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Automated Objects Delivery System for Interior Locale using Line Following Robot with Optimized Security Parameters

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Automated object delivery robots are increasingly sought for convenience, reliability, efficiency, supporting organizational productivity, elderly assistance, and reducing human error and labor costs in indoor delivery tasks. While various security measures have been implemented for the delivery robot's safety, the design strategies used in existing studies do not suffice as they do not use biometric technology for unlocking the robot and real-time image tracking of robot thievery via mobile app. This research-based project aims to design and develop an object delivery system within small to medium-scale buildings using a robotic prototype controlled via an Android app. The robot navigates using a line-following technique with IR sensors, avoids static obstacles with an ultrasonic sensor, verifies the receiver with a fingerprint scanner, detects the destinations using an RFID module, and captures images of illicit attempts using an ESP32 camera module sending them in the app simultaneously. The designed prototype along with the Android app has undergone several feature tests with varying conditions. The results suggest that the system can securely carry a payload weighing 20 kg and is capable of navigating 10 km with a speed of 5 m/s depending upon the battery power. This project plans to tackle significant Sustainable Development Goals (SDGs) specifically, achieve Quality Education through SDG 4, Decent Work and Economic Growth in SDG 8, and Industry, Innovation, and Infrastructure in SDG 9.

Keywords: Internet of Things, Line following robots, Hybrid Security, Indoor delivery robots, Real-time image tracking

Introduction:

Delivery robots are in high demand by learned people worldwide because of their exceptional productivity, automation, high security, durability, and affordability. These robots are used not only as elderly helpers but also to replace manual goods delivery in workplaces, restaurants, businesses, and other locations. In recent years, a variety of robots have been introduced into people's lives to assist them in various capacities, such as handling and sorting robots in factories and warehouses [1], medical robots in hospitals, service robots in hotels, food delivery robots in restaurants, for example, Savioke, Kiwibots, and many others [2].Autonomous delivery robots are already used for last-mile deliveries for many services in countries such as the United States, Japan, China, and several other European nations [3]. Because of their excellent accuracy, precision, endurance, and speed, preprogrammed robots have always been particularly successful in a variety of structured industrial applications. Amazon robot services are widely used, which include robotic pickers and autonomous mobile robots [4][5]. Robots can boost productivity at work without taking breaks or vacations while also drastically lowering operating costs. Additionally, hospitals and healthcare sectors have been transformed by robots. [6] Evaluated the use of delivery robots in hospitals and care units to supply medications and other pharmacy items in an optimal and efficient manner. [7] Designed a robotic system that uses artificial intelligence to deliver prescribed medication to patients' wards. The delivery was quick, perfect, and on schedule.

The use of automation in manufacturing businesses is increasing and gaining daily acceptance. The basic purpose of automation is to create robots or apps that can undertake repetitive, time-consuming, critical, and dangerous jobs previously managed by humans [8]. Currently, automation is more than a buzzword. It is a tried-and-true method for increasing a company's capacity without adding operational costs [9]. Restaurants now use automated robotic systems to complete jobs more quickly. Customers place orders through mobile apps, and when the food is ready for delivery, the robot delivers it from the counter to a specific table.Many corporate activities may now be automated and run without the need for human intervention or ongoing monitoring. Automation frees up team members to focus on more complex jobs, allowing the company to grow faster and more sustainably. In order to better understand the technology and equipment trends in K-12 classrooms, Philips [10] partnered with Quality Education Data Inc (QED) to survey five hundred educators and media specialists in United States public schools. The survey's most significant finding was how highly educators view multimedia projectors as essential classroom aids; in fact, participating Audio Video (AV) experts anticipate that every school will have a projector within the next five years.

IoT devices have evolved and taken many forms based on different architectural designs and functionalities since the 20th century. However, indoor delivery robots face various challenges, including payload security, obstacle avoidance, varying lighting conditions, overall security, [11] etc. Despite being efficient, classical methods are exposed to illicit actions against parcel protection since the passwords or PIN codes used in the research [12] are prone to authentication breaches. The researchers have also examined the overall robot security using Pyroelectric Infrared (PIR) sensor nodes from a ZigBee Wireless Sensor Network (WSN) [13], but it is limited to a fixed signal range of the 2.4 GHz band.

The primary problem that this project attempts to solve is that in the manual delivery of things, humans are more likely to make mistakes and increase labor costs. As a result, there is no guarantee of the safety and security of products being transported manually by humans. In addition to the previously mentioned issue [10], the lack of pre-installed multimedia projectors in many institutions has a negative impact on educational quality causing time to be lost in classrooms. As a result, we have proposed this robotic model integrated with a mobile app to help erudite people automate the task of object delivery within an indoor environment. An Android app that enables object communication between sender and recipient—such as which objects should be delivered to which location and at what time—is connected to this robotic system. An extra security feature for receiving thief images is also included in the application's design.

The remainder of the paper is organized as follows: Section I introduces the research and proposed solution; Section II discusses the literature review of related work; Section III describes the novelty of the proposed solution; Section IV contains the project's objectives along with background; Section V provides a brief description of the project's methodology and materials used; Section VI consists of the testing and results; and Section VII concludes the paper with limitations and future work.

Literature Review:

In a study by Wei Wang and Prosanta Gope [14], the authors proposed a delivery system that uses a robot based on two modules for two levels of cooperative and non-cooperative user authentication schemes. They utilized machine learning techniques, including the convolutional neural networks model, for the evaluation of voice and visual inputs, whereas the XGBoost model was used to determine valid PIN codes. Since they have implemented client-server architecture for parcel delivery, after the robot user sends the delivery request, the server directs the robot toward the desired location. The pin code received at the time of the request is validated through the voice of the requesting user upon reaching the destination location. Offline non-cooperative user authentication mode, consisting of face recognition, is entered if the authentication of repeated cooperative mode fails. Their results concluded that the lightweight Artificial Intelligence (AI) models speed up the overall calculations and as certain secure parcel delivery. Despite the usage of voice and visual biometrics, the user validation process can be improved with other intrinsic features since unclear or relatively similar voices and identical or blurred facial images can cause erroneous delivery.

The literature in the paper [15] showed the modules-based approach for the design of their delivery robot to survey, examine, and improve the delivery of essential supplies within healthcare vicinities and hospitals. These modules include hardware and software modules, respectively. The proposed robotic system is intended to follow a user-indicated white or black path, and the Arduino, serving as the main circuit board, uses Pulse Width Modulation (PWM) to regulate the speed of the robot when turning right or left, respectively. In the medical industry, this robot delivers prescriptions, patient data, drugs, and injections. Besides being a productive solution for hospitals, the proposed robotic prototype doesn't suffice the need to carry heavier payloads with necessary security. Because of its structural hiatus, the robotic model fails to take sharp turns and isunable to save the payload from illegitimate actions, which results in the reduction of its measure of efficiency.

The object delivery system proposed in the paper [16] makes use of the app developed using the Massachusetts Institute of Technology (MIT) App Inventor connected via Bluetooth to control various robot functionalities. The architecture of the robot is comprised of two layers with different responsibilities such that the upper part carries the load, whereas the lower part consists of all the circuitry, which involves the Arduino UNO, HC-06 Bluetooth module, L298N motor driver, infrared sensors, and direct current (DC) motors. Upon successful Bluetooth connection with the robot, the user of the application directs the robot to its desired path. Since Bluetooth connectivity has a limited operational range, the delivery bot would be in a non-functional state if it goes out of a certain connectivity area while navigating the delivery location.

The work presented in [17] elaborates on an assistive office robot for the conveyance of documents or small parcels. The system is comprised of three units, including the mobile robotic model, the computer-based workstation serving as a Representational State Transfer (REST) client, and the Android application serving as the third unit, responsible for taking user input through typed or voice commands. These units operate collaboratively using Wi-Fi. The proposed system determines the shortest delivery path using Simultaneous Localization and Mapping (SLAM) and Robotic Operating System (ROS) Indigo techniques. Despite the appreciable features, the payload security is overlooked as the design did not present any such technique to ensure reliable parcel delivery.

