GuardBox:

Secure, Smart, and Convenient Package Delivery

Special Topics in Computer Engineering CEN 309 01
Technical Project Report

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Abstract

This comprehensive technical report presents the development of GuardBox, an innovative Internet of Things (IoT) solution that addresses the growing problem of package theft and delivery insecurity. Package theft has become a significant concern in the e-commerce ecosystem, with billions of dollars in losses annually and millions of affected consumers. The GuardBox system integrates smart locking mechanisms, real-time monitoring capabilities, and user verification technologies to create a secure delivery ecosystem that protects packages from theft and tampering while providing recipients with peace of mind. Our solution combines hardware components like ESP32 microcontrollers, sensors, and servo motors with sophisticated software systems that enable remote monitoring and control. This report details the problem analysis, system architecture, hardware implementation, software development, and potential market applications of the GuardBox project, demonstrating its capacity to transform the final stage of the e-commerce delivery process.

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Chapter 1

Introduction

1.1 Project Overview

The GuardBox project emerged from the recognition that package security represents a critical vulnerability in the modern e-commerce supply chain. As online shopping continues to grow exponentially worldwide, the frequency of package theft incidents has escalated proportionally, creating significant financial and psychological impacts for consumers and businesses alike. The GuardBox system leverages IoT technology to create a comprehensive solution that addresses these challenges through an integrated approach to package security.

Our solution consists of a physical secure container equipped with smart locking mechanisms, sensors for package detection and tampering alerts, and wireless connectivity for real-time monitoring. The system enables recipients to receive instant notifications about deliveries and potential security concerns, while providing secure access controls that prevent unauthorized package retrieval. By connecting the physical world of package delivery with digital monitoring and authentication systems, GuardBox creates a seamless and secure delivery experience for all stakeholders in the e-commerce ecosystem.

1.2 Purpose and Scope

The primary purpose of the GuardBox project is to develop and implement a technological solution that significantly reduces package theft incidents and enhances consumer confidence in e-commerce deliveries. By providing a secure receptacle with intelligent monitoring capabilities, GuardBox aims to protect valuable deliveries while also generating data insights that can improve the overall delivery process.

The scope of this project encompasses the complete development lifecycle from initial problem analysis through system design, hardware implementation, software development, and market positioning. Specifically, the project includes the design and construction of a secure package container, the integration of electronic components for monitoring and control, the development of firmware for the embedded system, the creation of a user application interface, and the establishment of cloud connectivity for remote access and data management. Throughout all stages, we prioritized security, usability, and reliability to ensure the system provides maximum value to users.

Chapter 2

Problem Analysis

2.1 Problem Statement

The essence of the problem addressed by GuardBox is the vulnerability of delivered packages between the moment of delivery and recipient retrieval. Once a courier leaves a package at a doorstep or common area, it becomes susceptible to theft, tampering, or environmental damage. This vulnerability creates significant financial losses for consumers and retailers while generating anxiety and diminished trust in the e-commerce ecosystem. The lack of secure delivery options represents a critical gap in the otherwise increasingly sophisticated supply chain management systems employed by modern retailers and logistics providers.

The problem extends beyond the immediate financial impact of stolen items to include broader consequences such as reduced consumer confidence in online shopping, increased customer service demands, higher operational costs for retailers due to replacement shipments, and damaged brand reputation. Without effective solutions for the "last yard" of delivery, the benefits of advancements in other areas of e-commerce logistics cannot be fully realized.

2.2 Problem Severity

The scale and severity of package theft have reached alarming levels, as documented in recent market research and security studies. In 2024 alone, thieves stole an estimated $12 billion worth of packages in the United States, directly affecting approximately 58 million Americans. The average value of stolen packages stands at $204, representing a significant financial impact on individual consumers. Perhaps most concerning is that 25% of Americans report having experienced package theft at some point, indicating the widespread nature of this problem.

Consumer anxiety about delivery security has also reached notable levels, with nine in ten Americans expressing concern about stolen holiday packages, and 28% characterizing their concern as "very" or "extremely" serious. This anxiety influences consumer behavior, potentially limiting e-commerce adoption and growth. Despite these concerns, many consumers continue to practice insecure behaviors, with 14% taking no precautions to prevent package theft and approximately 40 million Americans admitting to leaving exterior doors unlocked while away from home.

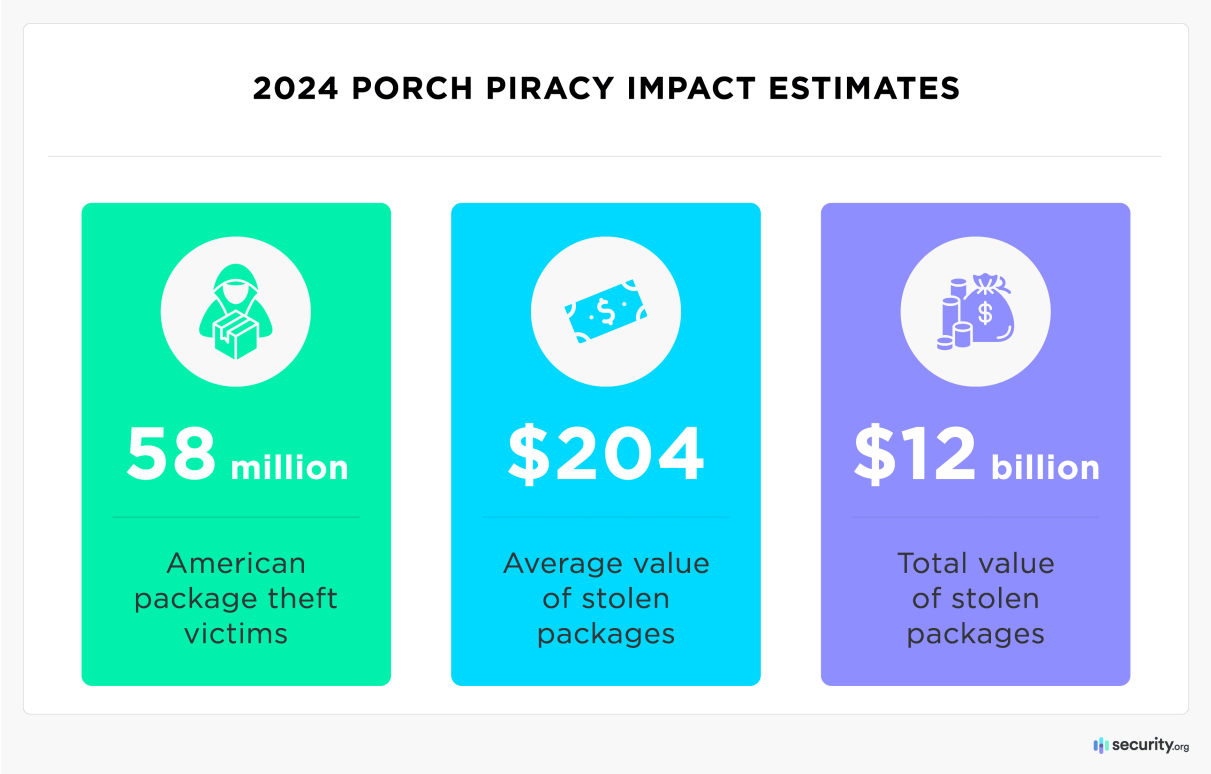


Figure 2.1: Chart showing package theft statistics

2.3 Problem Causes and Contributing Factors

Our analysis identified several key factors that contribute to the vulnerability of delivered packages and the frequency of theft incidents:

1. **Insecure delivery locations** represent the most fundamental vulnerability in the current delivery process. Packages left at doorsteps, in building lobbies, or other exposed areas provide easy targets for opportunistic theft. The physical accessibility of these packages, combined with minimal surveillance in many residential areas, creates a low-risk environment for potential thieves.

2. **Lack of real-time tracking and monitoring** systems for the final stage of delivery means that recipients often have no immediate knowledge of when a package has been delivered or if it has been tampered with. This information gap extends the window of vulnerability and delays potential response to theft incidents. Current tracking systems typically end with delivery confirmation, leaving a critical monitoring gap until the recipient physically retrieves the package.

3. **Identity verification issues** in the delivery process allow for potential misdeliveries or unauthorized package retrieval. Most current delivery systems lack robust authentication mechanisms to ensure packages are received only by authorized individuals. This verification gap can lead to packages being mistakenly delivered to wrong addresses or intentionally misappropriated by individuals falsely claiming authorization.

4. **Limited accountability structures** after delivery completion create difficulties in resolving disputes about missing packages. Once delivery personnel mark a package

as "delivered," the burden of proof regarding theft or misplacement often falls on the recipient, who typically lacks the necessary documentation or evidence to support their claim. This accountability gap complicates resolution processes and can result in financial losses for consumers or retailers.

Figure 2.2: Survey results showing the level of concern among online shoppers about package theft during the holiday season.

2.4 Affected Stakeholders

The problem of package theft impacts multiple stakeholders throughout the e-commerce ecosystem, each experiencing distinct consequences:

1. **Delivery companies and carriers** face increased operational costs when packages are stolen or reported missing. These costs include replacement shipping expenses, customer service resources dedicated to resolving claims, and potential insurance premiums to cover losses. Additionally, carriers experience reputational damage when deliveries fail to reach customers securely, potentially losing business to competitors perceived as more reliable.

2. **Retailers and e-commerce companies** suffer direct financial losses when they must replace stolen items at their expense. Beyond these immediate costs, they also experience decreased customer satisfaction, reduced repeat business, and negative online reviews that can damage their brand reputation. The erosion of consumer trust can have long-term impacts on customer lifetime value and acquisition costs.

3. **Individual recipients** experience the most direct impact through financial losses when packages containing purchased items are stolen. They also suffer significant inconvenience when they must report thefts, request replacements, and potentially wait extended periods for resolution. The psychological impact includes increased anxiety about future deliveries and potential reluctance to make online purchases, especially for high-value items.

Chapter 3

Solution Design

3.1 GuardBox Concept Overview

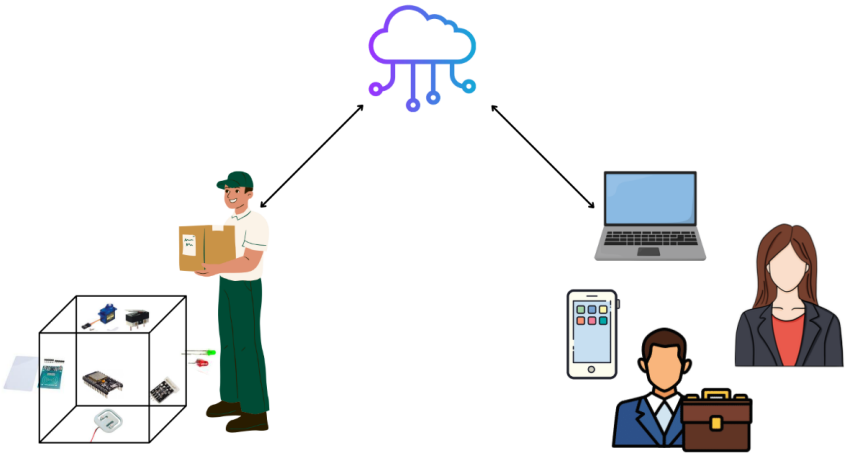


Figure 3.1: Drawing of our Solution.

The GuardBox solution was conceived as a comprehensive system that integrates physical security with digital monitoring and control capabilities. At its core, GuardBox represents more than just a secure container—it functions as an intelligent intermediary in the delivery process that protects packages while providing visibility and control to recipients. The system addresses each identified vulnerability in the current delivery model through purpose-designed features that work in concert to create a secure delivery ecosystem.

Our design philosophy emphasized the integration of proven security principles with modern IoT capabilities to create a solution that is both technically sophisticated and intuitive for users. We recognized that for widespread adoption, the system needed to balance robust security features with convenience and ease of use. Additionally, we prioritized scalability and adaptability to accommodate various installation environments and delivery scenarios.

3.2 System Architecture

The GuardBox system architecture consists of three interconnected layers that work together to provide comprehensive package security:

1. **The physical layer** forms the foundation of the system and includes the secure box enclosure, locking mechanism, and sensor array. The enclosure is designed to resist tampering and environmental exposure while providing sufficient capacity for typical deliveries. The locking mechanism employs a servo-driven system that can be actuated electronically based on authentication status. The sensor array includes weight sensors to detect package placement and removal, vibration sensors to identify potential tampering attempts, and door position switches to monitor access status.

2. **The control layer** serves as the system's intelligence center, processing sensor inputs, managing authentication, and controlling the locking mechanism. Built around an ESP32 microcontroller, this layer implements the decision logic that determines when to lock or unlock the box, when to generate alerts, and how to respond to various detected conditions. The control layer also manages power distribution and implements power conservation strategies to maximize battery life for installations without continuous external power.

3. **The connectivity layer** enables remote monitoring and control by connecting the GuardBox to cloud services through WiFi communications. This layer implements secure protocols for data transmission and user authentication, ensuring that only authorized users can access the system remotely. The connectivity layer also manages notification generation and delivery, keeping recipients informed about package status and potential security concerns in real-time.

These three layers interact seamlessly to create a cohesive system that maintains security while providing convenience and visibility throughout the delivery process. The modular architecture also allows for component upgrades or replacements without requiring complete system redesign, enhancing maintainability and future-proofing the solution.

3.3 Core Functionalities

The GuardBox system provides four essential capabilities that directly address the identified vulnerabilities in the current delivery process:

1. **Smart Lock System**: Utilizes servo motors and RFID technology to secure packages with electronic locking mechanisms that can only be accessed by authorized users. Unlike conventional locks requiring physical keys that can be lost or duplicated, GuardBox implements an electronic locking system controlled by a servo motor and accessible through RFID authentication or remote authorization via the mobile application. The lock automatically secures the box when a package is detected and the door is closed, eliminating the need for courier interaction with the locking mechanism. The system includes fallback mechanisms for power outages or system malfunctions, ensuring packages remain accessible to authorized recipients under all conditions.

2. **Real-Time Tracking**: Implements weight and vibration sensors to detect package placement, tampering attempts, and unauthorized access, with immediate alerts to the owner. Weight sensors detect when a package is placed in the box, triggering

status updates and owner notifications. Vibration sensors monitor for potential tampering attempts, generating immediate alerts when suspicious activity is detected. This comprehensive monitoring eliminates the information gap that typically exists between delivery confirmation and recipient retrieval, allowing for prompt response to potential security threats.

