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Enhancing Parcel Management by IoT Enabled Smart Locker System

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Abstract: The rapid rise of e-commerce has increased doorstep deliveries, but challenges such as missed deliveries, parcel theft, and dependency on customer availability still persist. This paper presents a Dual Door Smart Locker System that enables secure parcel drop-offs without requiring the owner's physical presence. The system features independent access points for delivery personnel and the owner, where the delivery door is remotely unlocked by the user, and the retrieval door requires secure authentication using a PIN or facial recognition. Additionally, the system includes an integrated smart letter box, where an IR sensor detects newly dropped mail and updates the cloud dashboard with real-time notifications. The architecture uses ESP32 microcontrollers, Firebase cloud services, a Python-based recognition engine, and a web dashboard to enable remote monitoring, access logging, and seamless communication between modules. Experimental results demonstrate reliable authentication, accurate mail detection, and efficient dual-door operation, making the proposed solution a practical and scalable approach for modern home-delivery ecosystems.

Keywords: Smart Locker, IoT, Dual Door Access, Facial Recognition, ESP32, Secure Parcel Delivery, Cloud Integration.

I. INTRODUCTION

The expansion of online shopping and courier services has transformed last-mile logistics, yet challenges such as missed deliveries, package theft, and dependency on user availability remain widespread. Traditional doorstep drop-offs lack security, and existing smart locker solutions often rely on single-door compartments that grant the same access level to both delivery personnel and owners. This unified access structure presents significant risks, including unauthorized retrieval, tampering, and limited authentication flexibility. Furthermore, residential mailboxes continue to operate as simple mechanical containers without real-time status updates or theft detection mechanisms.To address these limitations, this paper proposes a comprehensive **Dual Door Smart Locker Architecture** designed for household use.The system separates delivery access from user retrieval, thereby eliminating unauthorized contact with stored parcels. Delivery personnel can only access a dedicated compartment when the owner remotely approves the request through a cloud-connected web dashboard. The retrieval door, by contrast, incorporates multi-factor authentication through a **PIN keypad and facial recognition**, significantly strengthening security.As an added enhancement, the system integrates a smart letter box subsystem that detects new postal mail using an IR sensor. When a letter interrupts the IR beam, the event is recorded and pushed to Firebase, allowing the dashboard to instantly display a "New Mail Arrived" notification. A flip mechanism ensures that letters fall smoothly into a secure lower compartment, protecting them from tampering and environmental exposure.The architecture is powered by ESP32-based controllers, a Python facial-recognition engine, Firebase cloud communication, and a dashboard for remote monitoring and control. This combined design ensures real-time access management, improved delivery reliability, and enhanced user convenience. Compared with existing systems, the proposed solution directly addresses unresolved gaps in access security, mail detection, and dual-compartment design, offering a robust alternative for next-generation home delivery systems.

II. LITERATURE REVIEW

Smart parcel lockers have gained traction as an effective strategy for improving last-mile delivery reliability. Tang et al. analyzed customer perceptions of IoT-enabled parcel lockers and identified security, convenience, and trust as major adoption factors [1]. In a related study, Kahr et al. optimized parcel locker placement and layout to enhance logistical efficiency, further highlighting the importance of design in meeting user expectations [2]. Kurowski expanded on this by proposing geometric network designs for parcel locker deployments to reduce operational inefficiencies [3]. Ozyavas later demonstrated the sustainability benefits of integrating lockers into broader distribution networks, particularly in

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reducing missed deliveries and transportation emissions [4]. Customer preference studies also indicate that security features significantly influence user satisfaction with smart lockers [5].