The authors of the paper [18] have developed a robotic prototype that aids the needs of warehouse delivery. The prototype has made use of an (LSA08) Advanced Line Following Sensor along with an MDDS10 motor driver to detect the navigation path. The Grove Inter-Integrated Circuit (I2C) color sensor aims to detect three different colored backgrounds highlighting different work zones. The system is programmed to speed up or slow down based on the detected color mapped with the specific work zone. The color sensor used in the designed prototype can cause errors in the varying lighting conditions in different work zones. Apart from this, the calibration of circuit components could be more aligned to foster the carriage capacity and overall security of warehouse objects.

In the research[19], the authors have demonstrated the instigation of a medicine delivery robot operational for hospital wards to avoid contact with patients suffering from tuberculosis or COVID-19. This objective has been attained by effectuating the Robotic Mobile Delivery System (RMDS) using the Firebird V robot. The designed prototype navigates through the hospital ward using IR sensors, whereas the motion of the robot is achieved by the white line sensors. The AVR Studio is used to develop a specific program for indicating and updating the delivery status that is later displayed on the LCD (Liquid Crystal Display) screen and also to find the nearest exit spot after the completion of delivery. Despite being contactless, the prototype in this study doesn't emphasize any security measures for the medicines being transferred. Additionally, the system is confined to fixed delivery destinations, assuming there exist minimal to zero hindrances, which is an impractical approach.

Cheng-Yan Siao, Jhe-Wei Lin, and Rong-Guey Chang [20] have analyzed the development and operation of the delivery robot in the catering industry. The proposed system is comprised of laser sensors and a robotic arm to draw the navigation map, along with two path planning techniques, including global planning and regional planning, respectively. The system uses the Dynamic Window Approach (DWA) to re-evaluate the path after facing the obstacles. Furthermore, the accuracy in the mapping of the robot's path is achieved using the G mapping and the A* algorithm. Additionally, computer vision techniques are used to determine the desired destination table. Though the system is sufficiently reliable, it can be improved by including a security element that ensures the order is delivered to the right table when it is received at the delivery location.

The literature in the paper [21][22][23][24] has suggested the wheeled robotic system based on IoT and the line-following technique for delivering food items in restaurants. This proposed system involves the designed smartphone app for placing orders and for human-robot communication along with thinger.io, a software platform for reading and writing data to the sensors. The system's hardware design includes the Arduino Uno, which controls the whole system. The NodeMCU is used to transmit and receive orders to the robot wirelessly. An LCD mounted on the upper portion displays the order data; also, an RFID reader is affixed to the robot's body to check for and deliver the order to the targeted table. The IR sensors are fitted to let the robot detect the lined path. The developed system is suitable for small-scale indoor areas. However, keeping the security factors in mind, the extensions in the robotic model would result in safer and more reliable food delivery.

Elena Rubies, Ricard Bitriá, and Jordi Palacín[25], [26] describe the robust office automation solution for package deliveries. This system requires manual loading and automated unloading of parcels by using the Simultaneous Location and Mapping (SLAM) based on the Iterative Closest Point (ICP) algorithm along with the Senz3D RGB-D cameras for observation of the surroundings. The passive infrared (PIR) sensors are mounted on the hardware to detect human interaction. The combined functionalities of these peripherals presented the delivery system that was observed to transfer various office-based goods efficiently. Although the proposed model has shown remarkable success in package transferring capability, the research did not elaborate on any parcel protection strategy. Implementing the system with a sophisticated security feature will allow the discussed prototype to deliver exceptional results.

Most of the systems mentioned above either make use of passwords, or visual or voice input for securing the payload; however, these methods are vulnerable to cyber attacks, including brute force attacks, deepfake generation, and voice cloning for replicating the tone and speech patterns respectively. Additionally, the physical deterioration of the system is not tracked within reach. This may drive unsuccessful or faulty deliveries, which ultimately result in the wastage of resources. Therefore, this research focuses on the combined security of the payload and the robot using Fingerprint authentication and suspect identification through real-time camera imaging, hence obtaining a reliable delivery system.

Novelty Statement:

This study presents a hybrid security approach that combines fingerprint identification for verification of the user receiving the payload along with camera imaging that captures the unauthorized actions against the indoor delivery robot itself. Unlike already existing prototypes that operate on vulnerable intrinsic traits, our research strategy significantly ensures overall robot security to achieve delivery optimization.

Sustainable Development Goals (SDGs):

This research project is associated with the following SDGs:

- SDG 4: Quality Education
- SDG 8: Decent Work and Economic Growth
- SDG 9: Industry, Innovation, and Infrastructure

Background and Objectives:

The exponential growth of IoT has allowed autonomous devices to transport goods within indoor settings effectively. Thus, adding the power of these sensors, the specific objectives of the proposed research are described as under:

1. To design a robotic prototype to transport regularly used objects within indoor areas in a secure, cost-effective, and labor-saving manner.
2. To develop an Android mobile application that integrates with the prototype's hardware to program the delivery locations and to retrieve the theft images.
3. Analysis and comparison of the newly designed robotic model with already existing delivery robots.

The suggested solution will be modular and reconfigurable; therefore, it will be applicable to different fields and applications, while it will emphasize the needs of the educational institutions. The developed robotic prototype will be appraised at the university named Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan.

Materials and Methods:

This section focuses on the development and integration of both hardware and software components, ensuring flawless communication and efficient functioning of the object delivery robot.