3. **Remote Access System**: Enables users to monitor and control their GuardBox from anywhere using a mobile, desktop or web application. The application provides real-time status information, notification history, and remote lock/unlock capabilities. This functionality addresses the common problem of packages arriving when recipients are not home, allowing for remote monitoring and selective access authorization for trusted individuals when needed. The system employs secure communication protocols and multi-factor authentication to ensure that remote access capabilities do not compromise physical security.

4. **Secure Recipient Verification**: Ensures that only authorized individuals can retrieve packages from the GuardBox. The system supports multiple authentication methods, including RFID cards, mobile application authentication, and potential future integration with biometric verification. This multi-layered approach to authentication significantly reduces the risk of unauthorized access while maintaining convenience for legitimate recipients. The verification system maintains access logs for security auditing and dispute resolution if questions arise about package retrieval.

Together, these core functionalities create a comprehensive security ecosystem that protects packages throughout the vulnerable period between delivery and recipient retrieval. By addressing each identified vulnerability with purpose-designed capabilities, GuardBox provides a complete solution to the package theft problem.

Chapter 4

Hardware Implementation

4.1 Component Selection

The hardware implementation of GuardBox required careful selection of components that balanced functionality, reliability, cost, and power efficiency. Each component was evaluated based on performance specifications, compatibility with other system elements, and suitability for the intended operating environment. The key components selected for the system include:

Figure 4.1: ESP32 microcontroller.

1. **ESP32 microcontroller** serves as the processing and communication hub for the entire system. We selected this particular microcontroller for its powerful dual-core processor, integrated WiFi and Bluetooth capabilities, extensive GPIO options, and excellent support community. The ESP32 provides sufficient processing capacity for all required operations while maintaining reasonable power consumption, making it suitable for battery-powered installations. Its built-in security features, including secure boot and flash encryption, provide additional protection for sensitive system operations.

Figure 4.2: Load sensor.

2. **Load sensors**, based on load cell technology, were selected to detect package placement and removal. These sensors can detect weight changes as small as 5 grams, ensuring reliable detection even for lightweight packages. They are calibrated to filter out environmental noise, such as vibrations from passing vehicles or wind, preventing false triggers. The weight detection system also includes threshold adjustment capabilities to accommodate varying sensitivity requirements depending on the installation location.

Figure 4.3: Vibration sensor.

3. **A vibration sensor** based on a spring-loaded contact mechanism was employed to detect tampering attempts. When a sudden impact or shake is detected, the sensor triggers a notification to the user. To enhance security, the system monitors repeated vibration events, and if multiple tampering attempts are registered within a short period, it escalates the response by sending an emergency alert to indicate a potential security breach.

Figure 4.4: RFID Reader and Card.

4. **RFID reader and card system** provides convenient and secure authentication for package retrieval. We selected a 13.56 MHz MIFARE-compatible RFID system for its widespread adoption, security features, and reasonable cost. The system supports multiple authorized RFID cards, allowing family members or trusted individuals to retrieve packages when needed. The RFID system includes encryption capabilities to prevent unauthorized card cloning or spoofing attacks.

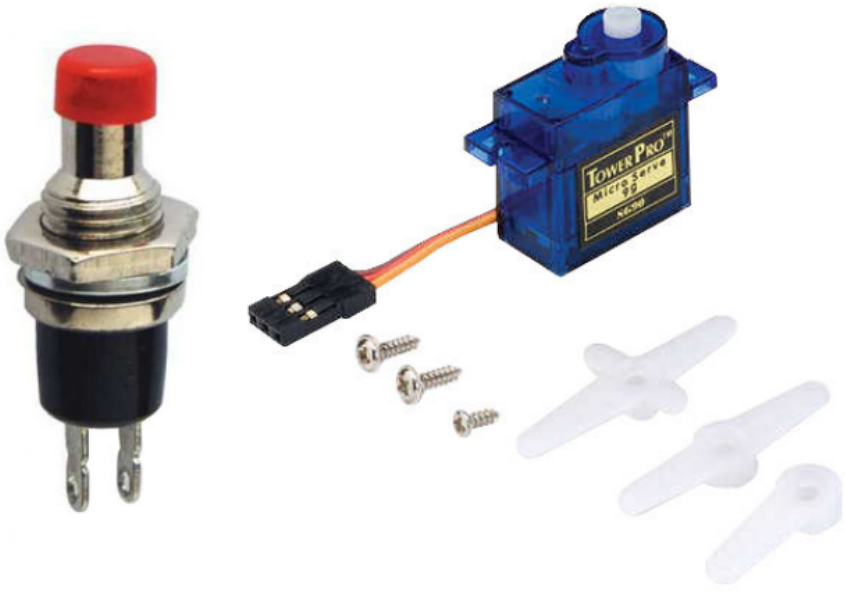


Figure 4.5: Servo and Push Button.

5. **Servo motor locking mechanism** was chosen for its reliability, precision, and power efficiency. The selected servo provides sufficient torque to operate the locking mechanism securely while consuming minimal power during standby periods. The locking system includes mechanical reinforcement to resist forced entry attempts,

providing physical security that complements the electronic authentication mechanisms. The servo mechanism is designed for quiet operation to avoid disturbances in residential installations.

Figure 4.6: Red and Green LED indicators.

6. **LED indicators** provide visual feedback about system status, with red LEDs indicating locked status and green LEDs showing unlocked status. These high-brightness LEDs are visible even in daylight conditions, ensuring clear status indication at all times. The LED system includes power-efficient control circuitry that minimizes battery drain while maintaining necessary visibility.

Figure 4.7: The box used for GuardBox.

7. **Physical enclosure** is constructed from durable metal to ensure reliable protection of packages and internal electronics, offering resistance against environmental

conditions and physical tampering while maintaining a secure and stable housing for all components.

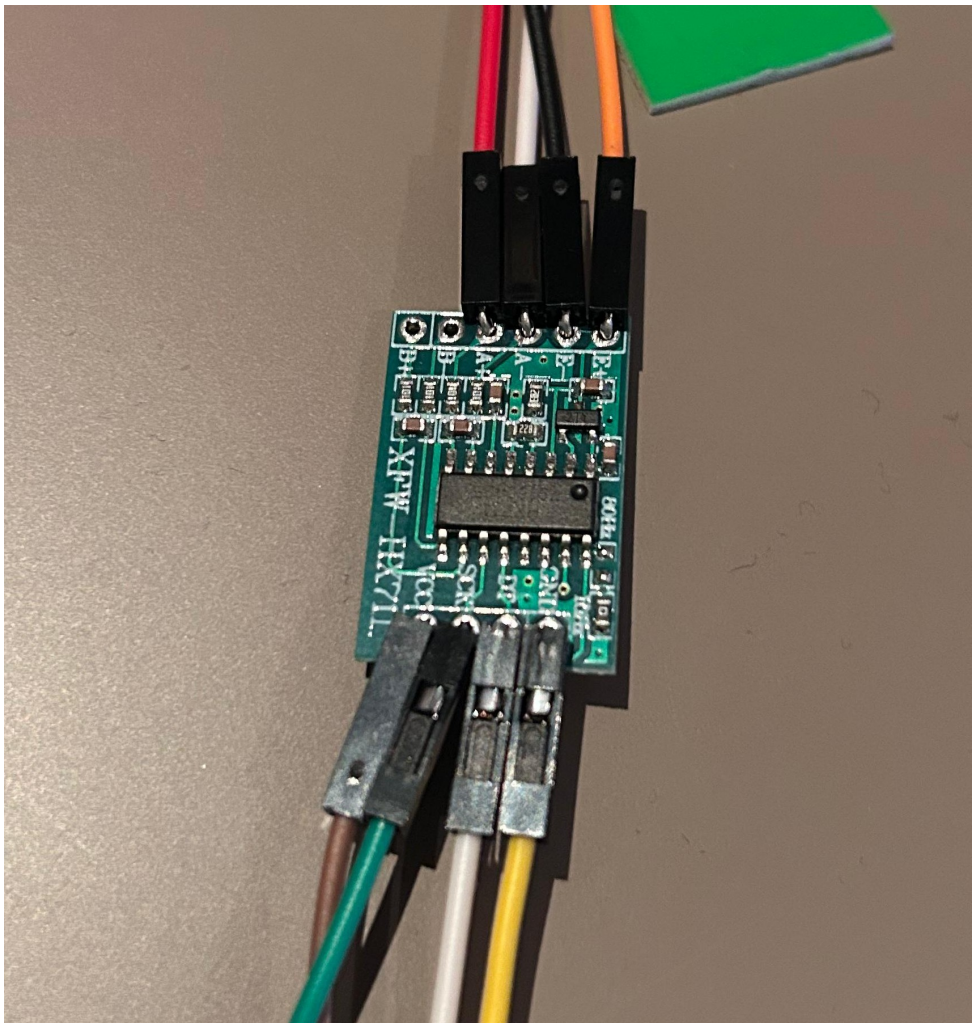


Figure 4.8: HX711 Load Cell Amplifier Module

The HX711 is a precision 24-bit analog-to-digital converter (ADC) designed specifically for weigh scales. It interfaces with a strain gauge-based load cell and provides the necessary amplification and digital output required for accurate weight measurements.

In the GuardBox system, it plays a critical role in detecting whether a package has been placed by converting the analog voltage changes from the load cell into digital signals processed by the ESP32. The key pins used are:

- **VCC** – Power supply (2.6V–5.5V)
- **GND** – Ground
- **DT (Data)** – Serial data output
- **SCK (Clock)** – Serial clock input

This module ensures real-time monitoring of package presence inside the GuardBox, enabling intelligent locking and delivery verification features.

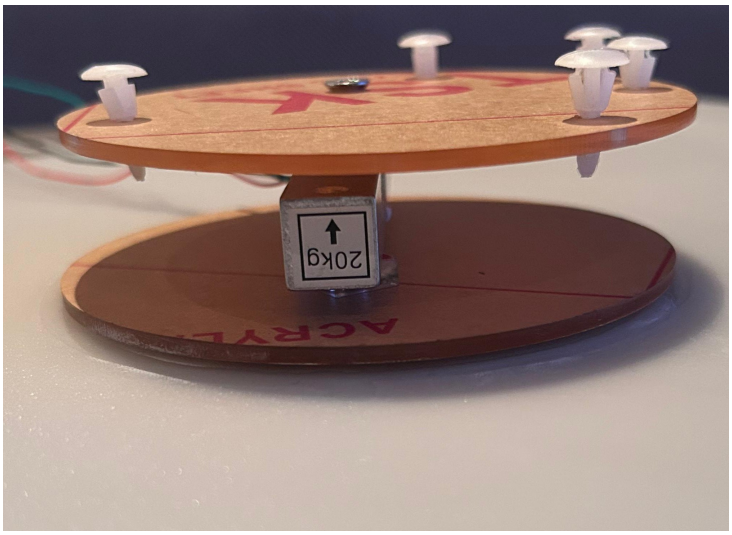


Figure 4.9: Final Weight Sensor Platform using Load Cell

This image shows the final mounted structure of the weight sensor subsystem used in GuardBox. A 20 kg strain gauge load cell is sandwiched between two circular acrylic plates. The top plate acts as the package platform, and the bottom plate provides a stable base. Plastic rivets or pins maintain separation and alignment. This mechanical setup ensures accurate load transfer onto the sensor for reliable weight readings.

Combined with the HX711 module, this configuration allows the system to detect delivery events and trigger secure locking logic based on weight thresholds.

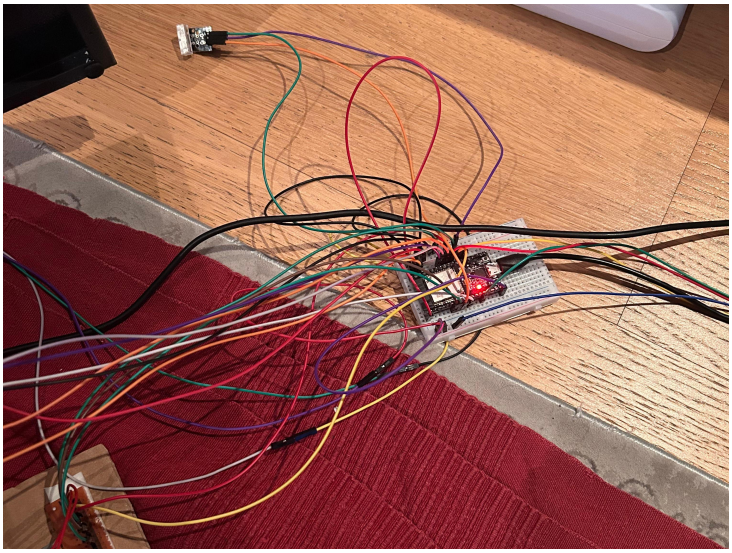


Figure 4.10: ESP32 Breadboard Wiring for GuardBox

This figure displays the complete wiring setup of the ESP32 development board used in the GuardBox system. Multiple sensors and modules are connected, including the HX711 (weight sensor), MFRC522 (RFID module), servo motor, vibration sensor, LEDs, and external button. All components are interfaced using jumper wires on a solderless breadboard for prototyping purposes.

Despite the temporary appearance of the breadboard setup, the overall hardware system incorporates both soldered and modular components. Critical modules such as the load cell platform, RFID reader, and vibration sensor were soldered for long-term stability and reliable connections. The breadboard shown here was primarily used for prototyping and flexible testing of logic and connections before finalizing the circuit. This hybrid approach ensured robustness in essential signal paths while maintaining adaptability during development. All components communicate in real-time with the Firebase-integrated backend to ensure responsive control and monitoring.

4.2 Circuit Design

The circuit design integrates all electronic components into a cohesive system that provides reliable operation under various conditions. The design prioritizes signal integrity, power efficiency, and fault tolerance to ensure dependable performance in real-world environments. Key aspects of the circuit design include:

1. **Power distribution system** provides regulated voltage to all components while implementing power management strategies to extend battery life. A step-down voltage regulator converts the input voltage (either from batteries or external power) to the 3.3V required by the ESP32 and most sensors. The power system includes capacitive filtering to smooth voltage fluctuations and protect sensitive components from power surges.

2. **Sensor interfaces** include signal conditioning circuitry to ensure accurate readings under varying environmental conditions. The weight sensor interface uses a high-precision instrumentation amplifier to boost the millivolt-level signals from the load cells to levels suitable for the ESP32's analog-to-digital converters. The vibration sensor interface includes band-pass filtering to isolate frequencies associated with tampering activities while rejecting environmental noise. All sensor interfaces include protection circuits to prevent damage from static discharge or wiring faults.