Technical research on IoT-enabled locker systems has emphasized cloud connectivity, sensor integration, and remote accessibility. Rostami and Kua provided a detailed review of IoT-driven parcel locker technologies, underscoring the advantages of real-time monitoring and cloud synchronization [6]. IoT-based implementations by Arif et al. demonstrated how microcontroller-driven smart lockers can support secure access through server-side logic [7], while Thomas and Mathew showed that Firebase-based architectures improve reliability in smart access systems using ESP32 controllers [8]. Sharma and Gupta designed a multi-factor authentication locker that uses PIN and RFID verification to prevent unauthorized parcel retrieval [9].Biometric-enabled access systems have also advanced significantly. Patel et al. demonstrated a facial-recognition-based entry system suitable for smart home environments [10]. Park and Kim improved on this with a deep-learning model that offered greater robustness under varied environmental conditions [11]. A cloud-assisted facial-recognition access control model was proposed by Li et al., enabling secure identity verification through remote servers [12].Low-cost embedded approaches such as ESP32-CAM deployments have been validated through real-time face-recognition experiments by Fernandes et al., confirming the feasibility of lightweight vision-based authentication for home systems [13]. Multi-factor IoT door-lock models have also been explored by Khan and Yousaf, who demonstrated that combining multiple authentication layers reduces unauthorized access attempts [14].In addition to parcel delivery, IoT-based mail monitoring has emerged as an extension of smart home infrastructure. Ravi and Kumar developed an IoT-enabled smart delivery box enabling contactless drop-offs and real-time notifications, underscoring the usefulness of automated monitoring subsystems [15].

III. SYSTEM ARCHITECTURE AND WORKFLOW

The proposed Dual Door Smart Locker is designed as an IoT-based system that integrates secure parcel delivery, authenticated owner retrieval, and real-time letter detection. The architecture consists of three main functional units: the **Delivery Door Module**, the **Owner Authentication Module**, and the **Smart Letter Box Module**, all interconnected through a cloud-based control system using Firebase.