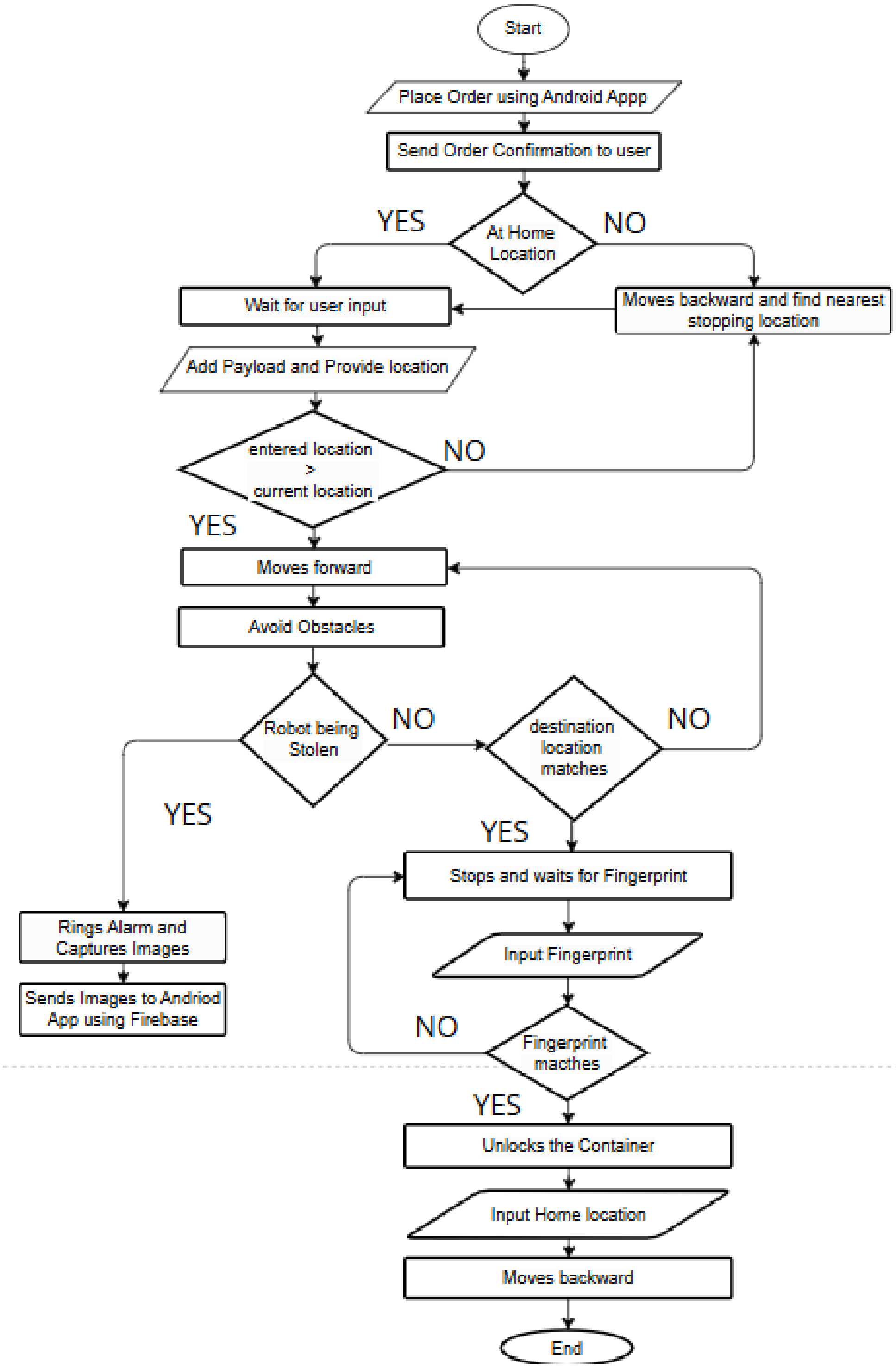

Figure 1. Flowchart for Working onthe Whole Project

The project's overall working flow is shown in Figure 1, emphasizing the synchronization between hardware and software to provide secure and efficient payload delivery.This part is further divided into two sections, which include hardware analysis and software analysis. The first section provides a detailed examination of the hardware design, communication protocols, and the robot's operational algorithm. The software analysis contains the description of the software, dependencies, and various services used, along with the Android application's execution flow.

Fabrication of Hardware:

At the initial stage of project setup, a metallic robotic base or chassis has been designed. A glass sheet has been placed on top of the frame base to support and mount the electronic circuit components over it, four windshield wiper motors have been fixed with four trolley wheels, and a wooden bar-shaped piece has been attached to the front and back sides of the chassis to calibrate the infrared sensors, respectively.The IR sensor is a type of electronic component that emits or detects IR radiation to identify specific features in its environment. These sensors can also be used to detect or measure the heat of a target and its motion. The purpose of using these sensors is to detect the black line that the robot follows for navigation as these are very precise for surface detection and capable of following lines, making them ideally suited to navigate the robot along predefined paths. Their compact size and cost-effectiveness further supported this decision. To make it easier to understand how to set up the components of an electronic circuit on a glass sheet, the sheet has been divided into three distinct areas hypothetically: left, center, and right. Observing from the rear side, the two 12V, 7 AH batteries have been placed on the initial portion of the left and right sections, followed by one ESP32 microcontroller attached with an LM2596 Buck Convertor or DC-DC voltage regulator on each section.

Two 2-channel relay modules have been placed, one in each section to operate the camera module and solenoid lock along with the electronic buzzer, respectively. Terminal block strip connectors, a perf board with two terminal block connectors, and two 3300 μF 35V capacitors make up the first center part (the space between two batteries). These are followed by a number of additional terminal block strip connectors that act as a link between the batteries and a subsequent 4-45 channel relay module. Another perf board with two 3-pin terminal block connectors, two 1000 μF 16V capacitors, and two 2-terminal block connectors is located in the very front of the middle area. The six infrared sensors are located on both the front and the back of the two bar-shaped wooden parts that are fastened to the chassis, with three sensors on each side. The RFID module has also been attached to the front wooden bar facing the ground to detect and read the RFID tags.

The delivery box, which serves as the container for objects to be transferred, has been situated above the chassis. This box carries with it some of the most essential components of this project. These components include the HC-SR04 ultrasonic sensors at the top front and top rear parts of the box. These sensors are very effective in detecting obstacles by measuring distances when sound waves are emitted and reflected back. In addition to this, three other components, which are an R307 optical fingerprint sensor, an I2C LCD, and a 3x4 keypad module, have been mounted on the right side of the box, whereas the ESP32 Cam module has been placed on the upper part of the box that is the cover to it. The solenoid lock has also been attached to the box cover but from its inner side for the purpose of payload security.These specific sensors were selected over alternatives for their proven efficiency, reliability, and compatibility with the system's operational needs. To assemble and execute the code for hardware, Arduino IDE has been used, and for the software part, Android Studio is used.In order to observe and analyze the complex circuit through its clear and visually appealing representation, the Fritzing software was used to design the breadboard circuit diagram of the connections of the entire circuit as shown in Figure 2. This circuit includes all of the components and peripherals connected with various pins of both microcontrollers.

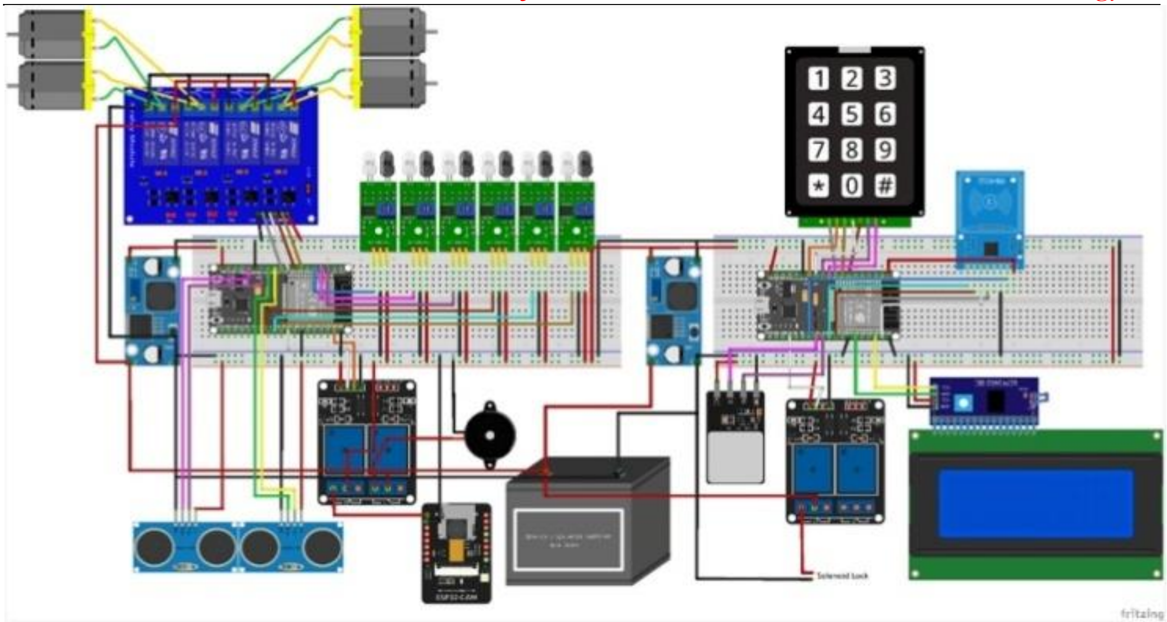

Figure 2. Complete Circuit Diagram of the Project

Communication Protocols for Components:

- Wi-Fi Protocol is used to make communication in-between the Android application and the proposed robotic model, where Firebase is the connecting point.
- ESP-NOW is a connectionless protocol for communication that supports the transfer of small data packets. This protocol serves as the communication medium between the two ESP32 microcontrollers in this project.
- UART is a widely used communication protocol to transmit serial data with configurable. This protocol has been used in this project to transmit the input from the fingerprint sensor.
- SPI (Serial Peripheral Interface) is the synchronous protocol for data communication within the constant stream without interruptions. The RFID module in this project utilizes this protocol to communicate with the microcontroller.
- I2C is a serial communication bus interface connection protocol used by electronic devices. This protocol has been used by the Serial Interface Adapter module for connecting the I2C LCD with the microcontroller to make the connections simpler.