3. **Servo control circuit** provides precise positioning control for the locking mechanism. The circuit includes pulse-width modulation (PWM) signal generation for position control and current limiting to prevent motor stalling damage. An optoisolator separates the digital control signals from the motor power circuit, protecting the ESP32 from electrical noise and potential back-EMF spikes when the motor operates. The servo circuit includes capacitive decoupling to minimize voltage drops when the motor activates, ensuring reliable operation even under battery power.

4. **Communication interfaces** provide connectivity between the ESP32 and external systems. The WiFi interface includes a matched antenna design to maximize signal strength and range, enabling reliable connectivity even in challenging installation environments. The SPI interface for the RFID reader includes careful routing to maintain signal integrity at the required 13.56 MHz operating frequency. All communication lines incorporate appropriate termination and filtering to reduce noise and prevent data corruption.

Chapter 5

Final Product

Figure 5.1: Initial State of GuardBox – Unlocked

The GuardBox is shown in its default unlocked state. The servo-controlled lock is disengaged, allowing the door to be opened. The RFID module and control switch are visible on the upper front panel, ready for interaction. This state simulates the pre-delivery condition.

Figure 5.2: Package Placed – Ready to Lock

The GuardBox has successfully detected a delivered package inside. The weight sensor confirms the presence of the parcel, which is visibly resting on the internal platform. The green LED indicates the system is in a valid state for locking. This safety mechanism ensures the box cannot lock unless a package is actually detected, preventing false-secure states and ensuring delivery integrity.

Figure 5.3: Box Locked – Package Secured

The package has been successfully delivered, and the door is now closed. A press of the external button confirmed that the delivery is complete. The red LED indicator signals that the GuardBox has automatically locked the servo mechanism, securing the package inside. This state ensures the box cannot be reopened without authorized access through the mobile app or an RFID card.

Figure 5.4: Final State – Locked and Monitoring

The GuardBox has returned to its secure state with the door locked and the system actively monitoring its environment. The red LED indicates the locked status. It can now only be accessed via an authorized RFID card or through the mobile app. The vibration sensor remains active and will immediately notify the user via Firebase in case of any physical tampering, enhancing package security post-delivery.

Chapter 6

Process Flow

The process flow of the GuardBox system describes the sequence of interactions between its core components—sensors, controller, cloud services, and user interfaces—from the moment an event is detected to the system's response. This chapter outlines the real-time communication, decision-making, and actuation mechanisms that ensure secure and synchronized operations across all platforms.

6.1 System Overview

The GuardBox operates through a continuous loop driven by sensor input, authentication triggers, cloud synchronization, and user commands. The process integrates hardware-based logic on the ESP32 microcontroller, cloud communication through Firebase, and front-end interaction across mobile, desktop, and web applications.

6.2 Event-Driven Flow

The system responds dynamically to the following primary events:

1. **Package Placement**:
    - The load cell detects a weight increase exceeding the threshold.
    - ESP32 validates the input and triggers an internal state change.
    - Locking logic engages the servo motor to secure the package.
    - System state is updated on Firebase, and the mobile/desktop app is notified in real-time.
2. **User Access Request (RFID)**:
    - The RFID module scans a presented tag.
    - The UID is compared against authorized entries in firmware.
    - If verified, the servo unlocks and Firebase records the access event.
    - A temporary bypass flag is set to ignore re-locking during retrieval.
3. **Remote Unlock Command**:

- The user issues a command via app interface.
- Firebase updates the '/locked' flag.
- ESP32 monitors this change, unlocks the box, and sets a remote unlock timer.

4. **Tampering or Vibration Detected**:
   - The vibration sensor detects abnormal movement.
   - The system logs an alert on Firebase and triggers visual/auditory indicators (e.g., flashing LED).
   - Mobile/desktop notifications are pushed to alert the user.

6.3 Continuous Loop Execution

The main firmware loop on the ESP32 follows this logical order:

- Poll RFID reader for card presence.
- Sample load cell and vibration sensor data.
- Check Firebase for remote unlock commands or state mismatches.
- Apply logic for lock/unlock transitions based on door state and package presence.
- Update Firebase with status: weight, vibration, and lock state.
- Refresh indicators (LEDs) and bypass timers.

This loop is optimized with delays and timers to avoid unnecessary Firebase reads/writes and to preserve power when idle.

6.4 Process Synchronization Across Platforms

All user-facing platforms (mobile, web, desktop) poll or listen to Firebase Realtime Database for updates:

- UI components reflect live lock status, weight data, and notifications.
- Any command issued from one interface is mirrored across others.
- Notifications (e.g., unlock events, tampering) are appended to local history and optionally shown via OS-level alerts.

6.5 Flowchart

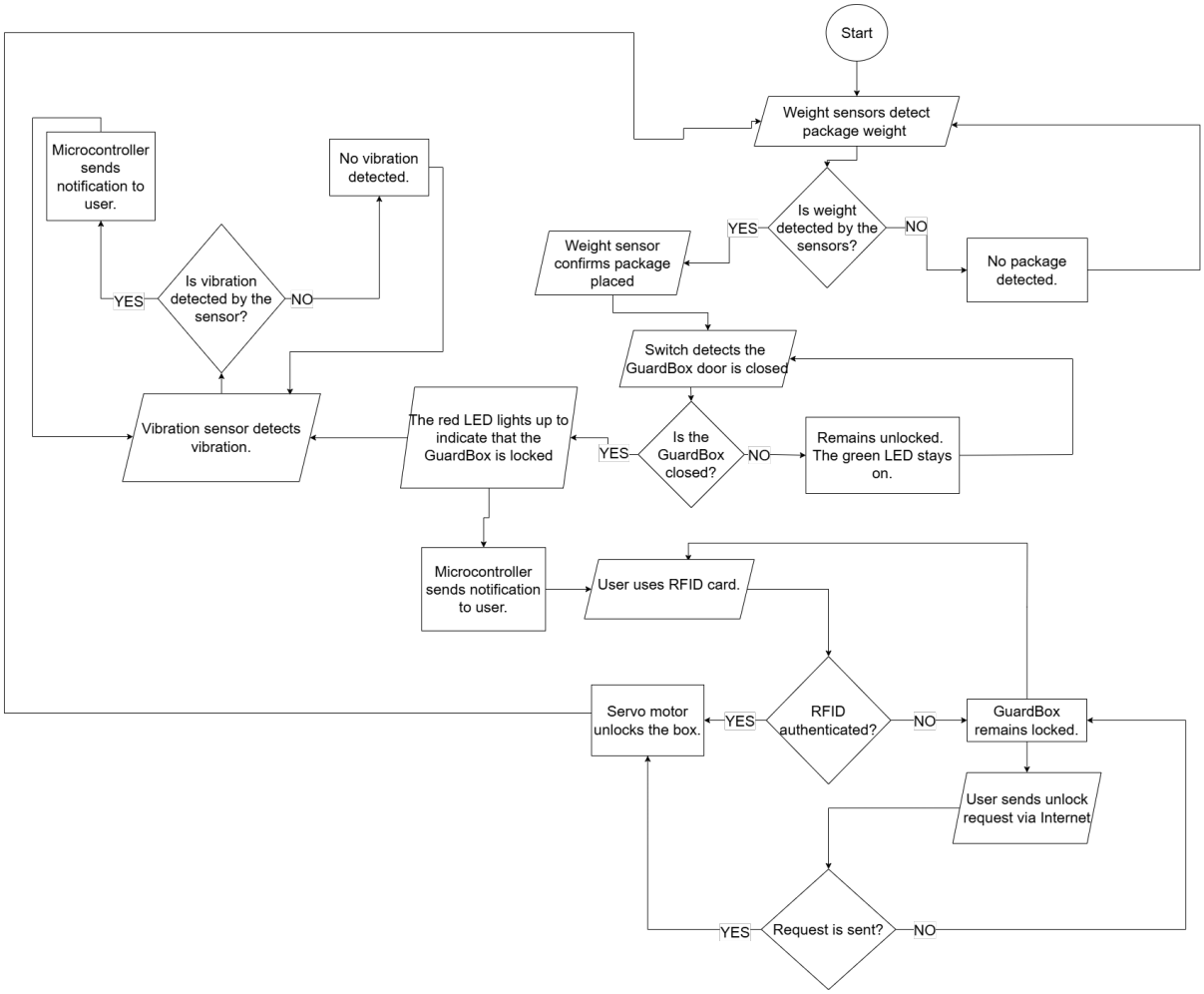


Figure 6.1: System-level process flow for GuardBox operations

6.6 Conclusion

The GuardBox process flow is carefully designed for robustness, responsiveness, and user convenience. Event-driven triggers combined with a persistent monitoring loop ensure that all security events and user commands are handled with minimal latency. By leveraging real-time database updates and secure embedded logic, the system delivers a tightly integrated experience across all platforms.

This logical process foundation directly informs the software architecture discussed in the following chapter, where each component is implemented to maintain the timing, responsiveness, and reliability described above.

Chapter 7

Detailed Software Development

7.1 Firmware Architecture

The GuardBox firmware that runs on the ESP32 microcontroller implements a sophisticated control system that manages all aspects of system operation. Designed with reliability and security as primary considerations, the firmware architecture follows embeldded systems best practices while incorporating specific features to address the unique requirements of package security. The firmware architecture includes:

1. **State machine architecture** forms the backbone of the control system, defining distinct operational states and the transitions between them. Six primary states govern system behavior: Idle (awaiting package delivery), Package Detected (when weight sensors activate), Locked (secured with package inside), Authenticating (during access attempts), Unlocked (when access is granted), and Alert (when tampering is detected). Each state has specific entry and exit actions, with clearly defined transition conditions that ensure predictable system behavior under all circumstances.

2. **Sensor management modules** handle data acquisition, filtering, and interpretation from all connected sensors. The weight sensor module implements adaptive calibration that adjusts to environmental factors and maintains accurate detection despite temperature variations or component aging. The vibration sensor module employs threshold-based detection combined with pattern recognition to distinguish between normal environmental vibrations and potential tampering attempts. These modules include fault detection capabilities that identify sensor malfunctions and implement appropriate fallback behaviors.

3. **Authentication system** manages user verification through multiple methods. The RFID module handles card detection, data reading, and verification against stored authorized IDs. The remote access module processes authentication requests from the mobile application, implementing secure challenge-response protocols to prevent replay attacks. Both authentication pathways include rate limiting to prevent brute force attacks, temporarily disabling access attempts after multiple failures.

4. **Communication modules** manage data exchange with external systems, including the cloud platform and mobile application. These modules implement industry-standard encryption and authentication to protect all transmitted data. The WiFi module includes connection management features that handle network interruptions

gracefully, storing critical data locally until connectivity is restored. Message queuing ensures that important notifications are not lost during temporary connection outages.

5. **Power management functionality** optimizes energy consumption based on operational state and power source. When operating on battery power, the system implements aggressive power conservation measures, including sensor polling rate reduction and WiFi duty cycling. The power management system monitors battery levels and implements graduated feature reduction as power decreases, prioritizing critical security functions over convenience features when necessary.

6. **Fail-safe mechanisms** ensure that system failures do not result in permanently locked packages or security vulnerabilities. Watchdog timers monitor system operation and trigger resets if firmware becomes unresponsive. Critical configuration parameters are stored in redundant memory locations with validation checksums to prevent corruption. The system includes manual override capabilities for emergency access in case of complete electronic failure, carefully designed to prevent security compromises while ensuring packages remain accessible to legitimate owners.

7.1.1 Functional Components of Applications

The application implements several critical functional components that enable comprehensive system monitoring and control, with each platform—mobile, desktop, and web—tailored to its environment through slight differences in design priorities, interaction flow, and feature emphasis while maintaining core functionality and synchronized performance:

1. The **user account management system** provides secure authentication and authorization services, ensuring that only legitimate users can access the GuardBox controls. The implementation includes secure login functionality, user registration capabilities, and password recovery mechanisms. Multi-factor authentication options enhance security for particularly security-conscious users.

2. **Device connection and configuration** capabilities enable users to pair their mobile devices with the GuardBox hardware through either Bluetooth for initial setup or WiFi for ongoing operation. The application guides users through the connection process with step-by-step instructions and visual feedback. Once connected, users can configure system parameters including notification preferences, sensitivity thresholds for sensors, and automatic locking features.

3. **RFID card management** functionality allows users to register, authorize, and deactivate RFID cards for physical access to the GuardBox. The interface provides a list of currently authorized cards with the ability to add new cards through a guided learning process or remove existing cards with a simple swipe gesture. This capability enables flexible access management for household members or trusted individuals.

4. **Real-time monitoring** forms the core of the application's functionality, with the implementation continuously polling the Firebase database for updates about the GuardBox status. The code employs a multi-threaded approach that prevents UI freezing during database operations, ensuring responsive performance even during

intensive monitoring. The application includes automatic retry logic for failed connections, maintaining system awareness even with intermittent network connectivity.

5. The **notification system** provides immediate alerts about important events, implementing both in-app notifications through the scrollable history panel and system-level notifications using the device's native notification framework. The system categorizes notifications by type and severity, allowing users to quickly identify critical alerts that require immediate attention. Advanced notification filtering options enable users to customize their alert preferences based on event importance and personal priorities.

6. **Remote control capabilities** enable users to manage the GuardBox from anywhere with internet connectivity. The lock control functionality allows users to secure or access the box remotely with a simple button press, with commands transmitted securely through the Firebase Realtime Database. The implementation uses a threaded approach that prevents UI blocking during command transmission, maintaining a responsive user experience throughout control operations.

7.2 Cloud Platform Integration

The GuardBox system leverages cloud services to enable remote monitoring, control, and data storage. The implementation uses Firebase as the primary cloud platform, providing reliable real-time database capabilities, user authentication, and messaging services. The cloud integration includes:

1. **Security measures** within the cloud implementation protect sensitive data and control functions. The implementation includes Firebase Authentication for user verification and Firebase Security Rules to restrict database access based on user identity. These measures prevent unauthorized control of the GuardBox while still allowing legitimate users convenient remote access from anywhere with internet connectivity.

2. **Data analytics potential** is built into the cloud architecture, with timestamped events creating a comprehensive activity log that could support future feature development. This historical data enables pattern recognition for security improvements, usage analysis for feature optimization, and potential integration with other smart home systems for enhanced functionality.

7.2.1 ESP32 Coding and Firebase Integration

The ESP32 microcontroller serves as the central control unit of the GuardBox system, and its firmware was written in C++ using the Arduino framework. Programming was done in the Arduino IDE, chosen for its wide community support and compatibility with ESP32 libraries.

