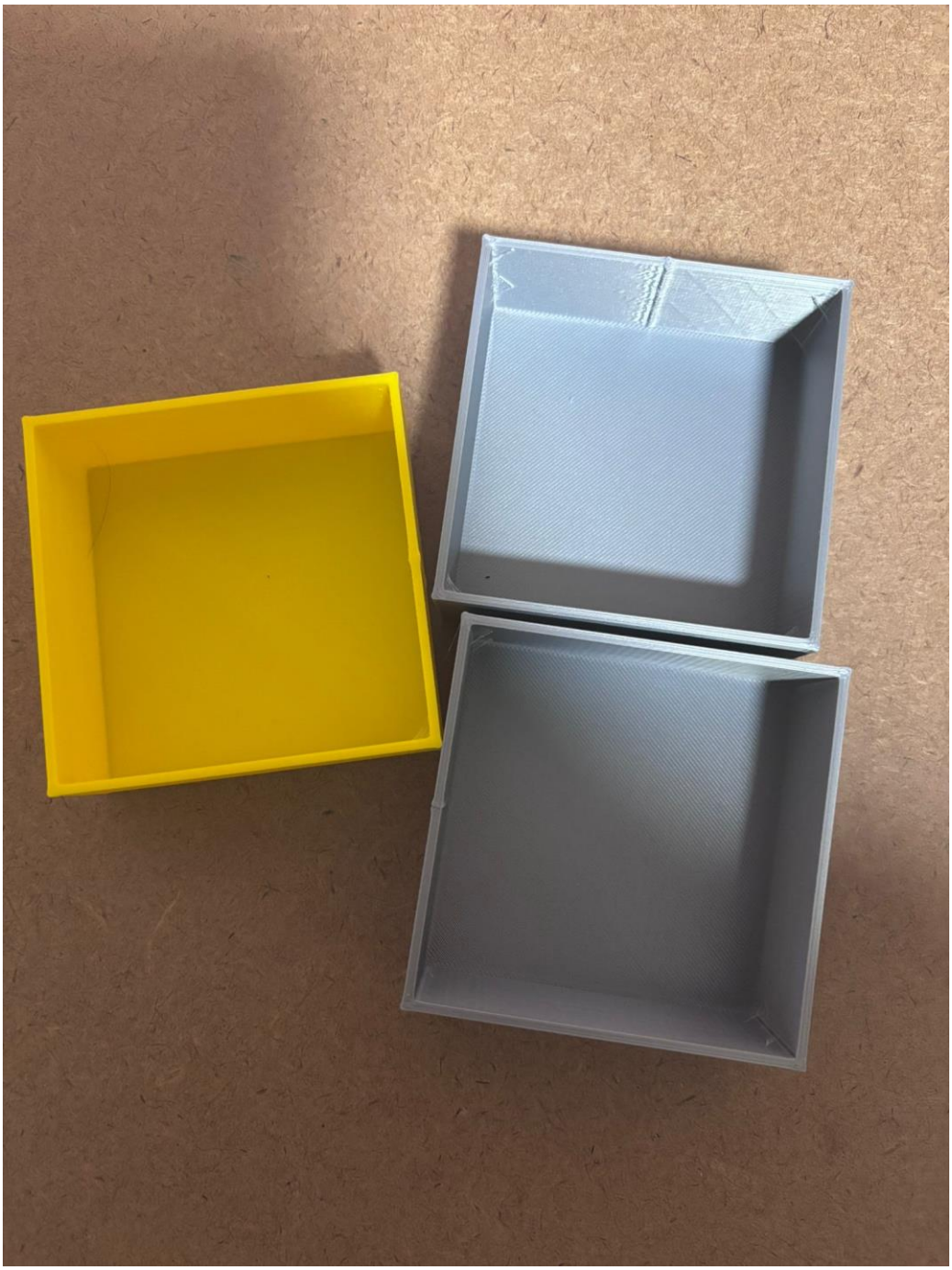

Figure 19 Parcel Containers