Algorithm for Robot's Operation:

The following steps constitute the overall working of the hardware of the automated object delivery robot. For ease of reference, specific sensors have been abbreviated as follows:

- FRS (Front Right IR Sensor)
- FCS (Front Center Sensor)
- FLS (Front Left Sensor)
- RRS (Rear Right Sensor)
- RCS (Rear Center Sensor)
- RLS (Rear Left Sensor)

Algorithm Steps:

1 Start

2 Check whether it is placed in the home location or between two locations (lc = 0 OR lc = 100).

- If at the home location, then proceed from Step 03.
- If between two locations, then the robot moves backward to find the nearest location.

3 Waits for input provision after the admin fills the carriage container with the desired object to be transferred.

4 With lc >lcentered as True, checks the direction variable dir.

- If it is SS (stop), then the robot stops with all IR sensors set to '0.'
- If it is UU (forward), then:
  - Activates front ultrasonic sensor
  - Checks IR sensor reading:
    - If FLS = 0, FCS = 1, FRS = 0 → forward motion
    - If FLS = 1, FCS = 0, FRS = 0 → leftward motion
    - If FLS = 0, FCS = 0, FRS = 1 → rightward motion

5 Checks and compares Ultrasonic sensor distance from the hindrances in the path. If the distance of the sensor is equal to or greater than 50 cm. (distancef>= distancethresh) move to the next step; otherwise, go to Step 07.

6 The robot stops having (FLS = 0, FCS = 0, FRS = 0) [condition valid only for this instance] and rings an alarm (hornstat = True); otherwise, it continues moving until it reaches the destination.

7 Checks if FCS, FRS, FLS, RCS, RPS, and RLS are '0' along with camerastat = True, sends images to Firebase, and repeats Step 06.

8 With (lc = centered) True, the robot stops and waits for the user's biometric input to unlock the container.

9 After the object is received when a user enters the '0' location, it moves backward with (dir = RR).

- Activates back ultrasonic sensor
- Checks IR sensor reading
  - If RLS = 1, RCS = 0, RRS = 0 → rightward motion
  - If RLS = 0, RCS = 0, RRS = 1 → leftward motion (keeping lefts and rights according to the front side of the robot)

10 Repeat Steps 05 to 07.

11 Upon reaching the home location, it again rings up the buzzer to notify its arrival.

12 End.

The block diagram for the connection of all hardware components is shown below in Figure 3.

Software Analysis:

Figma and Android Studio:

Initially, to work on the Android application, the "Figma" website was used to design the prototype for the application. The mobile application in this project named LASABOT was developed using Android Studio Chipmunk 2021.2.1 by the IntelliJ platform. To test the Android application inside the PC (personal computer), Android Emulator has been used. Two emulators named Pixel 3A XL with API 25 and Pixel 4 XL with API 26, respectively, were used for admin and user interchangeably.

Software Dependencies:

Various dependencies have been imported into software code, which includes

Firebase Authentication, Firebase Real-time Database, Firebase Messaging, and Firebase core for Firebase-related services. Others include dependencies for card view, recycler view, and material design for the layout features of the application, respectively.

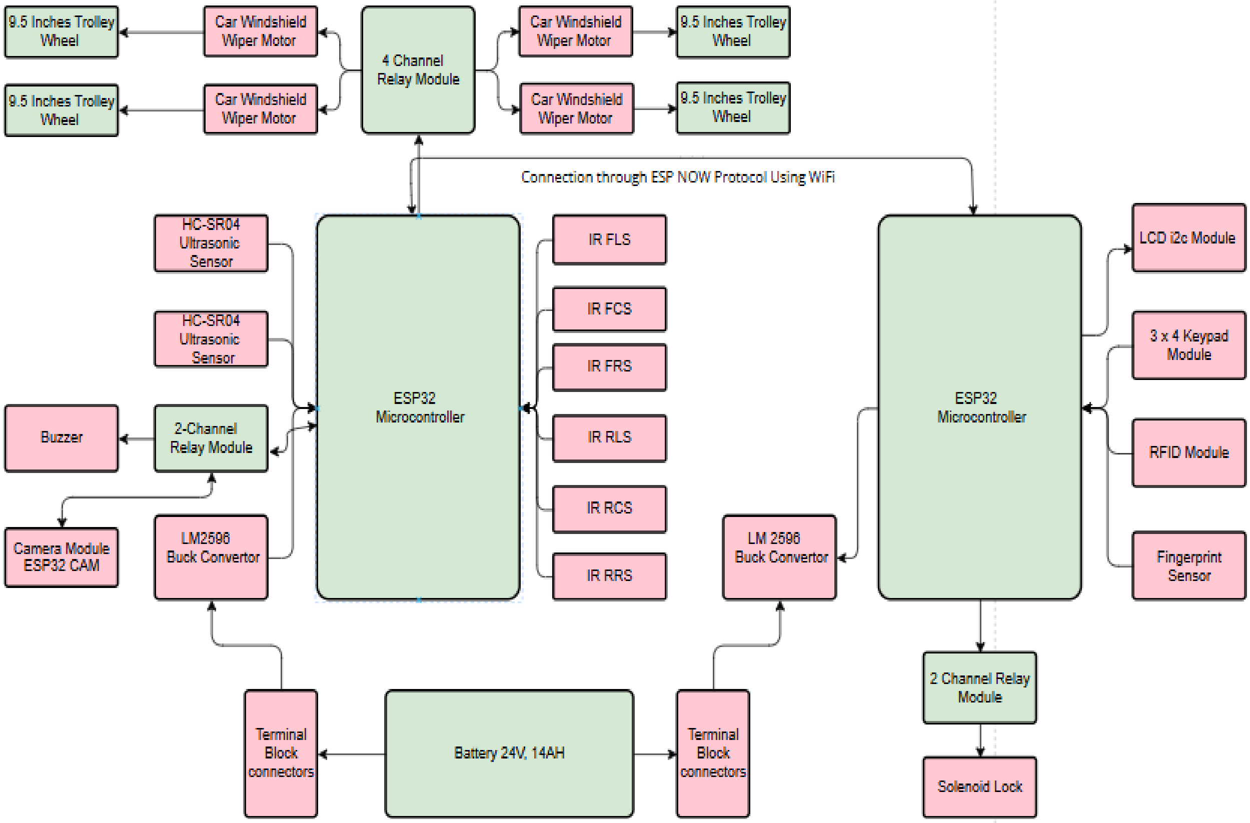

Figure 3. Block Diagram of Hardware Components

Firebase Services:

The Firebase trade-off includes Rapid Prototyping with pre-designed characteristics and efficient minimum viable products (MVP). It also provides offline support to use offline features like Cloud Firestore. Moreover, the Firebase Extension marketplace provides pre-built code modules that extend Firebase functionalities like A/B testing tools, and social authentication. Its ease of use and client-side SDKs made it an ideal choice for this project, where rapid deployment and live data syncing were key priorities Therefore in this research work Firebase serves as the backend tool for Android mobile applications. Three of the Firebase services which include Authentication, Real-time Database, and Cloud Messaging, have been used in this project.

Firebase Authentication:

This service has been used for the registration and record saving of the admins and users who are new to the application. Each time a new user or admin is registered, his/her authenticated email is displayed in Firebase's 'Authentication' section.

Firebase Real-time Database:

This service has been used for storing a variety of data, including admin/user signup data, data received after the successful placement of orders, and images of robbery.

Firebase Cloud Messaging API:

The Cloud Messaging API has been enabled for sending and receiving push notifications for notifying the order confirmation in both the admin and user panels.