The first step in the development was configuring the ESP32 to connect to a local Wi-Fi network. This was accomplished using the built-in WiFi library, where the SSID and password were defined in the firmware. Upon successful connection, the device obtained a local IP address and became capable of interacting with cloud services.

Firebase integration was achieved using the `Firebase_ESP_Client` library, which allows secure communication with Firebase Realtime Database and Authentication services. The API key, project URL, and user credentials were hardcoded in a secure section of the firmware. Once authenticated, the ESP32 continuously pushed and retrieved data from Firebase—updating the lock state, weight measurements, and vibration status in real time.

To avoid blocking the main execution loop, the Firebase operations were executed in intervals using non-blocking techniques and timed loops. This ensured that sensor readings, lock control, and network communication all remained responsive. In the event of a network failure or Firebase downtime, the ESP32 handled reconnection attempts gracefully and maintained core functions locally until the connection was restored.

This reliable cloud communication infrastructure enabled real-time synchronization with all user interfaces, making it possible for the system to instantly reflect changes from the mobile, desktop, or web applications.

7.3 Conclusion

The software development architecture of GuardBox is a carefully orchestrated blend of embedded firmware, cross-platform applications, and cloud-based synchronization. The firmware ensures that all core operations—sensor interpretation, state transitions, authentication, and safety responses—are executed with high reliability and security on the ESP32 microcontroller.

Meanwhile, the mobile, desktop, and web applications offer users responsive, real-time control through a consistent yet platform-optimized experience. These applications facilitate secure user management, device pairing, remote access, and event monitoring—all backed by a robust Firebase infrastructure. The cloud platform not only enables real-time data flow between users and devices but also lays the foundation for future data-driven improvements through analytics and security insights.

Together, these software layers create a seamless and dependable system that transforms GuardBox into a scalable, user-friendly solution for modern package security needs.

Chapter 8

Firebase Integration for Real-time Communication

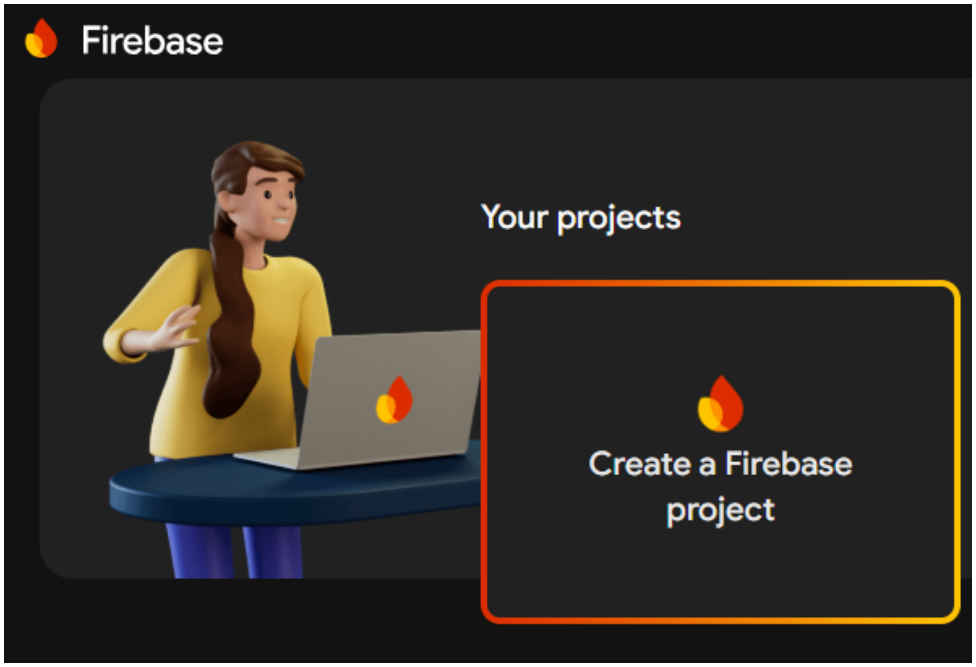


Figure 8.1: Creating a New Firebase Project

This interface is shown when initiating a new Firebase project. It allows users to begin configuring their cloud database, enabling real-time communication between the IoT system and connected applications.

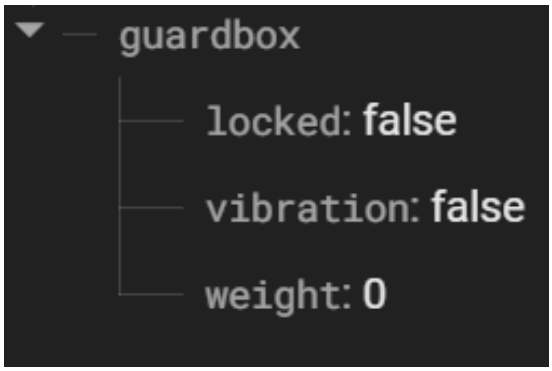
The application leverages Firebase services to enable real-time monitoring, control, and data synchronization:

1. The **Realtime Database** integration serves as the primary communication channel between the GuardBox device and mobile application. The database structure uses a simple yet effective organization with a main "guardbox" node containing key status indicators including "locked" status, "weight" readings, and "vibration" detection flags. This straightforward structure minimizes data transfer requirements while providing all necessary information for system monitoring and control.

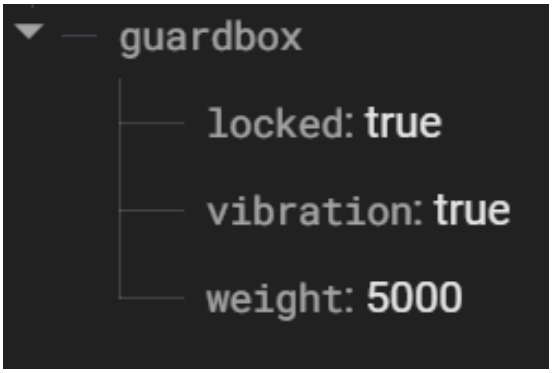
2. **Real-time synchronization** ensures that any status changes on the GuardBox device are immediately reflected in the mobile application. The implementation uses Firebase's event-driven data model, which pushes updates to connected clients without requiring constant polling. This approach reduces network traffic and power consumption while maintaining a responsive user experience.

3. **Command transmission** to the GuardBox uses database updates as the signaling mechanism, with the hardware device monitoring for changes to specific control nodes. This architecture provides reliable command delivery while minimizing direct exposure of the GuardBox to external networks, enhancing security by reducing potential attack vectors.

4. **Notification routing** through Firebase Cloud Messaging enables delivery of alerts even when the mobile application is not actively running. This capability ensures that critical security alerts reach users promptly, allowing for timely response to potential theft attempts or other security concerns.



(a) Initial database state (box empty, no alerts)



(b) Active state with package and vibration alert

Figure 8.2: Firebase Realtime Database: Status snapshots during normal and alert conditions

These two snapshots demonstrate how the Firebase Realtime Database reflects different operational states of the GuardBox. On the left, the box is empty and unlocked with no vibration. On the right, the system has detected a package, locked the box, and triggered a vibration alert, suggesting potential tampering.

This dynamic data model enables seamless synchronization between the physical GuardBox unit and all connected applications, allowing users to receive immediate visual and notification-based feedback as changes occur. By reflecting state transitions in real time—such as lock status, weight presence, or vibration detection—the Firebase Realtime Database ensures that the system remains responsive and transparent, enhancing both user trust and overall situational awareness.

Chapter 9

User Interface (UI)

The GuardBox system is supported by a multi-platform user interface strategy to ensure accessibility and ease of control across different environments. Three separate user interfaces have been developed to accommodate mobile, web, and desktop usage scenarios.

9.1 Mobile Application

The **GuardBox mobile application** is a native Android app that provides users with secure, real-time control over their package delivery box. Built in Kotlin using Android Studio, the app ensures remote management capabilities such as locking/unlocking the box, monitoring package status, and receiving security alerts through Firebase integration.

9.1.1 Development Environment

Android Studio served as the main IDE, with Kotlin selected for its concise syntax and null safety. Gradle (Kotlin DSL) was used for dependency management, and Git handled version control with a feature-branch workflow to support collaboration.

9.1.2 Architecture and Technologies

The app follows the **MVVM** (Model-View-ViewModel) pattern using Android Architecture Components like `ViewModel` and `LiveData` for lifecycle awareness. The UI adheres to Material Design principles using `ConstraintLayout`, `Navigation Component`, and `RecyclerView` for a modern and responsive interface.

9.1.3 Key Features

- **Real-Time Control**: Lock/unlock the box and monitor vibration or package status via Firebase Realtime Database.
- **Cloud Communication**: Firebase listeners provide instant feedback and UI updates on state changes.
- **Offline Support**: Data persistence enables basic monitoring even without internet, resyncing once reconnected.

- **Security**: Communication is secured via TLS, with encrypted local data using Android Keystore. Root checks and certificate pinning improve defense against tampering.

9.1.4 Performance and Testing

Performance was optimized using Android Profiler for rendering, memory, and battery usage. Testing was conducted through unit tests (`JUnit`, `Mockito`), UI tests (`Espresso`), and Firebase Emulator Suite for backend simulation.

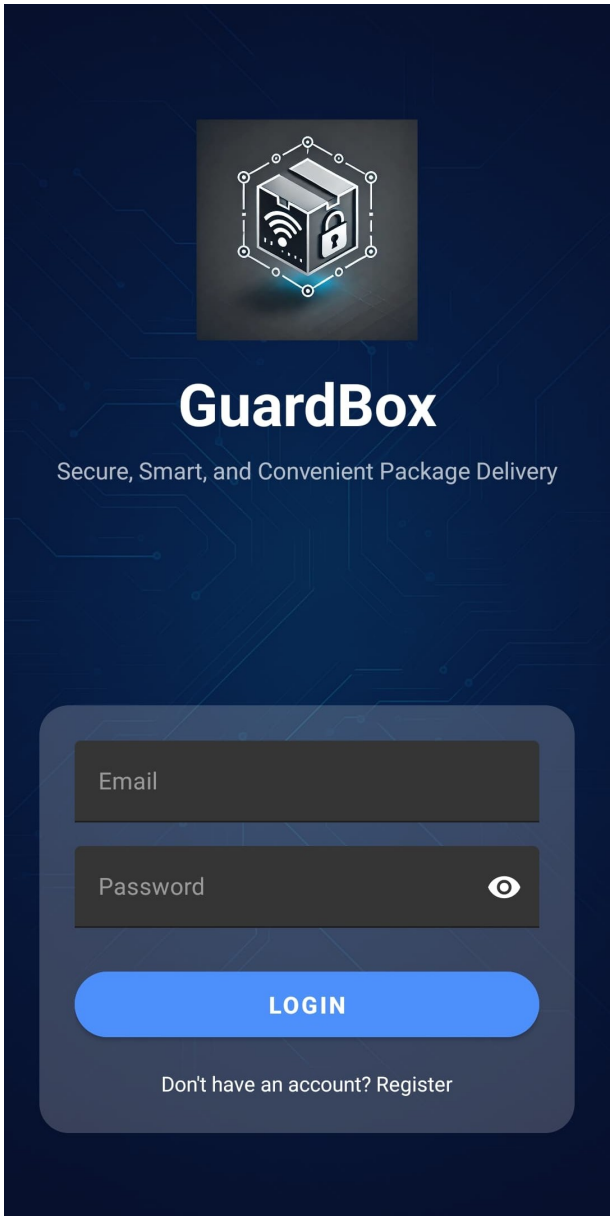


Figure 9.1: Mobile App UI

9.2 Web Application

The GuardBox web interface offers a responsive and modern dashboard for monitoring and controlling the delivery box remotely via any browser. Developed with HTML5, Tailwind CSS, and JavaScript, it focuses on interactivity, clarity, and device compatibility.

9.2.1 Interface Design

The UI is divided into three key sections: *Box Status*, *Lock Control*, and *Recent Notifications*. The status panel indicates whether the box is empty or holds a package, using visual and color cues. Lock control allows remote unlocking with real-time feedback, while the notification panel logs events such as deliveries and tampering alerts.

9.2.2 User Experience Features

- Animated transitions and hover effects
- Light/dark theme toggle for accessibility
- Feather Icons for clean SVG visuals
- Fully responsive layout for all screen sizes

9.2.3 Functionality and Feedback

The application communicates with Firebase Realtime Database to reflect live status updates. UI elements react immediately to user actions such as unlocking, with notifications logged dynamically via JavaScript—no page reloads required.

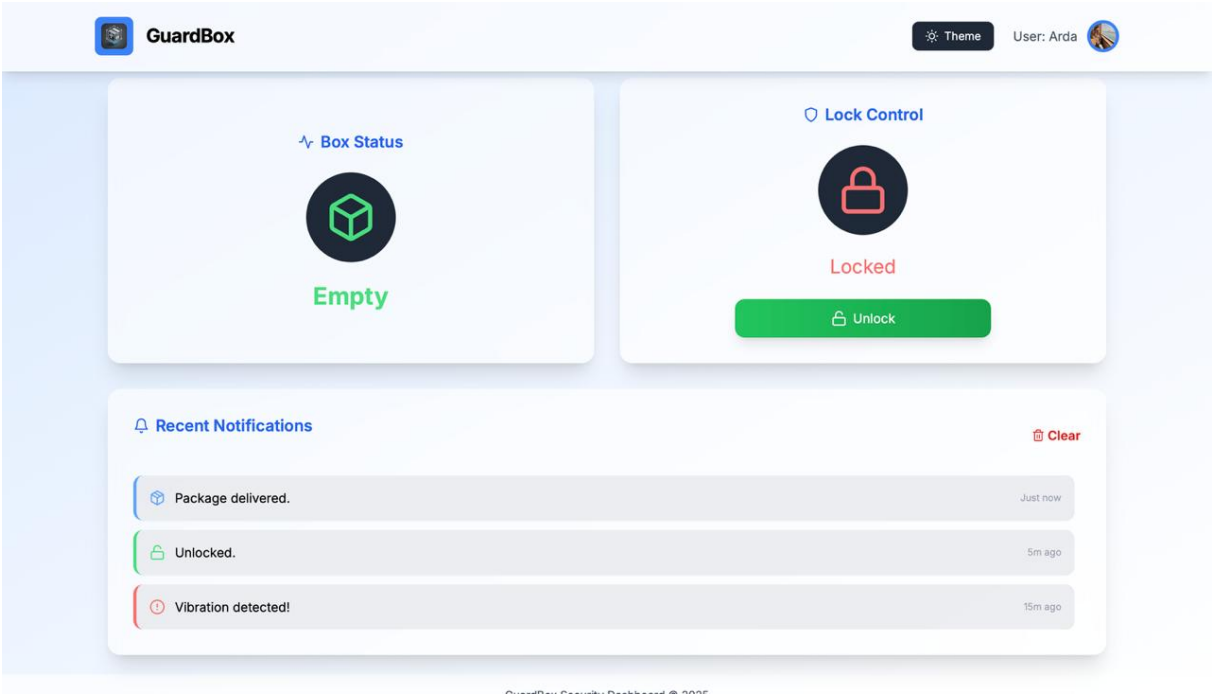


Figure 9.2: Web App UI

9.3 Desktop Application

The GuardBox desktop application provides a real-time control and monitoring interface, built using Python and the KivyMD framework. It is designed for cross-platform deployment on Windows, macOS, and Linux, offering a responsive GUI with Firebase integration.