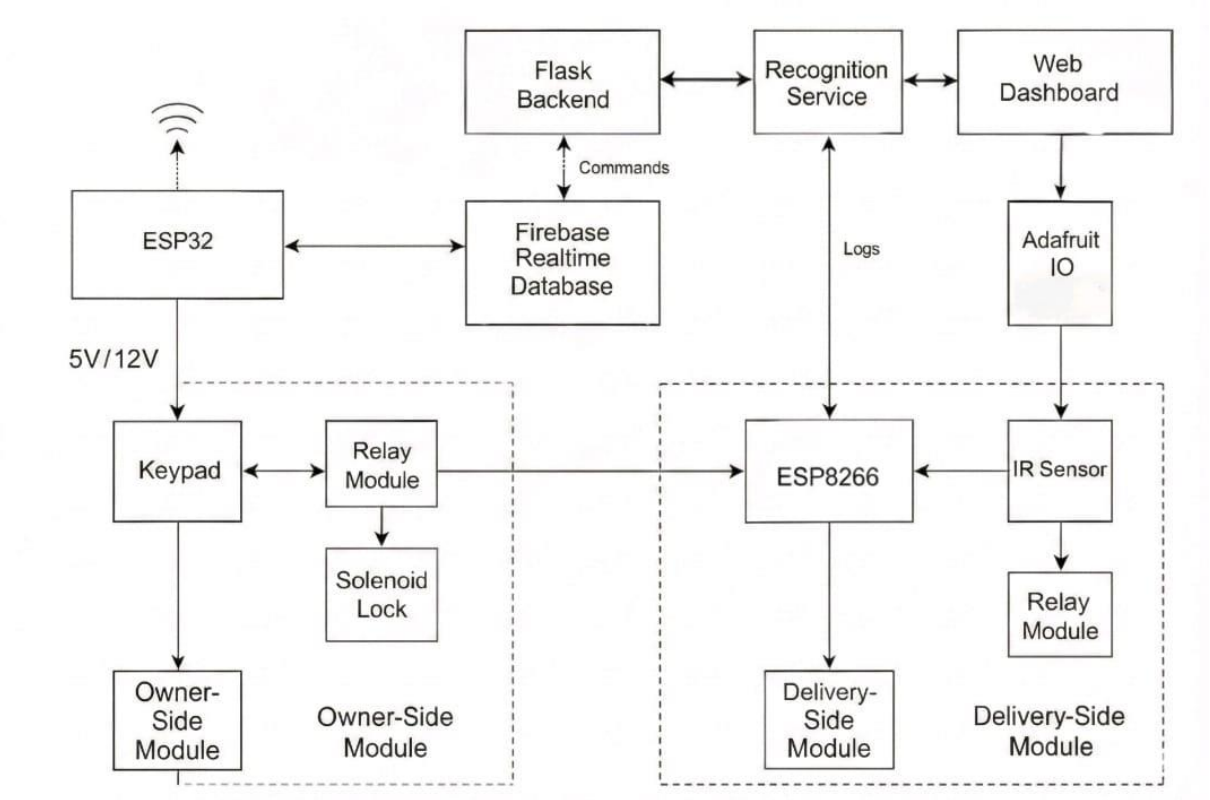

Fig 1: System Architecture of Smart Delivery Locker

3.1 System Architecture

The hardware architecture uses the following major components:

- **ESP32 (Delivery Unit):** Handles remote unlock commands, relay activation, and delivery door control.

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- **ESP32 (Owner Unit):** Interfaces with the 4×4 keypad, IR sensor, and relay for owner door operation.
- **ESP32-CAM:** Captures images for facial recognition and sends them to the backend system.
- **4×4 Keypad:** Allows PIN-based authentication for owner access.
- **IR Sensor:** Detects mail entry in the letter box section.
- **Solenoid Locks & Relay Modules:** Provide controlled opening and closing of both doors.
- **Firebase Realtime Database:** Stores door states, commands, PIN, logs, and mail detection.
- **Python Backend (Flask):** Performs facial recognition using *dlib* and *face_recognition* libraries.
- **Web Dashboard:** Allows the owner to remotely unlock doors, update PIN, check logs, and view mail status.

All components communicate wirelessly through Wi-Fi, and the system ensures real-time synchronization between hardware modules and the cloud server.

3.2 Working Principle

The system operates by coordinating the three units as follows:

A. Delivery Door Operation

1. When a delivery person arrives, the owner accesses the web dashboard.
2. The owner selects **"Unlock Delivery Door"**, which updates a command value in Firebase.
3. The Delivery ESP32 reads this command and activates the relay to unlock the delivery door.
4. After the parcel is placed, the door closes and the system resets to idle mode.

This ensures parcels can be delivered securely without the owner's physical presence.

Fig 2: Keypad and solenoid lock connection

B. Owner Door Authentication

1. PIN Mode:
   - The owner enters the PIN on the keypad.
   - The ESP32 validates it against the Firebase PIN entry.
   - On a correct match, the relay activates and unlocks the owner door.
2. Facial Recognition Mode:
   - The owner presses the face-recognition button.
   - The ESP32-CAM captures an image and uploads it to the Python backend.
   - If the face matches a registered user, Firebase sends an unlock command.
   - The ESP32 triggers the owner door relay.

The dual authentication approach enhances security and prevents unauthorized access.

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C. Smart Letter Box Detection

1. When a letter is dropped into the slot, it interrupts the IR sensor beam.
2. The ESP32 updates *mailStatus = true* in Firebase.
3. The dashboard immediately displays a **"New Mail Received"** alert.
4. The letter falls into the lower compartment through a flip mechanism.

This enables unattended, tamper-free handling of regular postal mail.

3.3 System Communication and Monitoring

All events—including parcel delivery, owner access attempts, face recognition results, and mail arrivals—are logged in Firebase. The dashboard fetches these logs in real time, giving the user full visibility and control over the smart locker's status.The integrated modular design ensures reliable operation, reduced manual involvement, and improved delivery security through cloud-connected monitoring.