Application Roles/Panels:

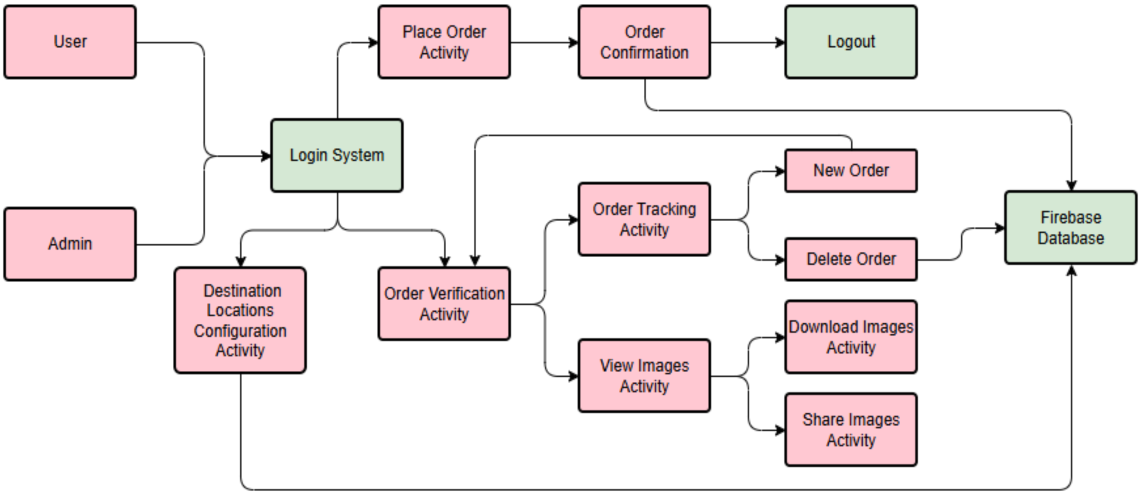

Figure 4. Block Diagram of Android Application

This application supports two primary roles: administrator and user. The only things that both roles have in common are the registration, login, and password reset procedures. Following their login, each role has access to a panel that is tailored to their particular responsibilities. Furthermore, Figure 4 depicts various roles associated with each panel.

Application Execution Flow:

Application Launch, Sign Up and Login:

Whenever the user or admin opens the app, a splash screen appears for 2 to 3 seconds, and then to use this application, the agent has to go through the process of registration. In registration, the agent is required to provide various details as shown in Figure 5. All this data is then saved in Firebase. After successful registration, the person is notified and asked to log in, where they have to enter their username and password only.

Admin Panel Workflow:

Admin has to enter credentials to log in as depicted in Figure 6. Then a new screen appears having two options for the admin; either configure destination locations or manage orders, as shown in Figure 7**Error! Reference source not found.**. Admin may choose any option from the two mentioned.

Configure Destination Locations:

For the very first time, if a person logs in as an admin he/she will have to configure destination locations. This screen is to map delivery locations. Admin will have to provide destination numbers (like 01, 02, 03, etc.) inside the location number input field and the corresponding RFID card numbers (like "33 E2 AE 15") in the RFID card number input field as depicted in Figure 8. After being inserted from the app, these mappings are saved in the Firebase Real-time Database. Upon startup, the ESP32 microcontroller retrieves these mappings from Firebase via an RFID reader and keypad module connection. The robot navigates toward the destination, scanning for the matching RFID card; after the user presses a destination number on the keypad to define the delivery location. The RFID reader verifies the accurate delivery location by continually scanning for the corresponding RFID card.

Manage orders:

However, if destination locations are already mapped, then the admin may choose to manage the orders.

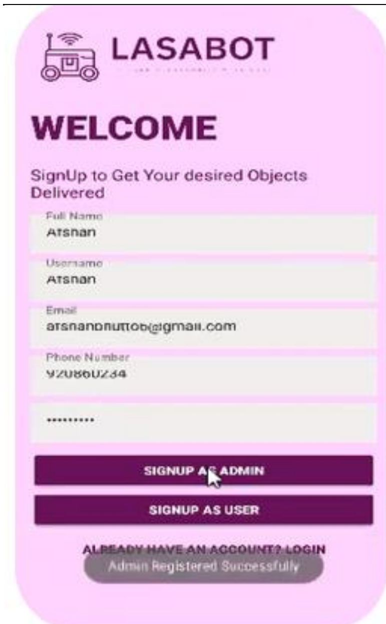

Figure 5. Registration Screen

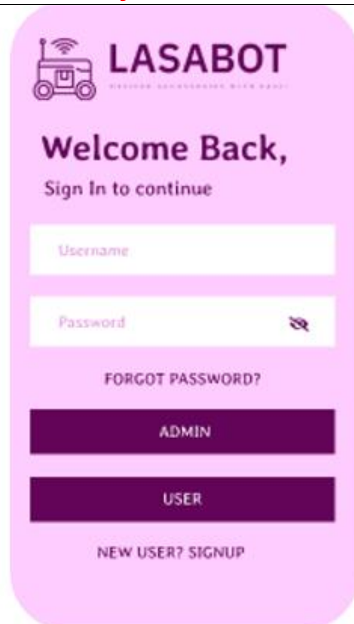

Figure 6. Sign In Screen

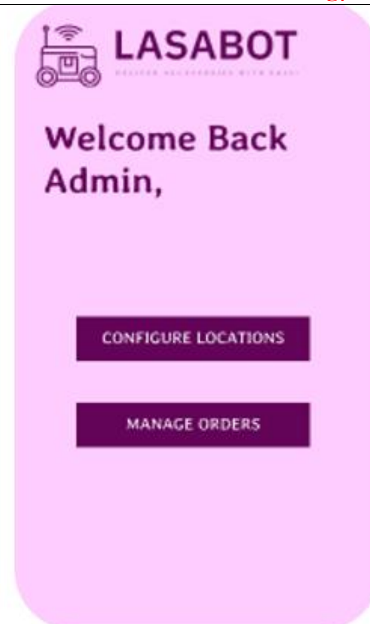

Figure 7. Admin Panel Options

Admin will interface with a screen where it has to fill two fields: the first field will require an admin to enter item details that are to be dispatched, and the second field will be about the estimated time of the delivery as shown in Figure 9. Once the order request is confirmed, the user will be notified at its end, and the admin is introduced with two options to either view the robot images or track orders as depicted in Figure 10. The admin may choose to view images that will be captured by the ESP32 CAM embedded in the robot in case of unusual behavior of the robot, like moving away from the black line that it is following or a robbery case. The images captured from the hardware side will be uploaded on Firebase; after that, these can be viewed in the application as depicted in Figure 11. Admin can download as well as share these images via the Gmail app.

Additionally, the admin can also track the scheduled orders placed in a queue, which is shown in Figure 12. The admin has the authority to proceed with those orders or delete them upon their successful completion. Whatever option the admin chooses for the order will be automatically updated on Firebase as well.

User Panel Workflow:

After successfully registering as a user, the person will have the authority to log in at their respective panel. Once the user successfully logs in, it will interact with the following screens to successfully place its order.

Order Placement:

After logging in as a user as depicted in Figure 13 to place the order for delivery, the user will have to provide some details, which will be entered using input fields. These include item name, location ID in number format, and place name as shown in Figure 14. All this data will be saved in the Firebase Real-time Database. Once an order is placed from the user panel, a notification is received at the admin panel using Firebase Cloud Messaging API (Application Programmable Interface). Afterward, the admin may choose to either proceed with that order or delete it.

