

Easy Parcel: An IoT-Based Parcel Storage System for University Villages

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Abstract

The rapid growth of e-commerce has significantly increased parcel delivery volumes, leading to new logistical challenges related to security, efficiency, and timely collection, particularly in high-density living environments. University residential areas are especially affected, as students often face difficulties retrieving delivered parcels due to limited mailroom operating hours, security risks, and inconvenient collection points. To address these issues, this study presents an IoT-based smart parcel storage system, Easy Parcel, designed specifically for university village environments to improve parcel accessibility, enhance security, and streamline delivery workflows. The proposed solution integrates an ESP32 microcontroller, a Flutter mobile application, and a Supabase cloud database to enable secure parcel registration, OTP-based authentication, barcode scanning, and real-time synchronization between the smart locker and user application. A fully functional prototype was developed and evaluated through system testing, demonstrating successful user authentication, real-time database communication, and accurate locker actuation for parcel release. The results confirm that the system effectively meets its objectives and provides a scalable foundation for future enhancements, including expanded locker modules and advanced authentication methods, supporting the transition toward smarter and more efficient campus parcel management systems.

Keywords: Smart Locker, Parcel Automation, ESP32, Flutter, Supabase, University Logistics

1.0 Introduction

In recent years, Malaysia has seen remarkable growth in its digital economy, with the e-commerce sector's income reaching RM918.2 billion in the first nine months of 2024. University students are a highly active segment of this online consumer base, relying on digital platforms for both personal and academic needs. However, this surge in online shopping has created significant logistical challenges for parcel management within university environments.

Many institutions, including Universiti Teknologi PETRONAS (UTP), use centralized parcel hubs. These hubs, while efficient at handling volume, often create accessibility issues. They are frequently located far from student residential villages, forcing students to walk long distances. This inconvenience is compounded by limited operating hours, long queues during peak periods, and additional service fees.

While smart locker systems are known solutions, and IoT integration can enhance security, a significant research gap exists. Many commercial systems utilize expensive hardware like

biometric scanners, making them cost-prohibitive for large-scale university deployment. Conversely, existing low-cost solutions are often not designed for the high-volume, multi-user environment of a campus. There is a specific need for a decentralized system that places affordable, secure lockers directly within student residential areas, and there has been limited exploration of integrating open-source backends like Supabase for this purpose.

This project introduces "Easy Parcel," a low-cost, decentralized IoT-based smart locker system tailored for university villages. The objectives of this research are: (1) To design and develop an IoT-based smart locker system; (2) To build a mobile application for students and couriers to manage access and track deliveries; (3) To implement a secure One-Time Password (OTP) lock system and barcode scanning for verification; and (4) To evaluate the usability and effectiveness of the complete system.

2.0 Methodology

This project followed the Design and Development Research (DDR) methodology, which involves iterative design, prototyping, integration, and testing. The system is composed of three main parts: the hardware prototype, the software (mobile app and backend), and the integration between them.

2.1 Hardware Development

A single-unit smart locker prototype was constructed to validate the core functionality. The hardware was built using low-cost, readily available components. The ESP32 microcontroller was chosen as the main control unit due to its built-in Wi-Fi capabilities, enabling it to connect to the internet and communicate with the backend system. For the actuator and inputs, a servo motor was used as the locking mechanism, while a 4x4 keypad module serves as the primary input for users to enter their OTP. Finally, user feedback is provided by an I2C LCD display, which shows real-time instructions and system status, such as "Enter OTP" or "Access Granted". Visual feedback is provided by green and red LEDs, and audible feedback is given by a buzzer.

2.2 Software Development

The software system consists of a mobile application and a cloud backend. A cross-platform mobile application was developed using the Flutter framework. The application features two distinct user roles. The Courier Mode allows couriers to log in, scan a student's QR code or manually enter details, and register a parcel. This action communicates with the backend to create a parcel record and generate a unique OTP. The Student Mode allows students to log in, view parcels "Ready for Pickup", and retrieve the OTP for their parcel. After collection, the student scans the parcel's barcode to verify and finalize the collection, updating its status. For the backend database, Supabase was chosen as the backend service. It provides an open-source, scalable solution with a PostgreSQL database, authentication, and real-time capabilities. The database was designed with two main tables: a PROFILES table for user authentication and role management and a PARCELS table to store all data related to a delivery, including student/courier IDs, status, timestamps, and the OTP.