9.3.1 Interface Overview

The interface consists of three main panels:

- **Box Status:** Displays current weight and package presence using icons and labels.
- **Lock Control:** Allows remote locking and unlocking with immediate visual feedback.
- **Notifications:** Logs events like status changes and vibration alerts.

9.3.2 Features and Synchronization

- Firebase Realtime Database is used to fetch and update the box state. Notifications are shown in-app and as desktop alerts via the Plyer library. A simple vibration detection system escalates alerts on repeated triggers.
- The application supports dark/light themes, periodic updates using Kivy's `Clock`, and threaded operations to maintain a smooth user experience.

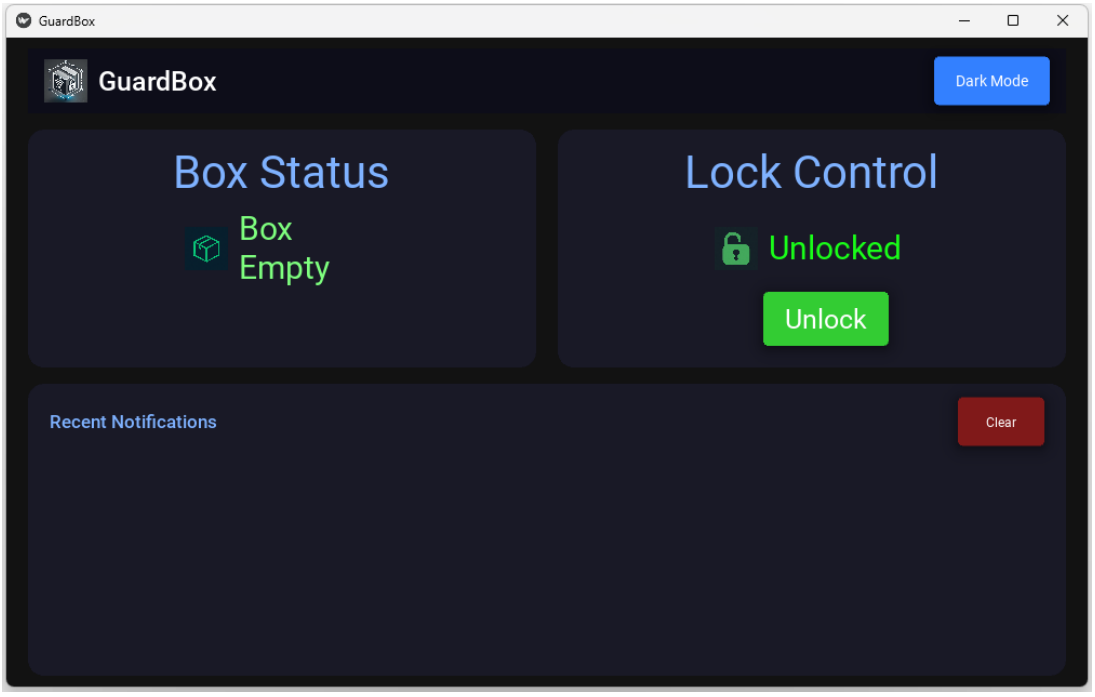


Figure 9.3: Desktop App UI

Chapter 10

User Experience

The GuardBox system delivers a unified user experience across desktop, mobile, and web platforms. Each version is designed to provide intuitive access to key functionalities such as lock control, package detection, and security notifications. By supporting multiple platforms, GuardBox ensures accessibility and usability in a variety of contexts and user preferences.

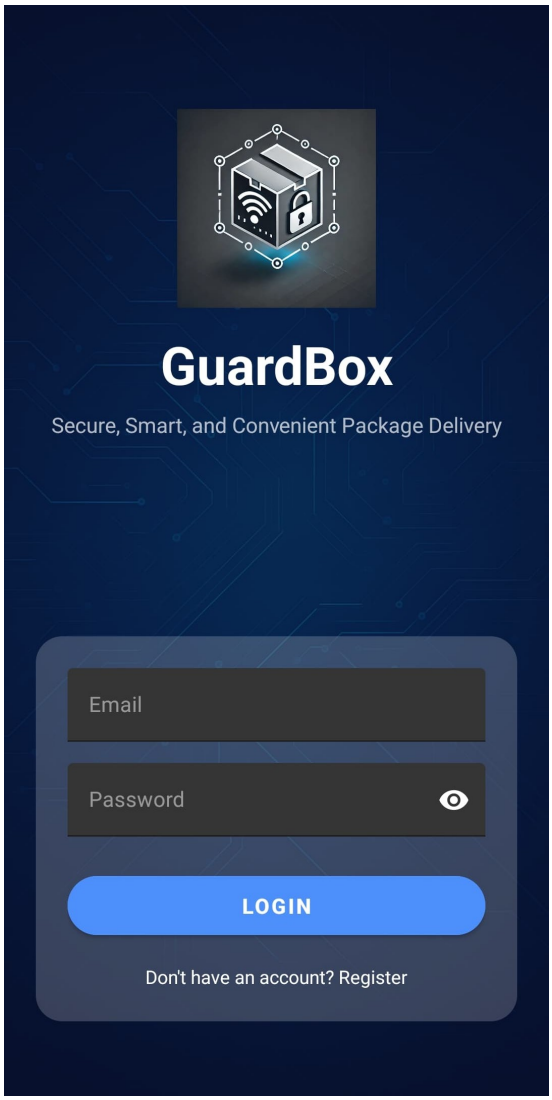
10.1 Cross-Platform Functionality

All interfaces offer real-time synchronization with the system's backend via Firebase, allowing users to monitor box status, control the lock mechanism, and receive alerts regardless of the device used. The mobile application is optimized for quick interactions and portability, the web version enables remote access from any internet-connected device, and the desktop application provides a structured interface suitable for both personal and administrative use.

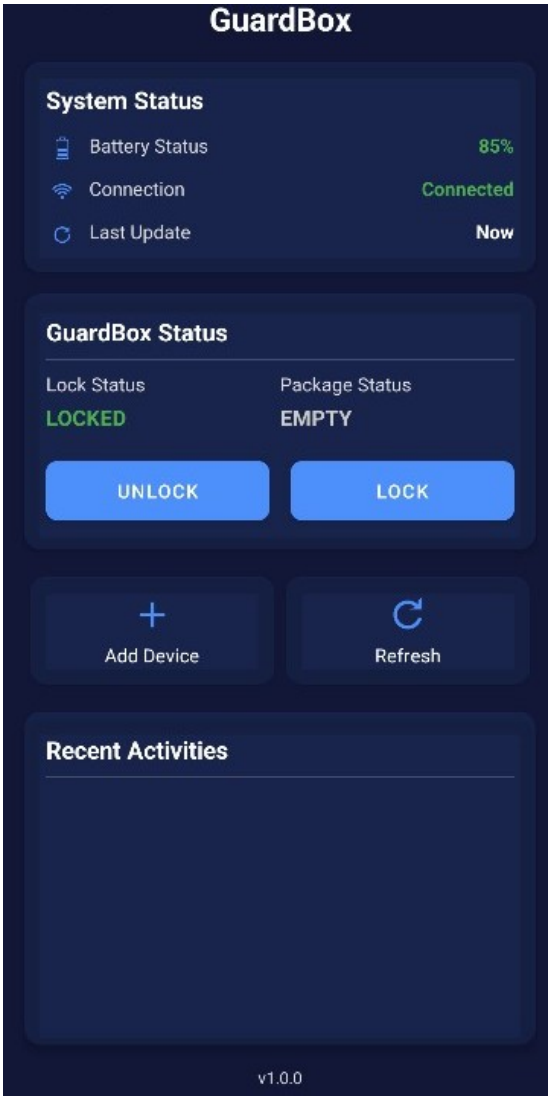
While all versions of the GuardBox application are functionally aligned, their design and usability cater to different user needs. The mobile application is tailored for everyday users, especially package recipients, who require fast access and real-time control on the go. With its simplified layout and touch-friendly design, it offers a seamless experience for checking delivery status, unlocking the box, or receiving tamper alerts with just a few taps. In contrast, the desktop application is more suited for administrative tasks, such as overseeing multiple GuardBox units, reviewing detailed logs, or configuring advanced settings. Its structured interface is ideal for scenarios where users spend more time managing the system, such as in office environments or logistics centers. By providing both mobile and desktop experiences, the system ensures flexibility and convenience for a diverse user base—whether they are casual users expecting a package or staff managing a secure delivery infrastructure.

10.2 Mobile Application Example

To ensure user-friendly access to GuardBox, a dedicated mobile application was developed. This app allows users to securely authenticate, monitor delivery status, and remotely control the locking mechanism.



(a) Login screen of the GuardBox mobile application.



(b) Main interface showing system and package status.

Figure 10.1: GuardBox mobile application screens: the left shows the secure login interface, while the right displays the real-time status dashboard.

The login screen (Figure 10.1a) provides a simple and secure authentication gateway. Once logged in, users are greeted with a control dashboard (Figure 10.1b) that presents the lock and package status, battery level, and recent activity. The interface is optimized for quick actions like unlocking, refreshing, or pairing new devices.

Figure 10.2: Activity History section in the GuardBox mobile application.

The **Activity History** screen (Figure 10.2) provides a summarized view of the user's interactions with the GuardBox. It displays daily, weekly, monthly, or all-time metrics such as number of deliveries, unlock events, total connected time, and triggered alerts. This overview helps users stay informed about their package activity and identify any unusual access patterns or alert conditions quickly.

The GuardBox mobile application serves as a powerful and user-friendly companion to the physical smart package delivery system. With its clean interface, real-time synchronization, and essential functionalities like remote locking, system status monitoring, and activity tracking, it offers a reliable and intuitive experience for everyday users. Designed with portability in mind, the app ensures that users can manage and secure their deliveries on the go. As the system continues to evolve, the mobile application lays a strong foundation for future enhancements, such as push notifications, biometric login, or AI-powered insights, further improving convenience and peace of mind for end users.

10.3 Desktop Application Example

The desktop version of GuardBox, developed using the KivyMD framework, provides a responsive layout with distinct sections for box status, lock control, and recent notifications. The interface includes visual cues such as icons, color-coded labels, and desktop notifications triggered by system events. A theme toggle option is available to accommodate user preferences, and real-time data is pulled from Firebase at regular intervals to ensure up-to-date status information. This version is particularly useful in scenarios where continuous monitoring or interaction through a traditional PC setup is preferred.

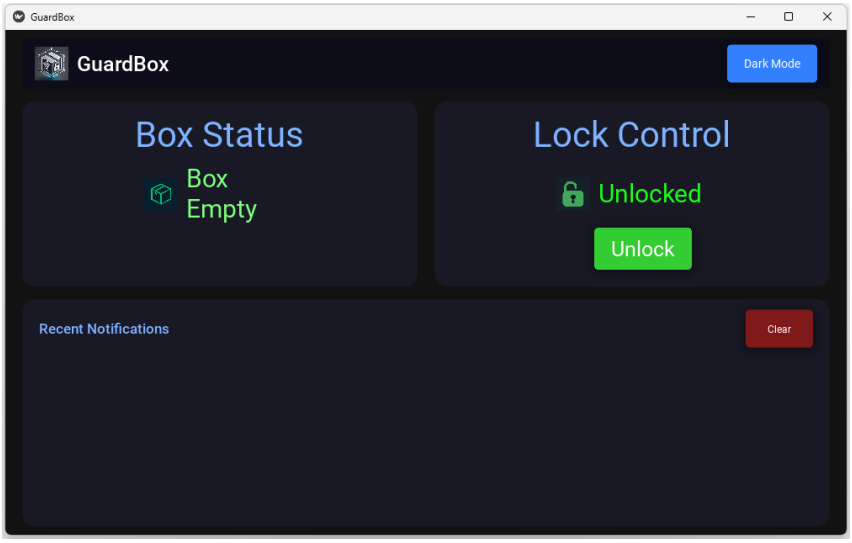


Figure 10.3: Desktop application interface displaying box status and lock control in the main dashboard.

This screenshot shows the core layout of the GuardBox desktop application. The interface clearly presents the current state of the delivery box, indicating that it is empty and currently unlocked. Users can easily issue an unlock command and view real-time status updates. The design includes a theme toggle for switching between dark and light modes, along with a dedicated notification panel for logging recent activity.

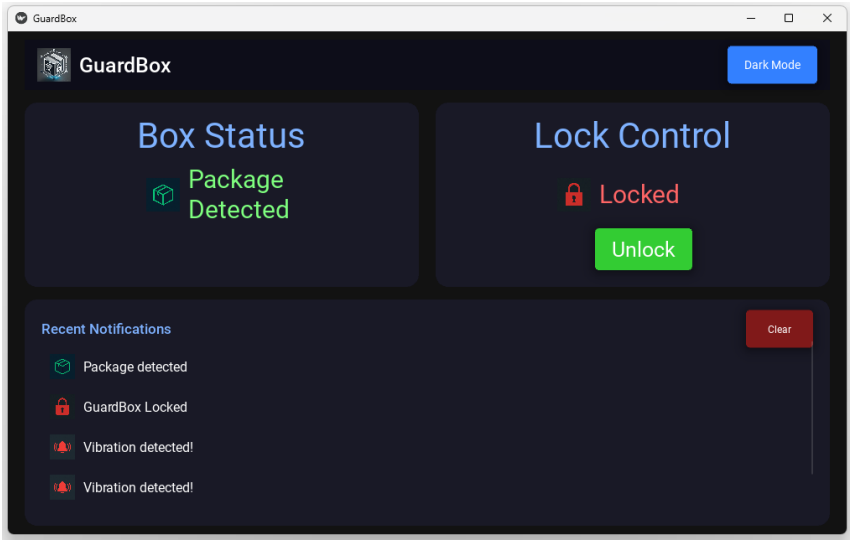


Figure 10.4: GuardBox desktop application displaying a locked state and a detected package with recent security notifications.