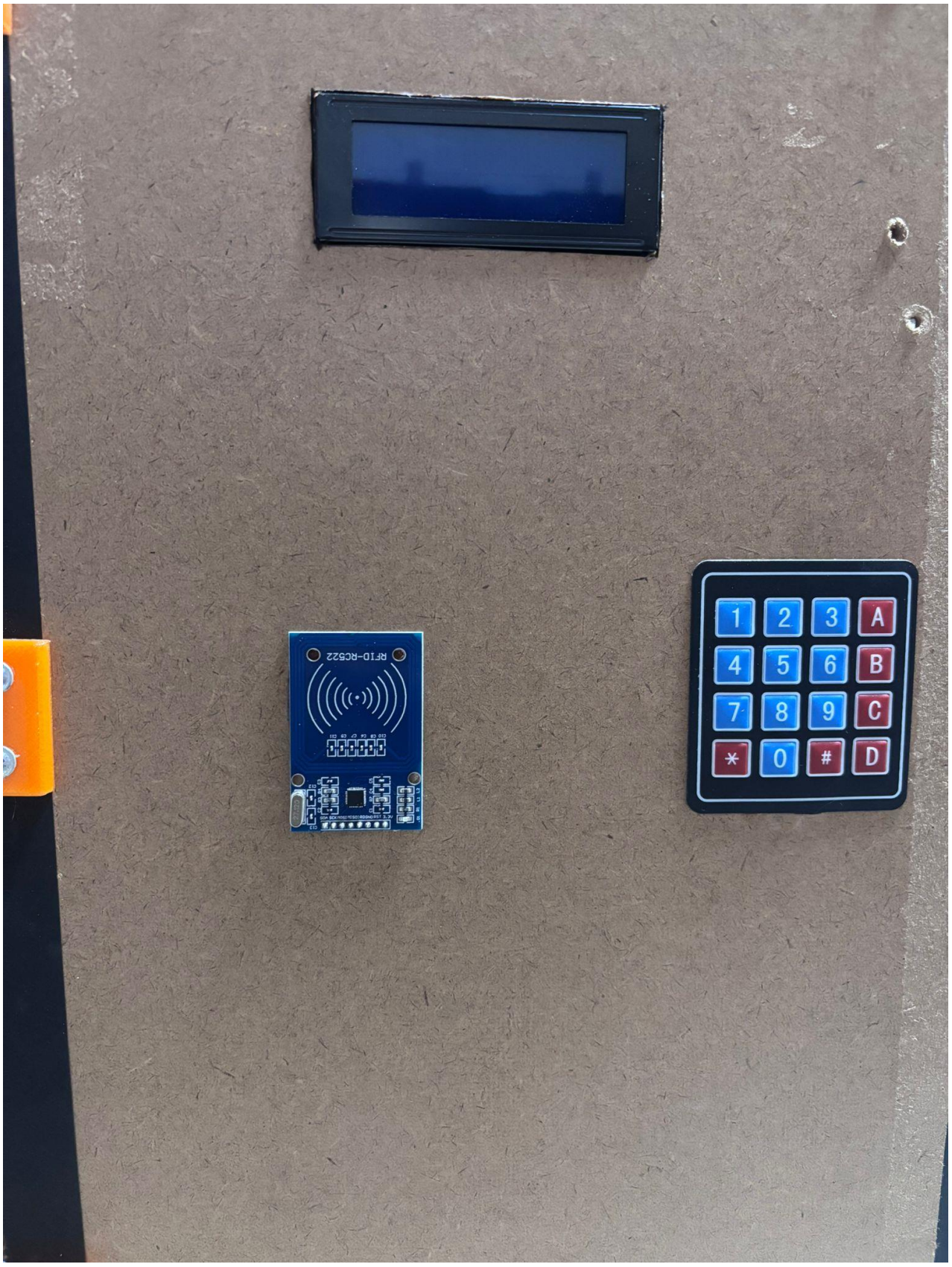

Figure 20 User Interaction Space