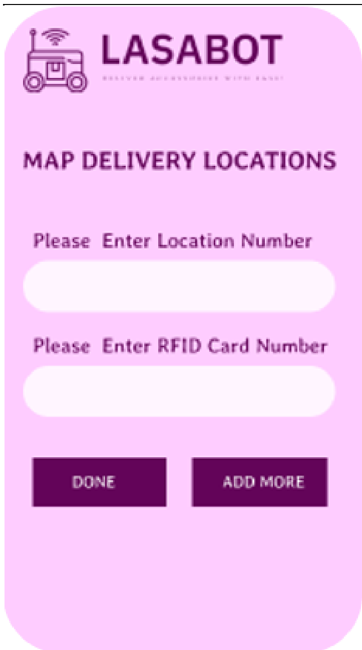

Figure 8. Configure Destination Locations

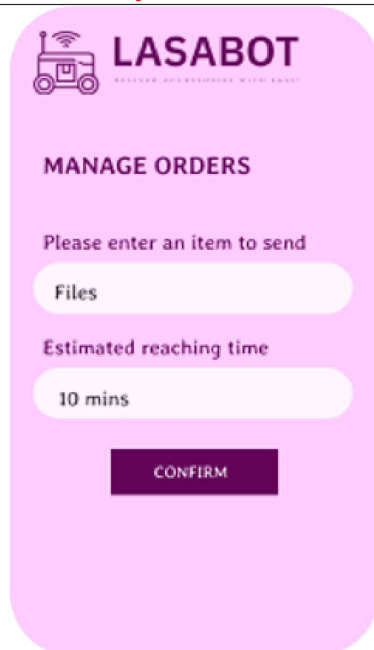

Figure 9. Managing Orders at Admin Panel

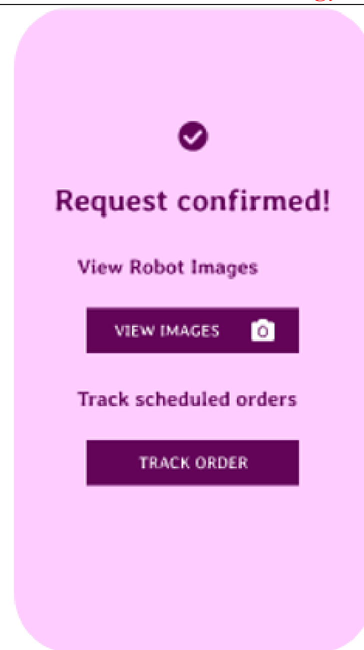

Figure 10. View Images or Track Orders

Figure 11. View Stealer Images

Figure 12. Manage Scheduled Orders

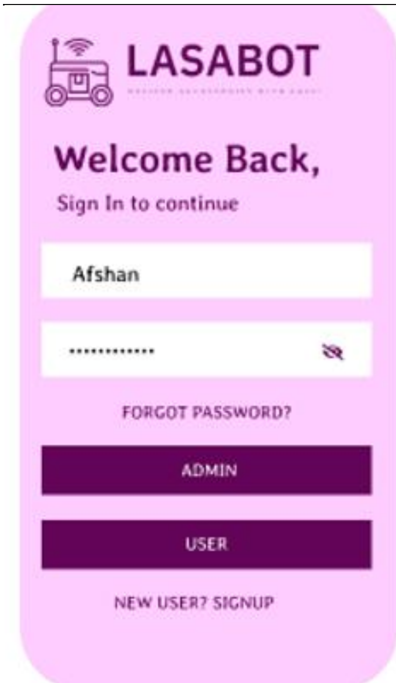

Figure 13. User Login

Figure 14. Placing Order at User Panel

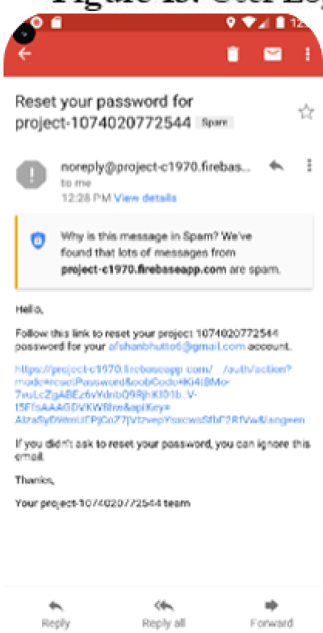

Figure 15. Password Reset Email

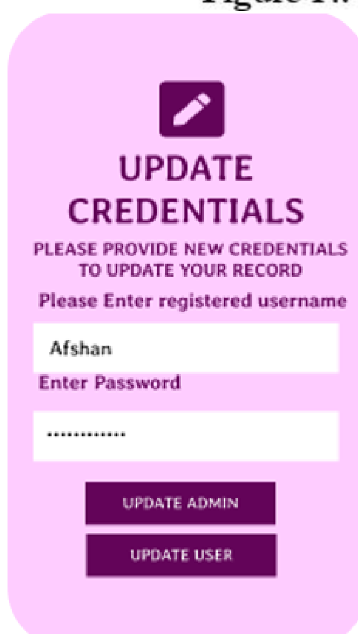

Figure 16. Update Credentials

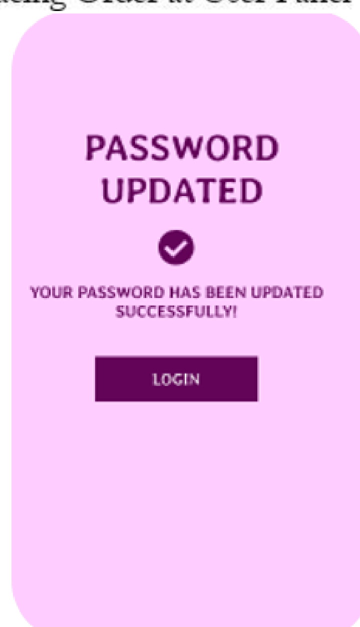

Figure 17. Password Updated

Validation of Credentials:

When a user chooses the "FORGOT PASSWORD" option on the login screen, the Forgot Password Process starts. The user will be interfaced with a new screen asking the user to input their username and registered email address, after which the user will receive a link to change their password via email as shown in Figure 15. By clicking that link, the end-user will be interfaced with a new screen to enter their new password as depicted in Figure 16.

Lastly, the end-user will click the "UPDATE ADMIN" or "UPDATE USER" button to save the modified password, depending on its function. Concluding the whole procedure, a confirmation message informs the end-user that the password reset was successful and he/she may log in with updated credentials as shown in Figure 17.

Testing and Results:

This section focuses on testing conducted for hardware and software parts. Testing is explained in the first part, followed by the results section.

Testing:

Hardware Testing:

Test for Line Following Technique:

As the proposed robotic model uses a black line to move towards the desired location, therefore initially three IR sensors were used in the middle section as shown in Figure 18, to detect the black line drawn on the ground using black tape as shown in Figure 19. After testing, it was discovered that using IR sensors in the middle section only makes it difficult for the robot to return back to its home location. After changing the sensor's configuration, the robot was unable to move in any direction.

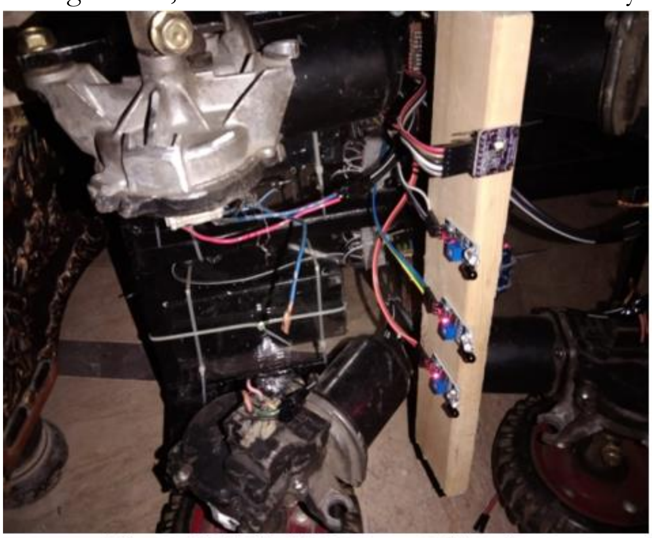

Figure 18. Initial IR Sensor Calibration

Figure 19. Robot Following Black-line on the Ground

Test for Carrying Payload:

This test was conducted to examine the robot for its payload-carrying capacity. After conducting the test, it was determined that the robotic model could carry up to 10 kg of weight. Further, it is shown in Figure 20, that items (books and bricks) of 7 kg weight were placed inside the robot to deliver at location number 03.