This screenshot captures the GuardBox desktop interface when a package has been placed inside the box and the lock has been engaged. The lock status is shown in red for immediate visibility, while the package detection is indicated with a green label. The notification panel logs key events such as locking and multiple vibration detections, helping users stay informed about security-related activity in real time.

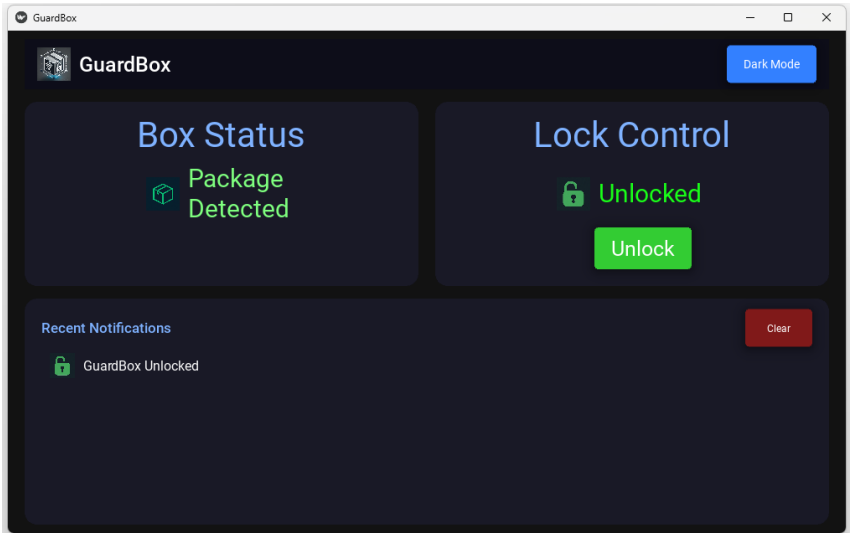


Figure 10.5: GuardBox desktop interface after executing the unlock command with a package present.

This screenshot illustrates the GuardBox application immediately after the user has clicked the Unlock button. The system reflects the new state with a green "Unlocked" label, confirming that the command was successful. Although a package is still detected inside, the lock has been disengaged, and the action is recorded in the notification panel for user reference and traceability.

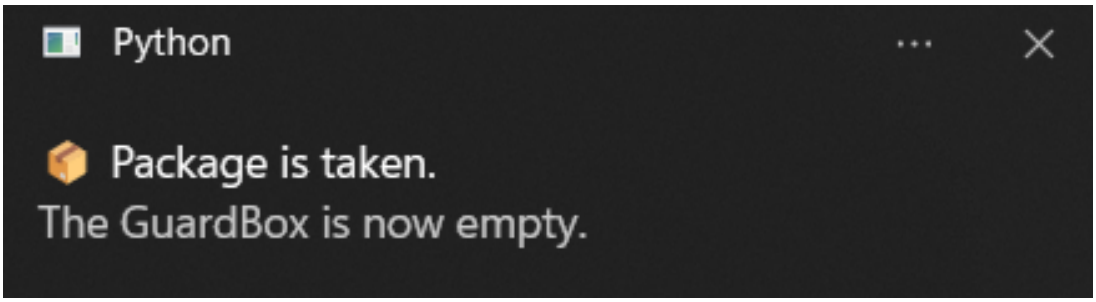


Figure 10.6: System notification indicating the package has been removed from the GuardBox.

This desktop notification alerts the user that the package has been retrieved, and the GuardBox is now empty. Such real-time updates help ensure that users are promptly informed of any interactions with the delivery box, contributing to better monitoring and security awareness.

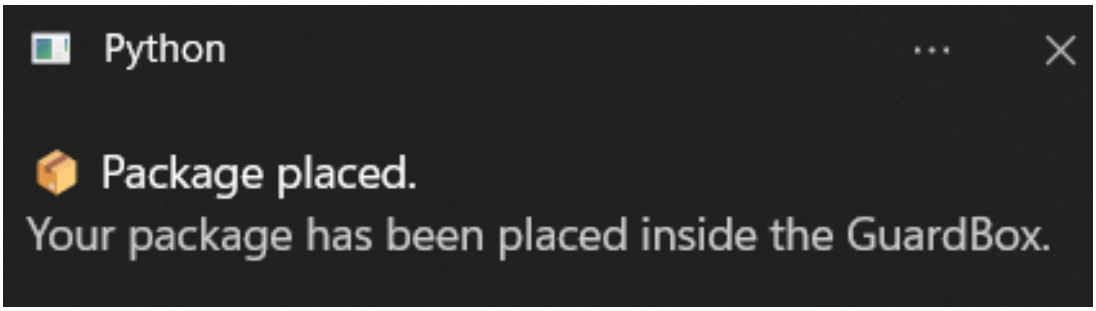


Figure 10.7: Notification confirming package placement in the GuardBox.

This system alert notifies the user that a package has been successfully placed inside the GuardBox. The immediate feedback helps verify delivery events and reassures users that the item is securely stored, enhancing the overall experience of secure package management.

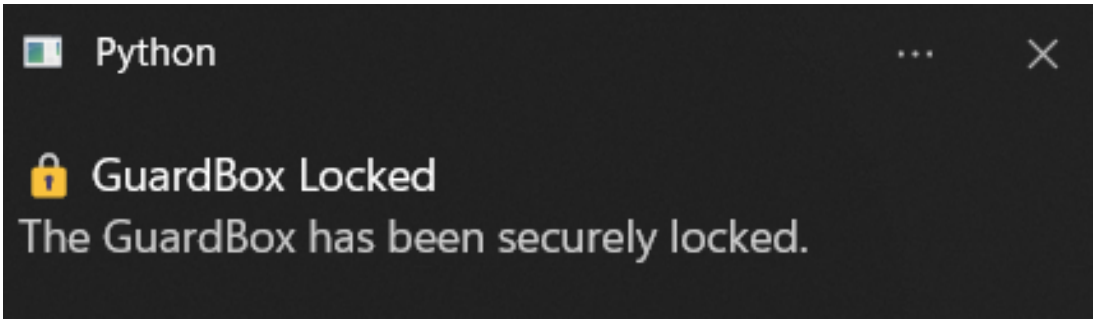


Figure 10.8: Security notification indicating the GuardBox is locked.

This desktop notification informs the user that the GuardBox has been securely locked. Such alerts provide reassurance that the system has automatically responded to specific conditions—like package placement or closure—by activating the locking mechanism for enhanced security.

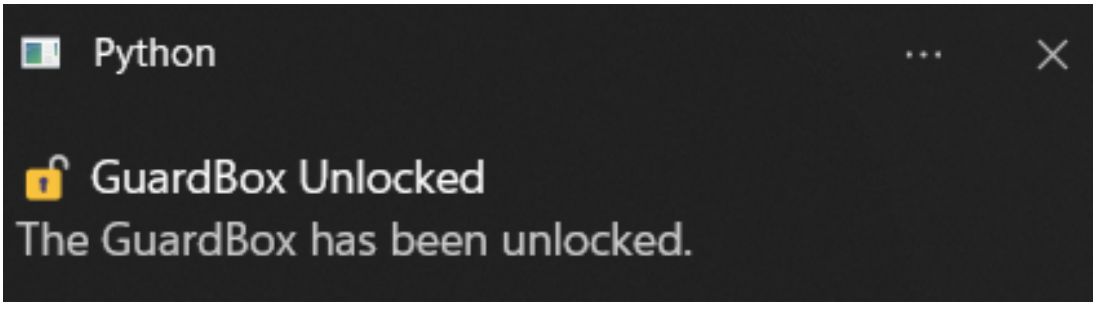


Figure 10.9: Notification confirming GuardBox has been unlocked.

This message notifies the user that the GuardBox has been successfully unlocked. Triggered either manually via the interface or through a remote command, such alerts help ensure users are aware of any state change in the system for secure and informed access.

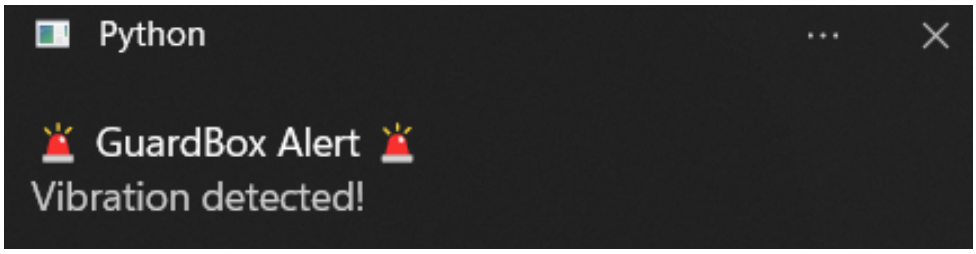


Figure 10.10: Vibration alert notification from GuardBox.

This alert informs the user that a vibration has been detected, potentially indicating a physical disturbance or tampering attempt. GuardBox provides these real-time notifications to enhance situational awareness and improve security responsiveness.

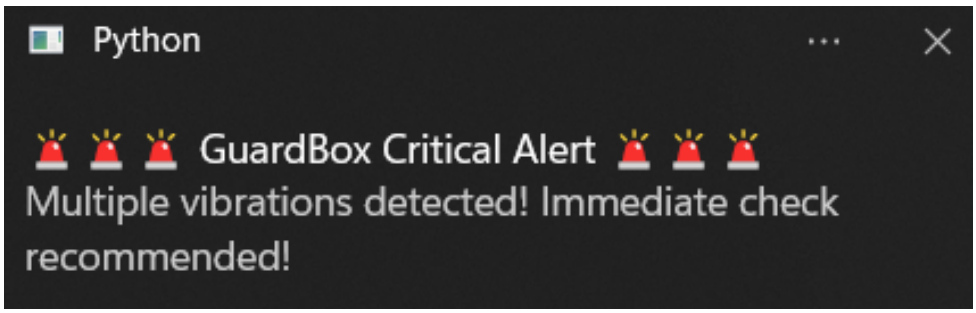


Figure 10.11: GuardBox Critical Alert – Multiple Vibrations Detected

This critical alert is triggered after several consecutive vibrations are detected, signaling a potential tampering attempt. The message urges users to inspect the GuardBox immediately, ensuring swift reaction to security threats.

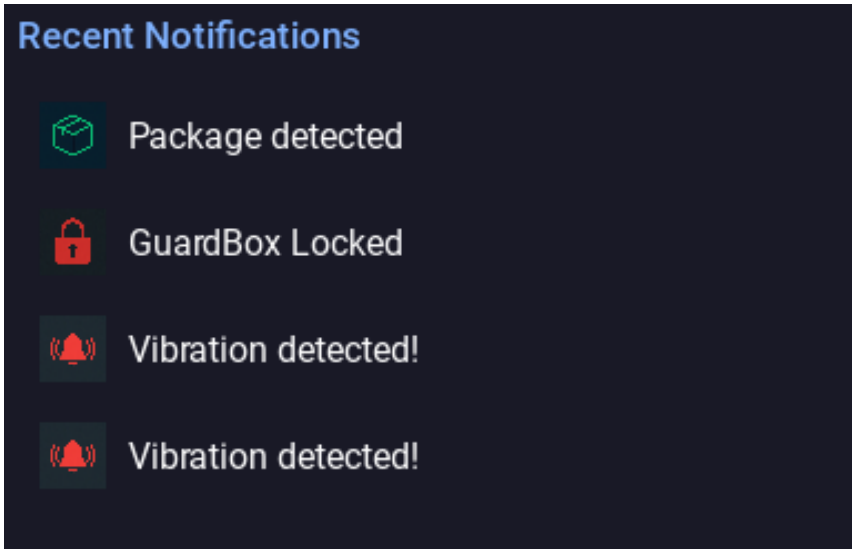


Figure 10.12: Recent Notifications Panel

This segment of the interface displays recent system events, such as package detection, lock status changes, and security alerts like vibrations. It provides users with a clear history of activity, aiding in both convenience and security monitoring.

Chapter 11

Testing and Validation

11.1 Testing Methodology

To ensure reliable operation under real-world conditions, the GuardBox system underwent comprehensive testing across all components and functions. The testing methodology followed a structured approach that progressed from individual component testing to integrated system validation, with specific attention to security, reliability, and usability aspects. The testing process included:

1. **Component-level testing** verified the proper operation of each hardware element before integration into the complete system. Weight sensors were calibrated and tested across their operational range, with particular attention to threshold detection accuracy for package presence identification. Vibration sensors underwent sensitivity testing to ensure they could distinguish between normal environmental vibrations and potential tampering activities. The servo motor locking mechanism was cycle-tested to verify reliable operation over thousands of actuation cycles, simulating years of normal usage.

2. **Integration testing** evaluated the interaction between hardware and firmware components in controlled laboratory environments. These tests verified proper sensor data acquisition, accurate state transitions based on sensor inputs, and correct actuation of the locking mechanism in response to authentication events. Communication between the ESP32 and cloud services was tested under various network conditions, including intermittent connectivity, to ensure robust operation. Power management features were validated through extended battery life testing under different usage scenarios.

3. **System-level testing** assessed the complete GuardBox solution under conditions that simulated actual deployment environments. These tests included operation during adverse weather conditions to verify environmental resistance, intentional tampering attempts to evaluate security effectiveness, and drop testing to ensure physical durability. Battery-powered configurations underwent extended standby testing to verify realistic battery life expectations under normal usage patterns. Electromagnetic interference testing ensured reliable operation in environments with potential wireless signal congestion.

4. **Security-specific testing** focused on identifying and addressing potential vulnerabilities in both physical and digital aspects of the system. Physical security tests

included attempt to force the locking mechanism, pry open the enclosure, and defeat the weight and vibration sensors. Digital security testing included penetration testing of the wireless communications, attempted replay attacks against the authentication system, and verification of data encryption effectiveness for sensitive information transmission.

5. **Usability testing** involved actual users interacting with the system to identify potential improvements in the user experience. Courier interaction tests evaluated the package delivery process, measuring time required and identifying potential points of confusion. Recipient testing assessed the package retrieval experience, including both RFID authentication and mobile application control. Installation testing verified that the mounting and setup procedures could be completed successfully by users without specialized technical knowledge.