Figure 21 Front View

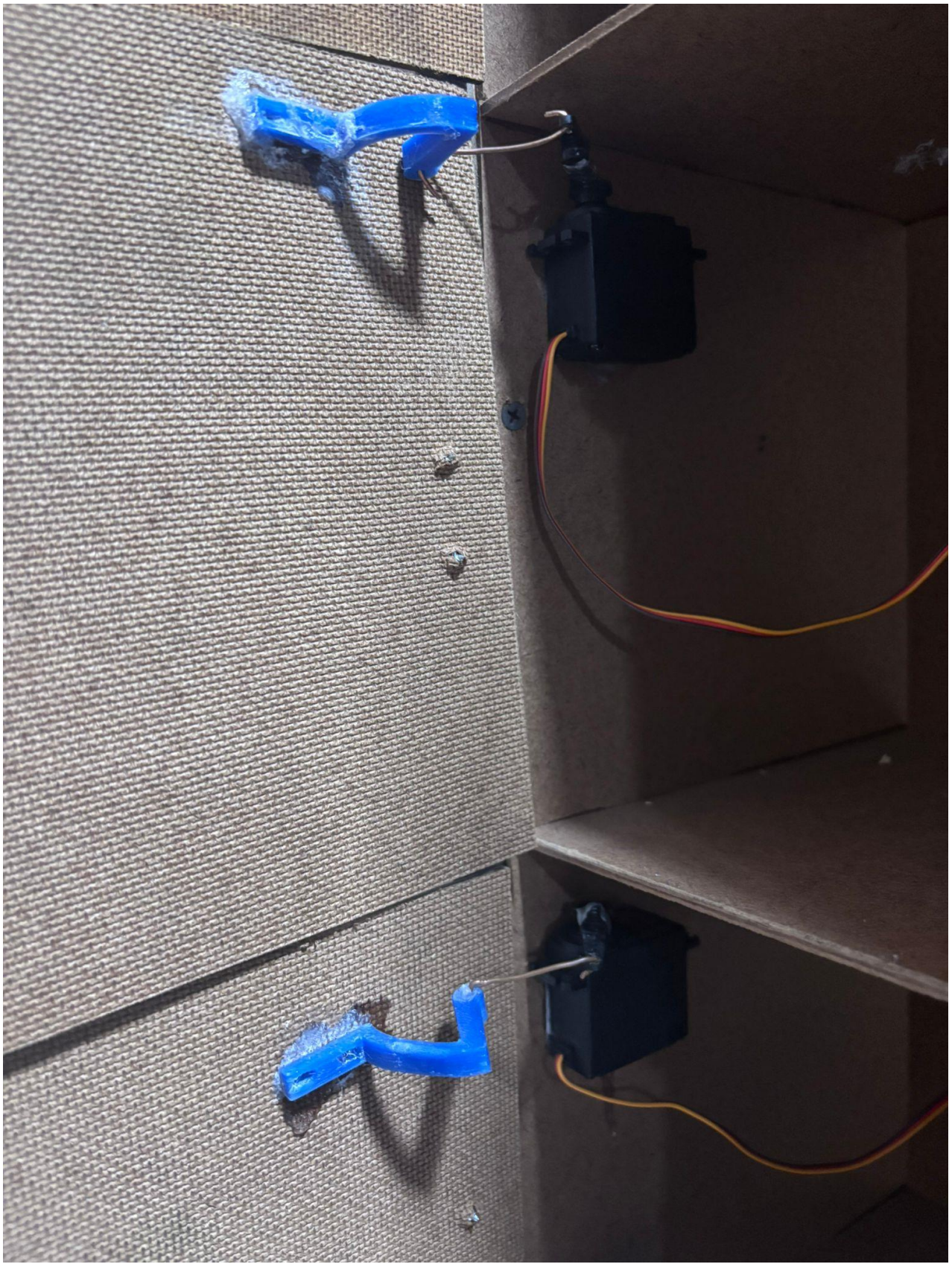

Figure 22 Doors(slots)