Test for Obstacle Avoidance:

Ultrasonic sensors were used to avoid obstacles. The robot was tested for this task, and it was discovered that it can avoid the obstacles in its path that are at a distance of 50 cm or greater and stop so as to avoid collision as shown in Figure 21. Once an obstacle is removed, the robot starts to move again.

Test for Destination Location:

Initially, the TCS34725 color sensor was used to verify the destination location. Each destination (room number)was assigned a specific location number and a color chit. The color sensor was programmed in such a way that, for example, if the entered location in the robot is 1 and the color paper chit present at that location is red with an RGB value of (255, 0, 0), the robot must verify for that color range and, if it matches, it must stop, indicating that it has arrived at the correct destination location, which is depicted in Figure 22.

Figure 20. Payload Carrying Capacity

Figure 21. Obstacle Avoidance

However, the problem with this technique was the variable intensity of light. When placed in a very bright or low-light intensity region, this was unable to detect the color chits properly. Therefore this technique was further replaced by RFID tags, which is explained later in the results section.

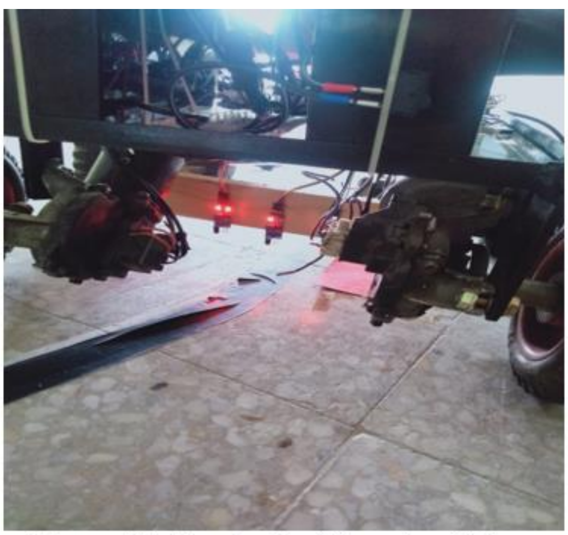

Figure 22. Destination Detection Using Color Sensor

Figure 23. Slope Climbing

Test for Receiver Verification:

A fingerprint sensor was used for this purpose. The robot's receiver is authenticated using biometric identification, allowing the cover of the objects' carrier box to be opened. However, while authenticating the fingerprints of various receivers an issue was encountered; the robot was unable to detect the fingerprints. The issue occurred due to improper hardware calibration, such as the loosening of the connecting wires.

Test for Slope Climbing:

This test was conducted to determine whether the robotic prototype is capable of sliding stairs or slopes. The prototype's wheels are incapable of sliding stairs, but it climbed the slope very smoothly. The slope dimensions on which the prototype climbing was performed are as follows:

- Height: 24 inches.
- Angle with the ground: 140-142 degrees. Figure 23 depicts the testing for slope climbing.

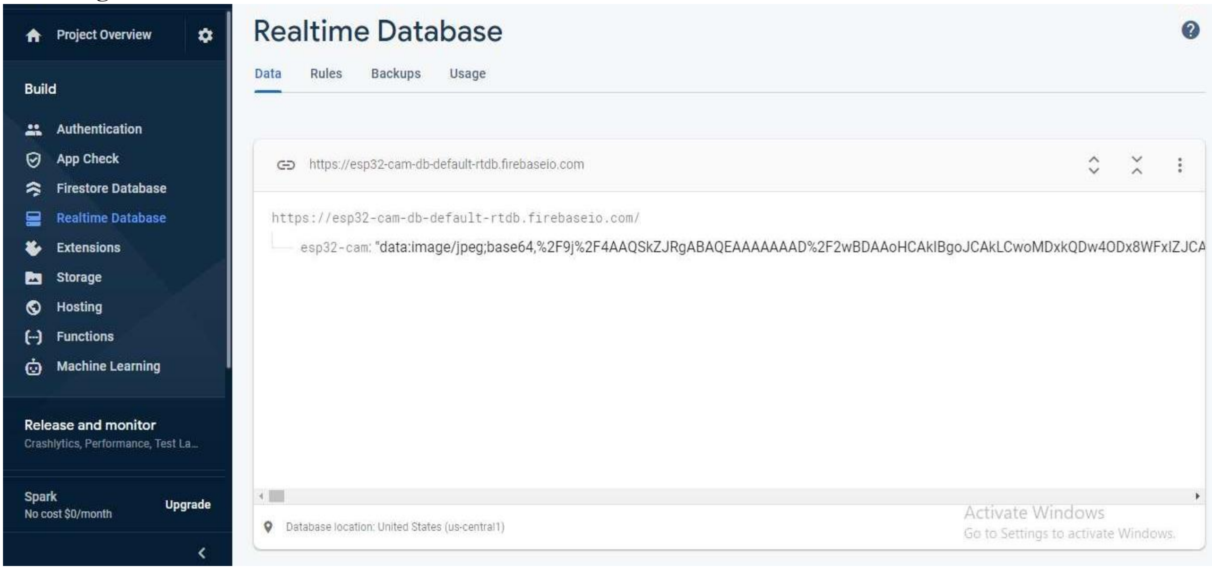

Figure 5. Storing a Single Real-time Image of Robot on Firebase

Test for Camera Module:

The ESP32 Cam Module is used so that when the robot is picked up from the black line, the alarm sounds, alerting the robbery. In addition, the camera module captures the robber's image only once, which is then uploaded to the Firebase Real-time Database as shown in Figure 5.

However, the issue here was that it is not always certain whether the robber was captured in a single image or not. The image captured by the robot only shows the surrounding area, not the actual robber. This flaw was considered and resolved later.

Software Testing:

Test for Uploading Images in Case of Robbery:

Initially, Google Drive was used to save images in case of robbery, but an unexpected issue was faced while opening the Google Drive app inside the application even though Google Drive API was properly configured from the Google Console Project. It was due to some restricted scopes that were not being validated properly. Therefore, this integration resulted in a problematic situation when viewing the images received from the camera module.

Test for Forgot Password in Application:

Initially, the OTP method was used to reset the password of the application, but it was not working properly, causing some issues. Although there was no runtime or any other error, still the device was unable to receive the OTP message. It was also checked for any emulator number errors to fix those, but it was not working properly. Therefore, it was decided to replace this functionality with another method.

Results:

Hardware Results:

In order to address the issue encountered during the line-following test, it was decided to use six IR sensors, three on the front and three on the back as shown in Figure 25. The robot was configured in such a way that it could use the front three IR sensors to detect lines for forward direction movement while the rear three IR sensors detected lines while moving backward. Following that, the robot was able to easily move to the destination as well as return to its home location once the order was delivered.

Tests for carrying payload, obstacle avoidance, and slope sliding were successful, and no issue was faced that might be resolved. The issue mentioned in the test for destination location was addressed in such a way that the color sensor was replaced with RFID tags. RFID tags with unique identities were placed at each location, such as room #01 with the number assigned '01,' room #02 with the number assigned '02,' and so on. When the robot arrives at its destination (in this case, room 3), the location is verified using the RFID tag attached to the floor depicted in Figure 26 and the LCD screen is updated as shown below in Figure 27.