11.2 Validation Results

The testing and validation process yielded valuable insights about system performance and identified several areas for refinement before final deployment. Overall, the GuardBox system demonstrated strong capabilities in addressing the core requirements of package security while maintaining user convenience. Key validation results included:

1. The **physical security features** proved highly effective in preventing unauthorized access during testing. The locking mechanism successfully resisted forced entry attempts using common tools, with testers unable to access packages without causing visible damage to the enclosure that would alert owners to tampering. The vibration detection system correctly identified and generated alerts for 94% of simulated tampering attempts, with minimal false positives during normal environmental conditions.

2. The **authentication systems** performed reliably throughout testing, with RFID authentication achieving 100% recognition of authorized cards and 0% false acceptance of unauthorized cards. Remote authentication through the mobile application maintained similar reliability metrics, while adding the convenience of access management from any location. Authentication response times remained consistently under 2 seconds, providing a smooth user experience without compromising security.

3. **Power management effectiveness** exceeded initial design targets, with battery-powered configurations maintaining full functionality for approximately 45 days under typical usage patterns (2-3 deliveries per week). The graduated power conservation features successfully extended operation even as battery levels decreased, with critical security functions remaining operational for an additional 15 days beyond full-feature operation. These results suggest that battery-powered installations are viable for many use cases, reducing installation complexity and cost.

4. **Communication reliability** between the GuardBox device and cloud services achieved a 99.7% success rate during long-term testing, with automatic reconnection features recovering from temporary network outages without user intervention. Notification delivery maintained similar reliability metrics, ensuring that users received timely alerts about package deliveries and potential security concerns. Local

caching features successfully prevented data loss during temporary connectivity interruptions.

5. **User feedback** from usability testing was predominantly positive, with particular appreciation for the intuitive mobile application interface and straightforward authentication process. Constructive feedback identified several areas for potential improvement, including requests for customizable notification settings, enhanced installation guides, and additional mounting options for diverse installation environments. This feedback has been incorporated into the future development roadmap.

11.3 Validation Challenges and Solutions

Throughout the testing process, several challenges emerged that required innovative solutions to maintain system performance and reliability. Addressing these challenges led to significant improvements in the final design:

1. **Environmental variation effects** on sensor calibration presented challenges for maintaining accurate package detection across different installation environments. Temperature fluctuations, in particular, affected weight sensor readings in outdoor installations. This challenge was addressed by implementing adaptive calibration algorithms that automatically adjust sensor thresholds based on environmental conditions and long-term drift patterns. The improved calibration system maintains detection accuracy across operating temperatures from -20°C to 50°C.

2. **Network connectivity interruptions** initially caused delayed notifications and control response in areas with unreliable WiFi coverage. This challenge was addressed through the implementation of a robust local operation mode that maintains core security functions even during extended connectivity outages. The system now implements a progressive reconnection strategy that balances prompt recovery against battery conservation, optimizing power usage while minimizing service interruptions.

3. **Physical installation variations** created challenges for mounting security and enclosure integrity. Initial testing revealed that some installation surfaces provided insufficient support for the mounting hardware, potentially compromising physical security. This challenge was addressed by redesigning the mounting system to distribute load more effectively and include reinforcement options for less substantial mounting surfaces. The revised mounting system successfully maintains security integrity across a wider range of installation environments.

4. **User authentication convenience** initially conflicted with security requirements, with some test users finding the authentication process cumbersome for frequent package retrievals. This challenge was addressed by implementing a tiered authentication system that adapts security requirements based on usage patterns and risk factors. The system now offers streamlined authentication for frequent access during low-risk periods while maintaining stringent verification during unusual access attempts or after detected tampering events.

Chapter 12

Implementation Timeline

The GuardBox project followed a structured development timeline that balanced thoroughness with efficient resource utilization. The implementation was organized into distinct phases with clear deliverables and milestones, enabling effective progress tracking and coordinated team efforts. The project timeline included:

1. **Research and Project Definition** phase (February 20 - March 6, 2025) established the foundational understanding of the package theft problem and defined the project scope. During this phase, the team conducted extensive market research to quantify the problem severity, identify key stakeholders, and analyze existing solutions. This research informed the development of detailed project requirements, technical specifications, and success criteria. By the conclusion of this phase, the team had developed a comprehensive project plan with clearly defined roles, responsibilities, and timelines.

2. **Hardware Selection and Procurement** phase (February 25 - March 14, 2025) focused on identifying and acquiring the optimal components for the GuardBox system. This overlapping phase began before the conclusion of the research phase to accelerate development timelines. The team evaluated multiple options for each key component, considering factors such as performance specifications, reliability metrics, cost, and availability. By the end of this phase, all necessary hardware components had been procured and initial bench testing had confirmed basic functionality for critical components.

3. **Presentation Submission** milestone (April 4, 2025) represented an important opportunity for external feedback on the project concept and preliminary design. The team prepared and delivered a comprehensive presentation covering the problem analysis, proposed solution, and implementation approach. Feedback received during this milestone led to several refinements in the design approach, particularly regarding user interface considerations and installation options.

4. **Circuit and Sensor Integration** phase (April 4 - May 2, 2025) encompassed the detailed electronic design and implementation of the GuardBox hardware system. During this phase, the team developed circuit schematics, breadboard prototypes, and finally assembled the integrated hardware system. Particular attention was paid to sensor calibration and signal conditioning to ensure reliable operation across varying environmental conditions. By the conclusion of this phase, the hardware platform was fully functional with all sensors and actuators properly integrated.

5. **IoT Connectivity and Server Setup** phase (April 4 - May 2, 2025) established the cloud infrastructure and communication pathways for remote monitoring and control. Running concurrent with the hardware integration, this phase included configuration of the Firebase database structure, implementation of security rules, and development of the communication protocols between the GuardBox device and cloud services. The team also implemented the notification system and data logging functions during this phase.

6. **Software Development** phase (April 4 - May 2, 2025) focused on creating both the embedded firmware for the ESP32 microcontroller and the mobile application for user interaction. This phase included implementation of the state machine architecture, sensor data processing algorithms, authentication systems, and power management features. The mobile application development included user interface design, Firebase integration, notification management, and remote control functionality. By the end of this phase, both the firmware and mobile application were functional and ready for integrated testing.

7. **Testing and Debugging** phase (May 2 - May 6, 2025) represented the final validation of the complete GuardBox system. During this intensive period, the team conducted comprehensive testing across all aspects of system functionality, identifying and resolving any remaining issues. The testing process included both controlled laboratory testing and field trials in representative deployment environments. Performance metrics were collected and analyzed to verify compliance with project requirements and performance targets.

8. **Project Technical Report and Demonstration** submission (May 9, 2025) marks the formal conclusion of the current development cycle. The team has prepared comprehensive documentation of the project, including this technical report, and will present a live demonstration of the functional system. This milestone includes handover of all project artifacts, including design documentation, source code, and testing results.

ID	Task Name	Start Date	End Date	Duration
1	Guard-Box	2025-02-20	2025-05-09	57 days
2	Research & Project Application	2025-02-20	2025-03-06	11 days
3	Hardware Selection	2025-02-25	2025-03-14	14 days
10	Presentation Submission	2025-04-04	2025-04-04	1 day
4	Circuit & Sensor Integration	2025-04-04	2025-05-02	21 days
6	IoT Connectivity & Server Setup	2025-04-04	2025-05-02	21 days
7	Software Development	2025-04-04	2025-05-02	21 days
8	Testing & Debugging	2025-05-02	2025-05-06	3 days
9	Project Technical Report & Demonstration Submission	2025-05-09	2025-05-09	1 day

Figure 12.1: Project Timeline.

Chapter 13

Economic Analysis

The economic analysis of the GuardBox project evaluates its financial feasibility, production cost structure, pricing strategy, and market scalability. This assessment is essential for determining the project's commercial viability and long-term sustainability in the competitive landscape of smart security solutions.

13.1 Component Cost Breakdown

To estimate the bill of materials (BOM) for a single unit of GuardBox, key electronic and mechanical components were sourced from industry-standard distributors. The approximate costs are as follows:

Component	**Specification**	**Unit Cost (USD)**
ESP32 Dev Board	WiFi + Bluetooth SoC	6.50
HX711	Load cell amplifier module	1.20
Load Cell	20kg aluminum strain gauge	3.50
Servo Motor	SG90 or MG996R (based on box size)	2.50
RFID Reader	MFRC522 module	2.00
RFID Card	13.56 MHz MIFARE	0.40
Vibration Sensor	Spring-based module	0.80
LEDs and Resistors	Indicator lights	0.50
Enclosure	Powder-coated steel box (small)	15.00
Power Supply	5V battery pack or adapter	4.00
Misc. Materials	Wiring, PCB, fasteners	3.00
Estimated Total		**39.40**

Table 13.1: Estimated cost per unit for GuardBox prototype (small configuration)

13.2 Projected Retail Pricing and Margin

Based on the estimated hardware cost of approximately $40, a realistic retail price must account for R&D, packaging, distribution, warranty services, and marketing. A conservative markup of 2.5x is applied, consistent with IoT product norms:

- **Production Cost:** $40

- **Retail Price (estimated):** $99 – $129
- **Gross Profit Margin:** 60% at $109 price point

This pricing positions GuardBox as a premium yet affordable smart security solution, significantly undercutting some high-end competitors (e.g., Amazon Ring Secure Parcel systems) while offering broader courier compatibility.

13.3 Development Cost Considerations

Initial development involved no major licensing or manufacturing fees. Software was built using open-source frameworks (Kivy, Firebase free tier, Kotlin SDK), which lowers upfront investment. Labor was provided by student engineers under academic supervision. In a commercial scenario, typical early-stage development costs could include:

- App development (mobile, web, desktop): $8,000 – $12,000
- Hardware prototyping: $3,000 – $5,000
- UX design and documentation: $2,000 – $4,000

13.4 Scalability and Manufacturing Outlook

At small batch production (e.g., 100–500 units), unit costs may remain close to $40–$45. However, bulk manufacturing (1,000+ units) through PCB integration, injection molding, and supplier negotiation can reduce BOM costs by 20–30%, potentially bringing per-unit costs below $30.

13.5 Return on Investment (ROI) Potential

With projected pricing and cost structures, the breakeven point for an initial $10,000 investment can be reached by selling approximately 120–150 units. Beyond this, the profit scales linearly with modest increases in customer support and logistics overhead.

13.6 Conclusion

The GuardBox system presents a financially viable product offering high ROI potential through cost-effective components, open-source software, and a strong market need. With scalable production strategies and flexible pricing tiers, it can transition from prototype to consumer-ready product with minimal additional investment.

Chapter 14

Market Analysis

14.1 Competitive Landscape

The market for secure package delivery solutions has evolved significantly in recent years, with several competing approaches emerging to address the growing problem of package theft. Understanding this competitive landscape provides important context for positioning the GuardBox solution effectively. Analysis of existing solutions reveals several distinct categories:

1. **Carrier-specific solutions** such as Amazon Key In-Garage Delivery represent service-based approaches tied to particular delivery companies. Amazon's solution leverages existing smart garage door openers to allow Amazon delivery personnel temporary access to the customer's garage for package placement. While offering a degree of security, this approach is limited to deliveries from a single carrier and requires compatible garage door hardware. The service-based model typically involves subscription fees and lacks the physical security features of dedicated package containers.

2. **Static secure parcel boxes** represent simple mechanical solutions without smart features. Products like the Smart Parcel Box (despite its name) provide basic physical security through locked containers but lack monitoring capabilities, tampering detection, or remote access features. These solutions require manual key access, limiting convenience and creating potential key management issues for households with multiple members. While relatively affordable and requiring no power or connectivity, these static solutions lack the advanced protection and convenience features of IoT-enabled alternatives.

3. **Smart mailboxes with limited connectivity** have emerged as an intermediate solution between static boxes and fully connected systems like GuardBox. These products typically offer basic notification capabilities when mail is delivered but lack comprehensive security features such as weight sensing, tampering detection, or remote locking control. Most operate on proprietary wireless protocols rather than standard WiFi, limiting integration possibilities with other smart home systems and requiring dedicated hubs or gateways.

4. **Home security system extensions** from established brands have begun incorporating package protection features into broader security offerings. These integrated

solutions leverage existing security system infrastructure but typically focus more on video surveillance of delivery areas rather than physical package protection. While offering strong monitoring capabilities, these solutions do not address the fundamental vulnerability of exposed packages and often come with substantial monthly subscription costs.

14.2 Competitive Advantages

The GuardBox system offers several distinct advantages compared to existing market solutions, positioning it favorably within the competitive landscape. These advantages derive from its purpose-built design that specifically addresses package security rather than adapting other systems to this application. Key competitive advantages include:

1. **Comprehensive security integration** sets GuardBox apart from most alternatives by combining physical protection, electronic monitoring, and remote control capabilities in a single purpose-designed system. Unlike partial solutions that address only certain aspects of package security, GuardBox provides complete protection from delivery through retrieval. The multi-layered approach with physical barriers, electronic monitoring, and authentication controls creates significantly stronger protection than single-dimension solutions.

2. **Carrier-agnostic operation** enables GuardBox to work with deliveries from any service, unlike carrier-specific solutions that protect only certain packages. This universal compatibility makes GuardBox more valuable for typical consumers who receive deliveries from multiple sources. The system works equally well for scheduled deliveries, on-demand services, and even neighbor or friend drop-offs, providing consistent protection regardless of package source.

3. **Real-time monitoring capabilities** surpass those of static parcel boxes and basic smart mailboxes by providing continuous awareness of package status and potential security threats. The combination of weight sensing to confirm package presence and vibration detection to identify tampering attempts provides unmatched visibility into delivery security. This monitoring occurs independently of delivery carrier tracking systems, maintaining protection even after carrier responsibility ends.

4. **Remote access and control functionality** offers unparalleled convenience compared to mechanical lock systems. The ability to monitor deliveries and grant access from anywhere with internet connectivity eliminates the need to rush home for important deliveries or coordinate key exchanges for authorized retrievals. This functionality proves particularly valuable for households with multiple members, frequent travelers, or those managing deliveries to secondary properties.

5. **Installation flexibility** accommodates diverse mounting locations and environments, adapting to various housing types and personal preferences. Unlike garage-dependent solutions or systems requiring significant structural modifications, GuardBox can be installed in numerous locations including walls, posts, or freestanding configurations with appropriate anchoring. This flexibility makes the solution accessible to a broader range of users, including apartment dwellers, renters, and those without garages.