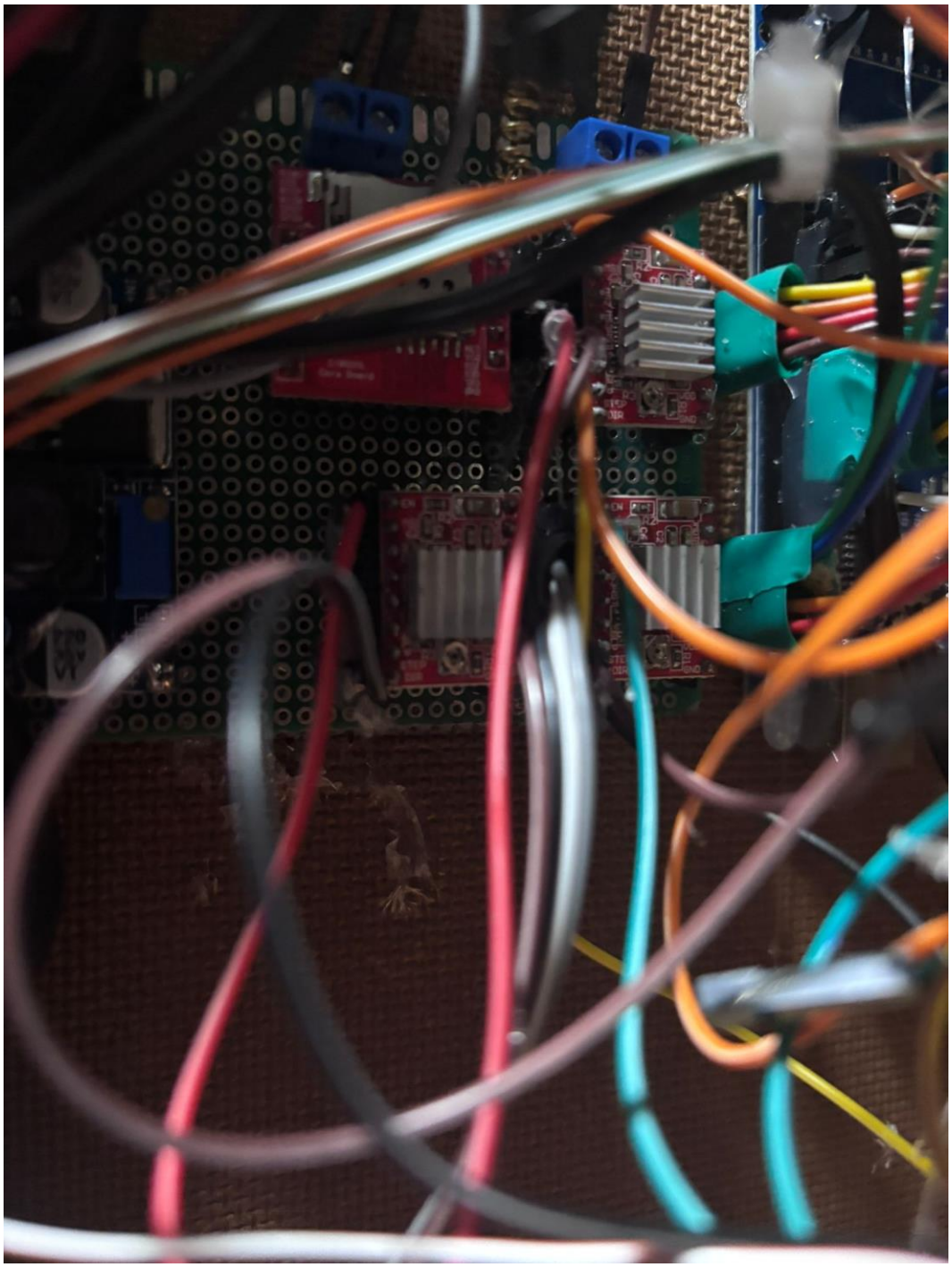

Figure 23 Circuit Board

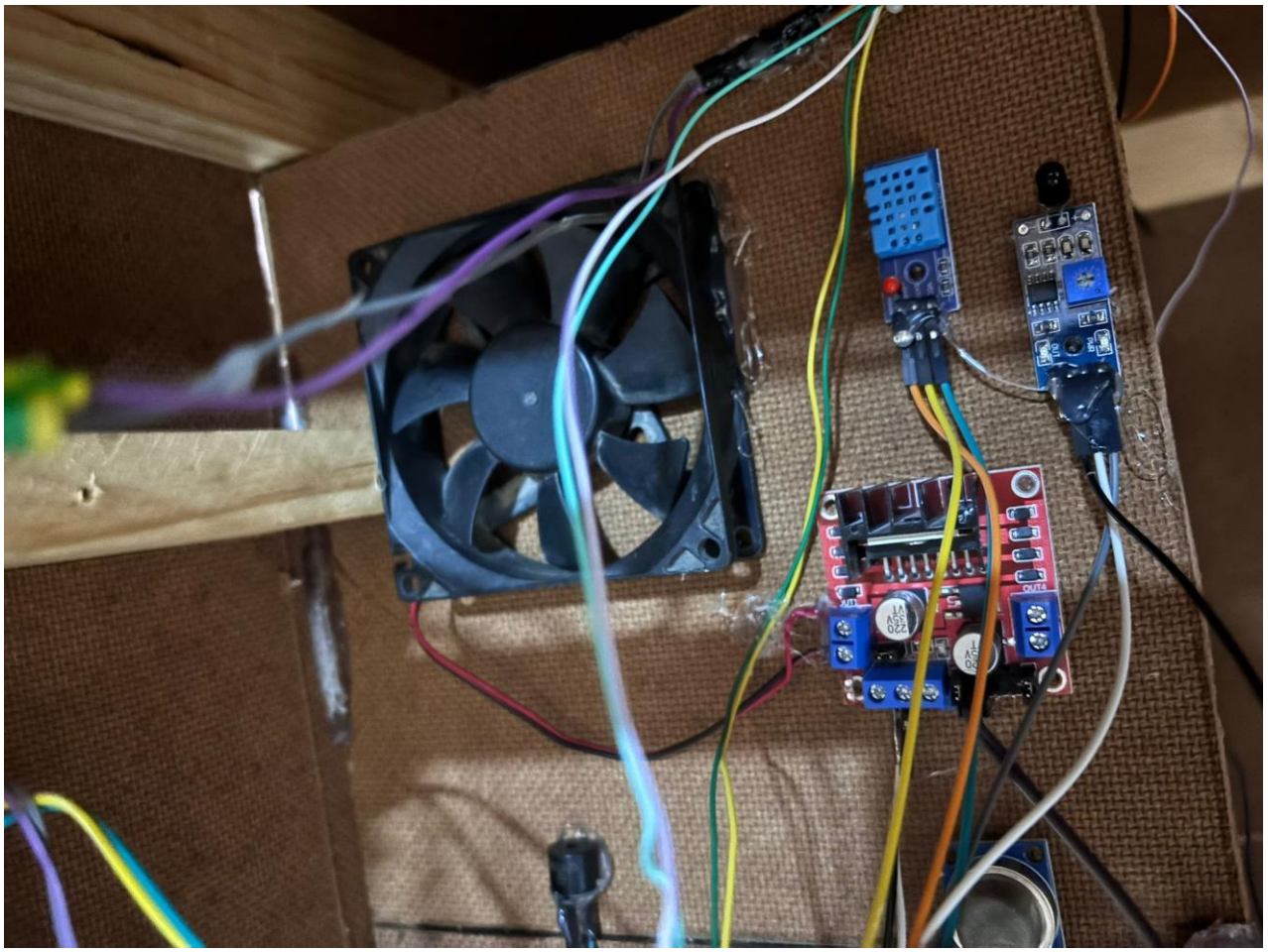

Figure 24 Sensors

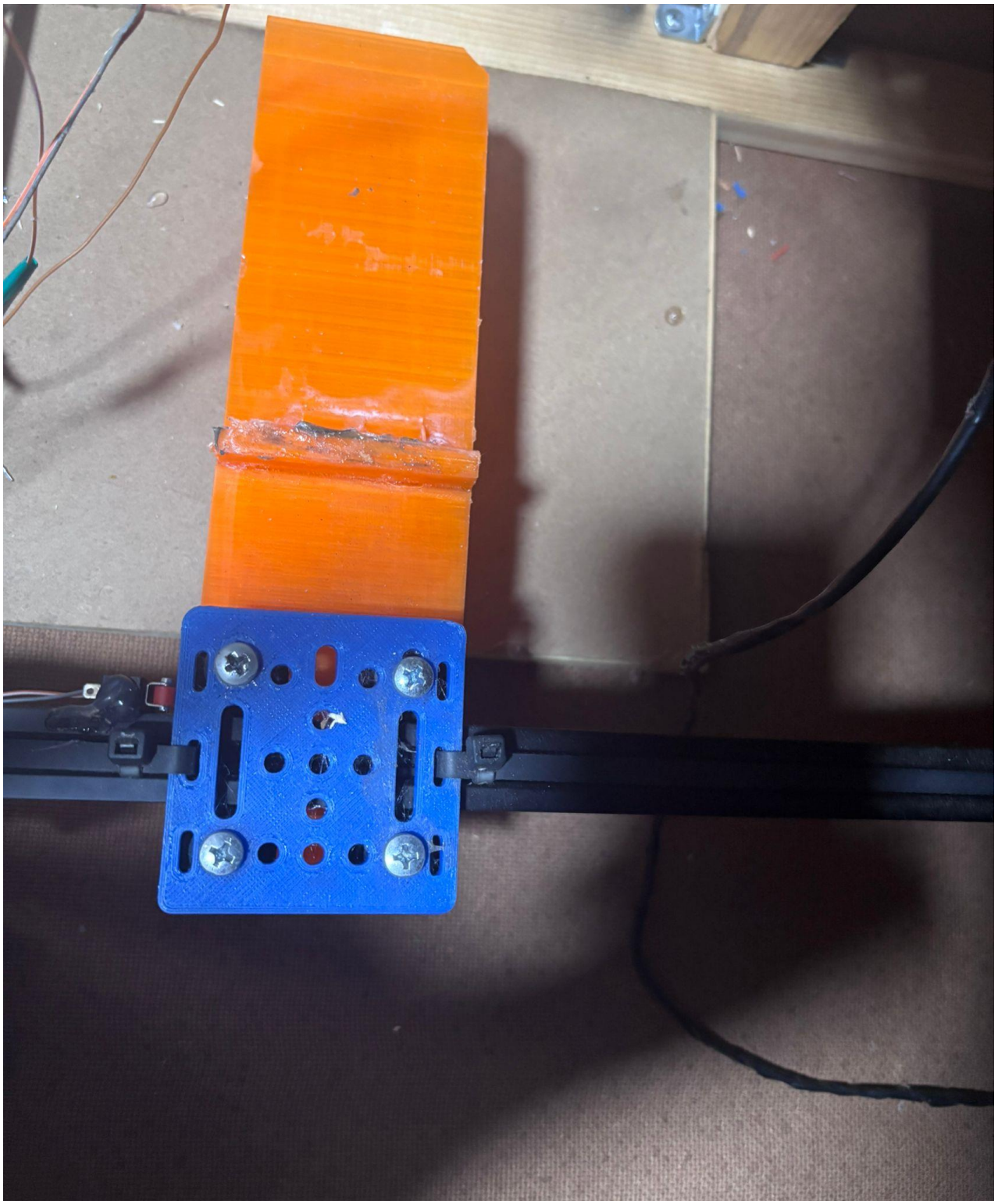

Figure 25 CNC end

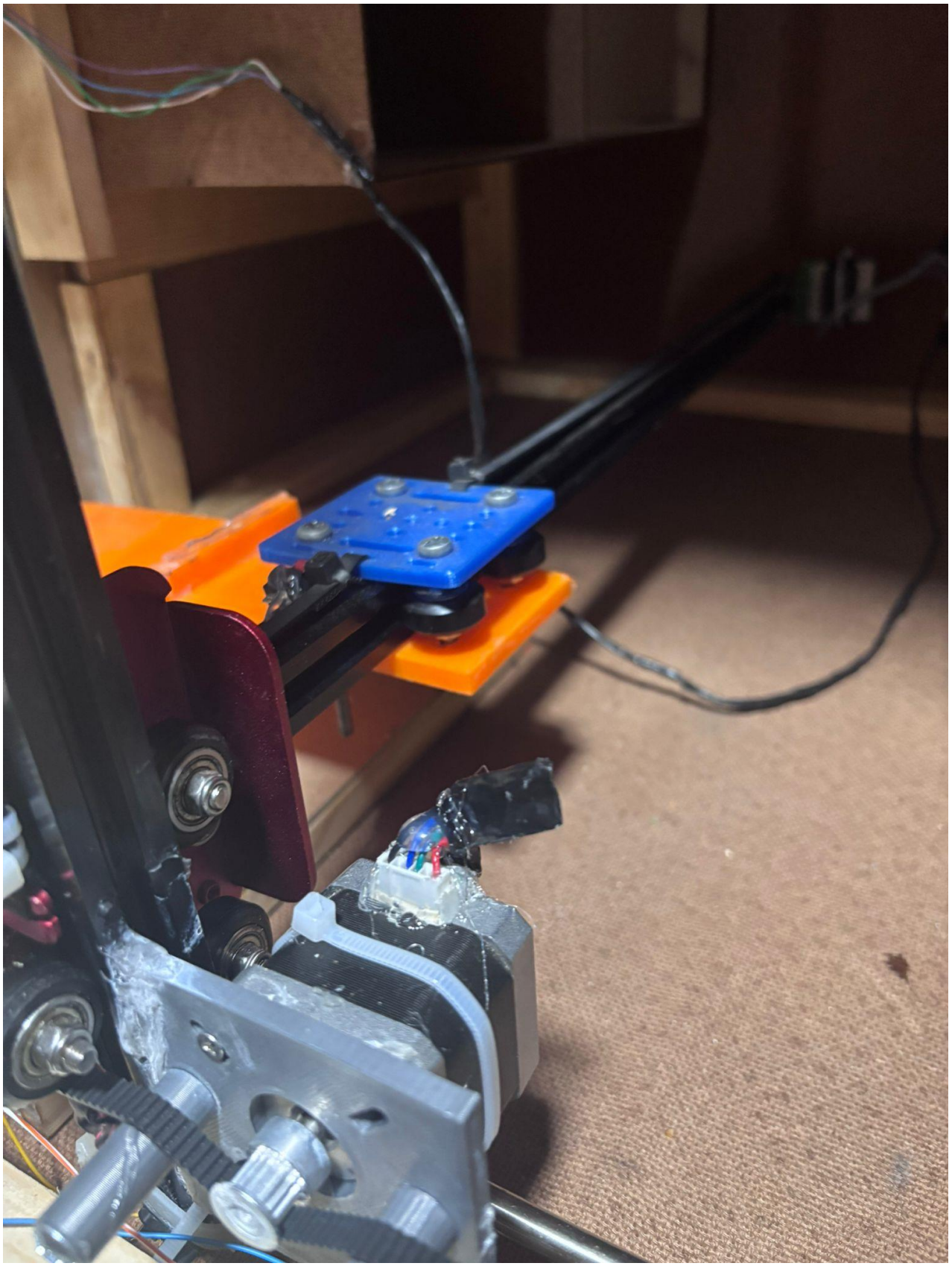