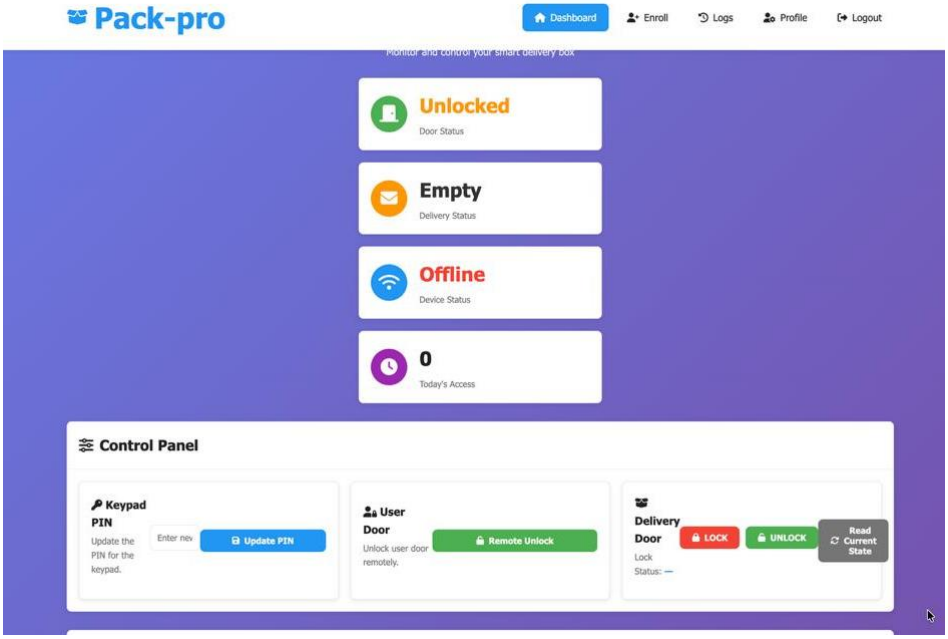

Fig 3: Packpro Website

IV. RESULTS AND DISCUSSION

The smart locker system was evaluated by testing the functioning of its key modules, including the delivery door, owner authentication mechanisms and the smart letter-box unit. The performance of each module was measured in terms of response, accuracy and operational stability under normal usage conditions.

Table 1. Performance Summary of the Smart Locker System

Module	Test Performed	Observation	Result
Delivery Door Unit	Remote unlock command from dashboard	ESP32 responded immediately and relay activated correctly	Successful door opening and secure parcel drop
Owner Door – PIN Authentication	PIN entry on keypad	Correct PIN unlocked door; incorrect attempts were rejected	Reliable and secure PIN-based access
Owner Door – Facial Recognition	Image capture and backend matching	Registered faces matched accurately under normal lighting	Successful owner authentication
IR Letter Box Module	Mail dropped through slot	IR beam interruption detected and dashboard updated	Accurate mail detection with real-time alert

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Dashboard & Firebase	Real-time status updates	Commands, logs and notifications synced without delay	Stable communication and smooth operation
Overall System	Continuous multi-module testing	No errors, stable response and secure dual access	System performed reliably under all test conditions

The system operated reliably across all tested modules. The delivery door responded promptly to cloud-based unlock commands, ensuring secure and unattended parcel drop-off. The owner authentication unit demonstrated consistent performance through both PIN verification and facial recognition, providing secure access control. The IR-based letter detection module accurately identified new mail and updated the dashboard in real time. Overall, the integrated system exhibited stable communication, dependable hardware response and efficient coordination among all components.

Fig 4: Smart Parcel Box

V. CONCLUSION

The proposed Dual Door Smart Locker system provides a comprehensive and secure approach to managing unattended parcel and mail delivery in residential environments. By incorporating separate compartments for delivery personnel and owners, the system eliminates unauthorized access while maintaining user convenience. The integration of PIN-based entry, facial recognition authentication, and IR-based letter detection ensures multi-layered security and accurate event monitoring. Cloud-based synchronization through Firebase, combined with ESP32 and ESP32-CAM modules, enabled reliable real-time control, logging and system responsiveness. Experimental evaluation confirmed stable hardware performance, quick cloud communication and dependable detection accuracy across all modules. Overall, the developed architecture demonstrates an effective, practical and scalable solution for enhancing home delivery security and improving last-mile delivery efficiency.

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