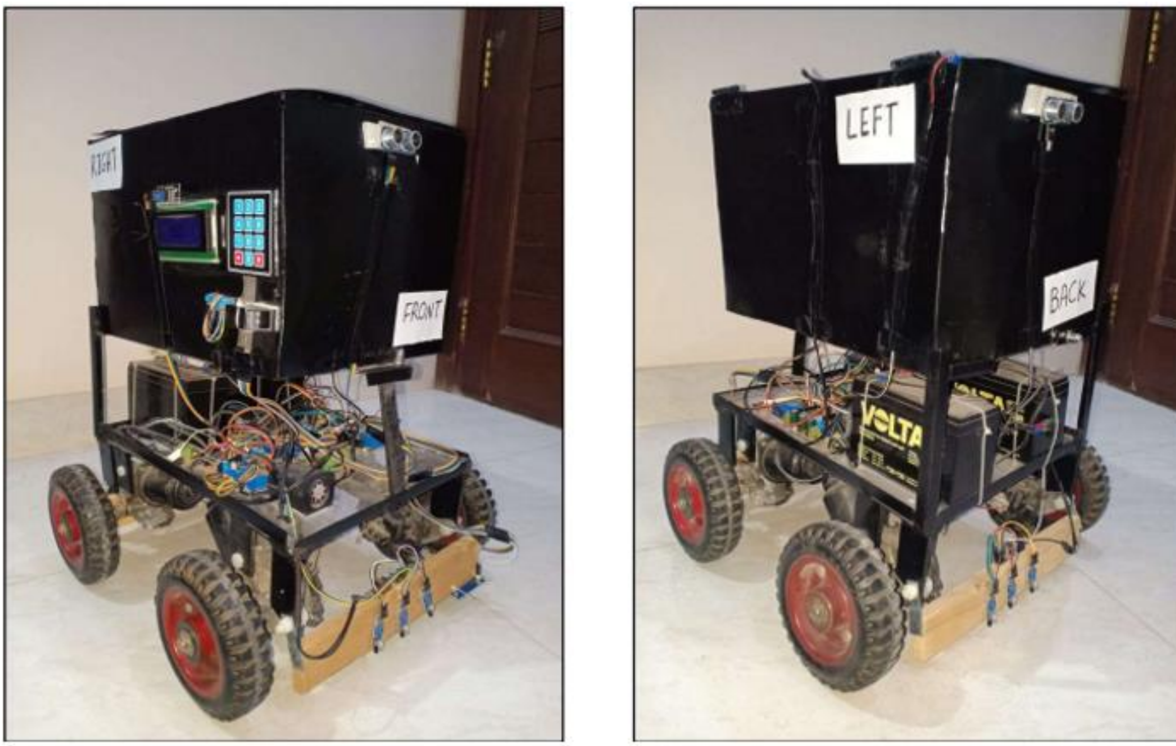

Figure 25. All Four Sides of the Robotic Model Showing Six IR sensor calibration

Figure 26. Destination Location Detection Using RFID

Figure 27. Location Updated on LCD

It was discovered that the problem with not detecting the fingerprints of the receivers was that the fingerprint sensor was not properly connected. As a result, the wired connection between the fingerprint sensor and the ESP32 microcontroller was tightened, and the sensor began to work properly and detect fingerprints as shown in Figure 28.

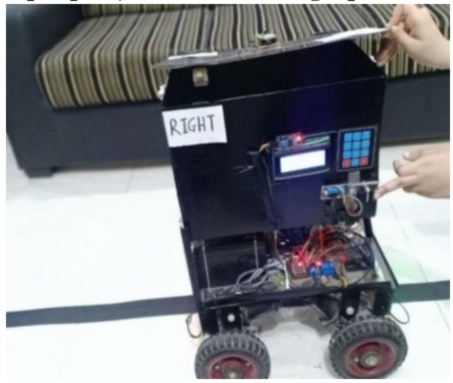

Figure 28. Unlocks on Fingerprint Verification

The issue described in the testing for the camera module was later considered and analyzed. Then the module was configured in such a way that it will take continuous images in case of stealing so that the thief is not well enough hidden from the camera, and all of those images in Base 64 format will be updated and uploaded on the Firebase Real-time database, as shown below in Figure 29. Overall, the module performed well, when it was tested under low light and rapid motion in diverse scenarios to evaluate reliability in capturing unauthorized actions.

Software Results:

After testing the robbery image upload, it was deduced that Firebase, rather than Google Drive, would be the best fit for saving the images of the robbery, as well as providing several other features that proved to be better for achieving all of the functionalities required in the Android application.

Subsequently, for the forget password functionality, the Password Reset Email method was chosen, in which a password reset link will be sent to the user's registered email address. Then the user may reset the password at their ease. Consequently, to sum up the results section, Table 1below summarizes the key specifications of the robotic model, emphasizing its reliability and suitability for secure payload delivery. The data highlights the robot's capability to operate efficiently over significant distances with a dependable battery backup and robust payload security.

Figure 29. Storing Multiple Real-time Images of Robots on Firebase

Table 1. Key Specifications of the Robotic Model

Parameters	Details
Distance	10km
Speed	0.3m/s
Robot weight	25kg
Payload Capacity	10kg
Battery backup	5 hours
Security of payload	High
Accuracy	Expected accuracy
Cost-effectiveness	Average/medium

Comparative Analysis:

Parameters	Robotic System in [21]	Proposed Prototype
Distance	7.9 km	10km
Speed	0.5 m/s	0.63m/s
Robot weight	0.26195kg(≈262grams)	25kg
Payload Capacity	1-2 kg	10kg
Battery backup	2.5 Hr	5 Hr
Security of payload	Not specified	Using Biometrics

presents a comparative analysis, revealing that the system designed in [21] gives a relatively less reliable robotic prototype as it lacks the stable security mechanism for the payload including other deficiencies with approximate values. The proposed model of this research emphasized overall security besides focusing on the necessary indoor delivery requirements.

Table 2. Comparative Analysis

Parameters	Robotic System in [21]	Proposed Prototype
Distance	7.9 km	10km
Speed	0.5 m/s	0.63m/s
Robot weight	0.26195kg(≈262grams)	25kg
Payload Capacity	1-2 kg	10kg
Battery backup	2.5 Hr	5 Hr
Security of payload	Not specified	Using Biometrics

Conclusion:

In conclusion, robots that autonomously deliver objects have become indispensable for outdoor as well as indoor environments. This paper describes a strategy for automated delivery that navigates the line-following, performs secure payload transfer via fingerprint authentication, and communicates between sender and receiver through an Android application. After thorough research and analysis, it was concluded that the proposed robotic model can save human effort and delivery time instead of manual delivery, perform optimal delivery as it is capable of doing repetitive tasks without getting bored, and can also deliver goods securely with the use of an authenticated fingerprint unlock and real-time image tracking. The model has been tested successfully; thus, its practical usability is presented, which is a base for further development in the area of secure and autonomous shipment, particularly in the near future.

Limitations:

Currently, the prototype can be used in closed-loop environments as it has certain limitations. For example, it can avoid only static objects in its path but it cannot be operated in open-ended environments, such as roads where real-time situations involving moving objects are common. Additionally,the robotic prototype is limited to black-line navigation, lacks stairs-climbing capability as it is not yet fully autonomous, and due to limited power sources and considering cost-effectiveness it doesn't provide amazingly fast speed. Furthermore, the Android app is restricted to Android platforms only, and any app issue can disrupt admin-user communication for order placement. The prototype is also designed in such a way that it can carry a maximum weight of 10 kg. However, with modifications for commercial use, its payload capacity could be increased to 20 kg.

Future Work:

Considering the limitations mentioned above and future enhancements, the following functionalities can be implemented:

- The line-following techniques can be replaced with other smart technologies, which can include Light Detection and Ranging (LiDAR), SLAM technologies, etc., to reduce the overhead of drawing lines every time.
- A robot can be upgraded to work without the need for an Android application by implementing a Graphic User Interface (GUI) based system within the robotic prototype.
- An Indoor Positioning System (IPS) may be included in an Android application in order to track the robot remotely from anywhere within an indoor environment.
- It may be enhanced further and include a robotic arm so that the robot will require less or no human effort while placing ordered objects inside the carrier box.

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Project details: Nil

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