Figure 26 Z axis

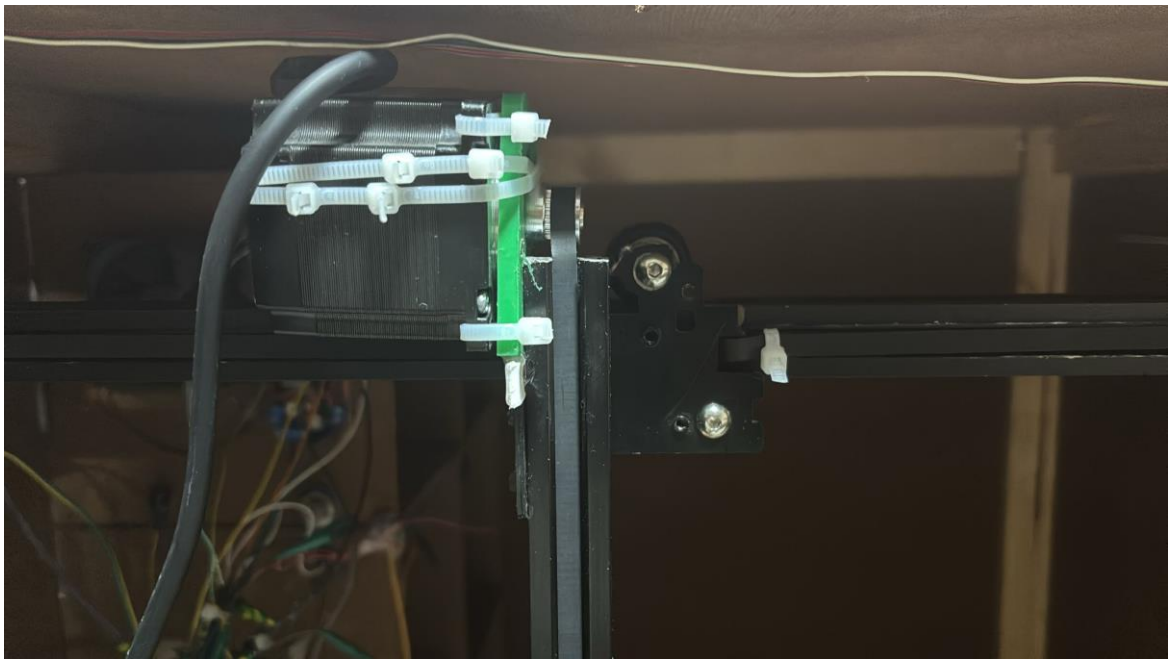

Figure 27 Y axis

Figure 28 X axis

Conclusion and Future Work

Conclusions

This project successfully implemented a smart automated parcel locker system integrating CNC robotics, secure authentication, environmental monitoring, and IoT communication. The system demonstrated improved security, efficiency, and user convenience for last-mile delivery applications.

Future Work

For future enhancements:

• Add camera-based QR code scanning for improved authentication.

• supporting more features on mobile app like showing map and show path to the nearest machine, payment using mobile app and real visa.

• Expand locker count and integrate cloud-based database for package tracking.

• Use solar panels for sustainable power supply.

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