2.3 System Integration

The three components are integrated to create a seamless workflow, as illustrated in the system architecture. The process begins when a courier uses the Flutter app to create a parcel record.

The app sends this data to Supabase, which generates and stores an OTP. The student, notified via the app, logs in and presses "Get OTP". The app then sends this retrieved OTP to the ESP32 via an HTTP POST request over the local Wi-Fi network. The ESP32, running a lightweight web server, receives and stores this OTP. The student enters the OTP using the locker's keypad, and the ESP32 validates this input against the stored OTP. If it matches, the ESP32 activates the servo motor to unlock the door. Finally, the student scans the parcel barcode with the app, which verifies this against the Supabase record and updates the parcel status to "Collected".

3.0 Result and Discussion

The "Easy Parcel" system was evaluated through functional, integration, and user interface testing.

3.1 Hardware Prototype Results

The hardware prototype performed reliably. Upon startup, the ESP32 successfully connected to the Wi-Fi network and displayed its IP address and a ready-state message on the LCD. The system correctly received the OTP sent from the mobile app via the HTTP request. During user interaction testing, entering the correct OTP on the keypad resulted in the immediate activation of the servo motor to unlock the door and the green LED to light up. Entering an incorrect OTP triggered the red LED and buzzer, prompting the user to "Try Again," as intended.

3.2 Software and Database Results

The Flutter application and Supabase backend functioned as a robust system. Role-based authentication successfully separated student and courier dashboards. The courier workflow, from scanning to parcel registration to correctly generated and stored parcel records in the Supabase database in real-time. The student workflow was also successful. Students were able to view their "Ready for Pickup" parcels, retrieve the OTP, and successfully transmit it to the hardware. The final verification step, scanning the parcel's barcode, correctly updated the parcel's status to "Collected" in the Supabase database and moved the item to the "History" tab. Integration testing confirmed that all database transactions and real-time updates were stable and consistent.

3.3 Discussion of Objectives and Contribution

All four project objectives were successfully achieved. An IoT-based smart locker was designed and developed using an ESP32, servo, and keypad, fulfilling the first objective. A mobile application was built using Flutter, successfully supporting both courier and student roles for tracking and verification, which met the second objective. Seamless communication was established via an HTTP POST request from the app to the ESP32 for OTP transmission, achieving the third objective. Finally, the system's usability and effectiveness were evaluated through user testing, with feedback confirming the system is practical, easy to use, and an improvement over manual processes, thus meeting the fourth objective.

Compared to existing systems, "Easy Parcel" provides a distinct advantage. It automates the inefficient manual process, reducing wait times and enhancing security. Critically, it offers a cost-effective and flexible alternative to expensive, proprietary commercial lockers. By leveraging open-source tools like Flutter and Supabase, it provides a scalable and adaptable solution specifically suited for decentralized deployment in university residential areas. This work also contributes to the UN Sustainable Development Goal (SDG) 11 (Sustainable Cities

and Communities) by using digital innovation to create a smarter, safer, and more efficient campus environment.

4.0 Conclusion and Recommendations

This project successfully demonstrated the design, development, and validation of "Easy Parcel," an integrated IoT-based smart locker system. The solution effectively combines an ESP32-based hardware prototype with a Flutter mobile application and a Supabase cloud backend to create a secure, automated, and user-friendly parcel management process for universities. Testing confirmed the system meets all functional requirements and is well-received by users, validating its potential to solve the logistical challenges faced in campus environments.

Future work should focus on enhancing scalability and robustness. There are several key recommendations for improvement. First, integrating more stable network options, such as Ethernet or GSM modules, would reduce dependency on local Wi-Fi and ensure continuous operation. Second, expanding the single-unit prototype into a multi-locker configuration with individual compartment control would make the system more practical for large-scale deployment. Finally, developing an administrative dashboard for system monitoring, real-time analytics, and maintenance alerts would enhance system management.

Acknowledgement

The authors would like to express their gratitude to Universiti Teknologi PETRONAS (UTP) for providing the platform and resources to conduct this research, and to Dr. Siti Nurlaili Bt Karim for her invaluable guidance and support throughout this Final Year Project.

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