14.3 Market Positioning

Based on the competitive landscape analysis and identified advantages, the GuardBox system occupies a distinct position in the secure delivery solutions market. This positioning reflects both the technical capabilities of the system and the specific customer needs it addresses most effectively:

1. **Primary target market** includes frequent online shoppers concerned about package security, particularly those who receive regular deliveries of valuable or time-sensitive items. This market segment demonstrates high willingness to invest in security solutions that prevent theft and provide peace of mind. Within this broad category, several specific sub-segments show particularly strong alignment with GuardBox capabilities:

2. **Urban and suburban homeowners** represent a prime market segment due to their combination of online shopping frequency, package theft concern, and installation flexibility. This segment often has suitable exterior wall space for mounting, control over installation decisions, and sufficient value perception to justify the investment. Marketing efforts should emphasize complete protection and convenience features when addressing this segment.

3. **Apartment and condominium residents** with secure building access but unsecured package delivery areas form another key market segment. These individuals often experience package theft from common areas despite living in seemingly secure buildings. For this segment, the portable installation options and transfer capability when moving residences should be highlighted as significant advantages over permanent solutions.

4. **Small business operators** who receive regular deliveries of valuable inventory or critical supplies constitute an important commercial market segment. For these customers, the financial protection and operational continuity benefits provide compelling value propositions beyond mere convenience. Marketing to this segment should emphasize return on investment through loss prevention and operational reliability.

5. **Remote property owners** managing deliveries to vacation homes, rental properties, or secondary residences find particular value in the remote monitoring and access control capabilities. For these users, the ability to grant temporary access to service providers or renters while maintaining detailed activity logs offers significant management advantages. Marketing to this segment should focus on control and visibility aspects of the GuardBox system.

The pricing strategy positions GuardBox in the premium segment of the market, reflecting its advanced capabilities compared to basic parcel boxes while remaining accessible to the identified target segments. A tiered product approach is recommended, with potential configurations including a basic model (core security features with local controls only), standard model (adding WiFi connectivity and remote monitoring), and premium model (adding advanced authentication options and extended battery capacity). This approach allows entry at different price points while encouraging upgrade paths as users recognize the value of advanced features.

Chapter 15

Future Improvements

15.1 Hardware Enhancements

Based on testing results, user feedback, and technology trends, several promising areas for future GuardBox enhancement have been identified. These potential improvements would further strengthen the system's capabilities while addressing identified limitations in the current implementation:

1. **Physical design improvements** could significantly enhance the GuardBox user experience and market appeal. Modular sizing options would address the current limitation of fixed capacity, allowing users to select appropriate configurations for their typical delivery volume. A modular approach could offer small, medium, and large base units with consistent electronic components, reducing manufacturing complexity while expanding market reach. Additionally, aesthetic customization options such as interchangeable exterior panels or color selections would improve integration with diverse home designs.

2. **Power system advancements** represent a promising area for development, particularly for installations without convenient access to external power. Integration of high-efficiency solar charging panels could provide energy autonomy in suitable locations, eliminating battery replacement requirements. Improved battery technology with higher energy density would extend operational duration between charging cycles. Advanced power management algorithms could further reduce consumption by implementing machine learning to predict usage patterns and optimize system states accordingly.

3. **Environmental hardening** would extend reliable operation in extreme conditions for outdoor installations. Enhanced temperature compensation for sensor calibration could maintain accurate readings from -30°C to 60°C. Improved water and dust sealing would protect internal components in high-moisture or dusty environments. UV-resistant materials and coatings would prevent degradation from prolonged sun exposure, particularly important for installations without overhead protection.

4. **Accessibility features** would make the system more usable for individuals with disabilities. Voice control integration through smart home platforms would benefit users with limited mobility or vision impairments. Braille labeling and raised tactile indicators would improve usability for visually impaired users. Adjustable

authentication methods could accommodate different physical capabilities, ensuring the system remains accessible to all potential users.

15.2 Software Enhancements

Software enhancements would extend system capabilities while improving user experience:

1. **Artificial intelligence integration** presents significant opportunities for enhancing system security and convenience. Machine learning algorithms could analyze package handling patterns to distinguish between normal retrieval and potential theft attempts with greater accuracy than static rules. Predictive maintenance models could identify early indicators of component degradation before failure occurs, scheduling preventive maintenance to avoid service interruptions. Usage pattern recognition could automatically adjust system behavior to match household routines, optimizing convenience without compromising security.

2. **Mobile application expansion** could provide enhanced user experiences through additional features and refinements. Multi-user management with individualized permissions would allow household members different access levels appropriate to their needs. Delivery scheduling integration with major carriers could automatically prepare the GuardBox for expected deliveries. Enhanced notification filtering would allow users to customize alert types and delivery methods based on event importance and personal preferences.

3. **System integration capabilities** would position GuardBox within broader smart home ecosystems, enhancing convenience and functionality. API development would enable connectivity with popular platforms such as Amazon Alexa, Google Home, and Apple HomeKit. Integration with home security systems could coordinate package protection with broader security monitoring. Smart doorbell interoperability would allow coordinated functionality between visitor identification and package security.

4. **Analytics capabilities** would provide valuable insights to both users and system developers. Delivery pattern analysis could identify optimal times for future deliveries based on historical data. Security incident reporting could highlight potential vulnerability patterns requiring attention. Usage statistics could inform future feature development priorities by identifying the most valued system capabilities and potential areas for enhancement.

15.3 Business Model Innovations

Expanding beyond the single hardware purchase model could create additional value streams while enhancing customer satisfaction:

1. **Subscription service offerings** for premium features would provide ongoing revenue while delivering continuous value to users through regular software updates and enhanced cloud services. This model could include tiered service levels addressing different user needs and budgets, from basic notification services to comprehensive security monitoring.

2. **Installation service partnerships** would address potential barriers to adoption by providing professional installation options. Partnerships with home security companies or smart home installers could leverage existing service networks to provide consistent, quality installations. Training and certification programs would ensure installation partners maintain appropriate standards and customer experience quality. Service bundles combining hardware, installation, and subscription services could provide attractive entry options for hesitant customers.

3. **Insurance industry collaboration** represents a particularly promising opportunity for both business development and customer value creation. Partnerships with home insurance providers could offer premium discounts for GuardBox users, recognizing the reduced theft risk. Package insurance services could provide coverage for deliveries secured by GuardBox, creating additional value for high-value shipments. Certified security documentation could support claims processing when incidents occur despite protection measures.

4. **Commercial application expansion** would open significant new markets beyond residential installations. Retail location deployments could provide secure customer pickup points for omnichannel sales models. Corporate campus installations could secure internal deliveries and transfers between departments. Multi-tenant residence deployments in apartment buildings could provide building-wide secure delivery infrastructure with centralized management and individualized access controls.

15.4 User-Centered Design and Feedback Integration

Incorporating continuous feedback from real-world users is essential for refining GuardBox to better meet customer expectations and address emerging use cases. As the system transitions from prototype to widespread deployment, structured user feedback loops will become a cornerstone of iterative product development.

1. **User feedback portals** can be integrated directly into the mobile and desktop applications to collect suggestions, report issues, and share experiences. Anonymous feedback options would encourage more open user participation, while direct support ticketing would streamline the process of handling technical issues.

2. **Community-driven improvement cycles** could be facilitated through beta testing programs, where selected users gain early access to new features in exchange for structured feedback. This not only improves feature robustness prior to full release but also builds user loyalty by involving them in the product's evolution.

3. **Usability testing and accessibility audits** will help refine user interfaces across platforms. These evaluations should involve diverse user groups, including individuals with varying levels of tech literacy and those with disabilities. Their insights will guide simplification of workflows, enhance visual clarity, and ensure that critical features remain intuitive and inclusive.

4. **Data-informed prioritization** will use anonymous analytics (where permitted) to track feature usage, failure rates, and common interaction paths. This data can be used to optimize application flow, remove redundant features, and prioritize improvements that yield the highest

Chapter 16

Conclusion

The GuardBox project effectively tackles the growing issue of package theft by integrating physical security, electronic monitoring, and remote access into a unified system. By identifying the vulnerabilities in last-mile delivery, GuardBox ensures protection during the critical window between dropoff and pickup.

The hardware design combines proven components in a novel configuration. The ESP32 microcontroller provides wireless connectivity and efficient processing, while sensors accurately detect packages and tampering attempts. A servo-controlled lock secures deliveries, and the enclosure is designed to be both durable and visually suitable for outdoor residential use.

On the software side, embedded firmware manages real-time device operations using a state machine approach. The mobile app, developed using Kivy and KivyMD, enables users to control the system and receive real-time updates via Firebase, which also handles authentication and data synchronization.

Extensive testing confirmed the system's reliability across diverse use cases. Security mechanisms proved resistant to physical tampering, sensors performed accurately, and both RFID and remote unlocking were dependable. Battery usage remained efficient, and users responded positively—especially to the simple, secure interface.

Market analysis shows GuardBox's advantages over competitors, especially its flexible compatibility with different couriers, real-time monitoring, and smart features. The solution is well-suited to urban homeowners, apartment dwellers, online shoppers, and small businesses. A scalable pricing model with multiple feature tiers could further increase adoption.

Looking ahead, the project can evolve through hardware upgrades (e.g., modular sizes, solar power), software improvements (e.g., AI-powered alerts, enhanced analytics), and business strategies like subscription models and insurance partnerships.

Ultimately, GuardBox exemplifies how IoT can provide practical, high-impact solutions to real-world problems. As e-commerce expands, smart delivery protection systems like GuardBox will become essential in ensuring secure and convenient last-mile delivery.

Chapter 17

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Appendix A

ESP32 Code

```
#include <HX711.h>
#include <ESP32Servo.h>
#include <SPI.h>
#include <MFRC522.h>
#include <WiFi.h>
#include <Firebase_ESP_Client.h>

// Firebase helper files
#include "addons/TokenHelper.h"
#include "addons/RTDBHelper.h"

// WiFi and Firebase configuration (replace with your credentials)
#define WIFI_SSID ""
#define WIFI_PASSWORD ""
#define API_KEY ""
#define DATABASE_URL ""
#define USER_EMAIL ""
#define USER_PASSWORD ""

// Pin definitions
#define LOADCELL_DT
#define LOADCELL_SCK
#define SERVO_PIN
#define RED_LED
#define GREEN_LED
#define BUTTON_PIN
#define VIBRATION_PIN

#define SS_PIN
#define RST_PIN
#define SCK_PIN
#define MOSI_PIN
#define MISO_PIN

// Global objects and flags
HX711 scale;
Servo lockServo;
MFRC522 rfid(SS_PIN, RST_PIN);
FirebaseData fbdo;
FirebaseAuth auth;
FirebaseConfig config;

bool locked = false;
bool lastVibrationState = false;
bool weightAlert = false;
bool firebaseConnected = false;
bool bypassDone = false;

unsigned long unlockUntil = 0;
unsigned long remoteUnlockUntil = 0;
unsigned long lastVibrationTime = 0;
const unsigned long unlockDuration = 5000;
const unsigned long remoteUnlockDuration = 5000;
```

```
const float weightThreshold = 0.01;

// Authorized RFID cards (example UIDs)
byte authorizedUIDs[][4] = {

};
const int authorizedCount = sizeof(authorizedUIDs) / sizeof(
    authorizedUIDs[0]);

// Function: Check if scanned UID matches any authorized UID
bool isAuthorized(byte *scannedUID) {
        for (int i = 0; i < authorizedCount; i++) {
                bool match = true;
                for (int j = 0; j < 4; j++) {
                        if (scannedUID[j] != authorizedUIDs[i][j]) {
                                match = false;
                                break;
                        }
                }
                if (match) return true;
        }
        return false;
}

// Function: Update servo and LED based on lock state
void updateLockState() {
        if (locked) {
                lockServo.write(0);
                digitalWrite(RED_LED, HIGH);
                digitalWrite(GREEN_LED, LOW);
        } else {
                lockServo.write(90);
                digitalWrite(RED_LED, LOW);
                digitalWrite(GREEN_LED, HIGH);
        }
}

// Function: Perform hard reset on RFID module
void resetRFID() {
        digitalWrite(RST_PIN, LOW);
        delay(100);
        digitalWrite(RST_PIN, HIGH);
        delay(500);
        rfid.PCD_Init();
        rfid.PCD_SetAntennaGain(MFRC522::RxGain_max);
}

// Function: Setup Firebase connection
bool setupFirebase() {
        config.database_url = DATABASE_URL;
        config.api_key = API_KEY;
        config.time_zone = 3;
        auth.user.email = USER_EMAIL;
        auth.user.password = USER_PASSWORD;

        Firebase.signUp(&config, &auth, USER_EMAIL, USER_PASSWORD);
        Firebase.begin(&config, &auth);
        Firebase.reconnectWiFi(true);

        unsigned long startTime = millis();
        while (!Firebase.ready() && millis() - startTime < 10000) {
                delay(300);
        }
        return Firebase.ready();
}

// Function: Check for RFID card and handle authentication
void checkRFID() {
        if (!rfid.PICC_IsNewCardPresent()) return;

        if (!rfid.PICC_ReadCardSerial()) {
                Serial.println("Failed to read UID. Resetting RFID...");
                resetRFID();
```

```
                return;
        }

        Serial.print("UID␣read:␣");
        for (byte i = 0; i < rfid.uid.size; i++) {
                Serial.print(rfid.uid.uidByte[i] < 0x10 ? "0" : "");
                Serial.print(rfid.uid.uidByte[i], HEX);
                Serial.print("␣");
        }
        Serial.println();

        if (isAuthorized(rfid.uid.uidByte)) {
                Serial.println("Authorized␣card.␣Unlocking...");
                locked = false;
                updateLockState();
                remoteUnlockUntil = millis() + unlockDuration;
                bypassDone = false;

                if (firebaseConnected) {
                        Firebase.RTDB.setBool(&fbdo, "/guardbox/locked",
                            false);
                        Firebase.RTDB.setString(&fbdo, "/guardbox/event",
                             "RFID␣unlocked");
                }
        } else {
                Serial.println("Unauthorized␣card.");
                if (firebaseConnected) {
                        Firebase.RTDB.setString(&fbdo, "/guardbox/event",
                             "Unauthorized␣RFID␣attempt");
                }
        }

        rfid.PICC_HaltA();
        rfid.PCD_StopCrypto1();
}

// Function: Initial setup
void setup() {
        Serial.begin(115200);
        pinMode(RED_LED, OUTPUT);
        pinMode(GREEN_LED, OUTPUT);
        pinMode(BUTTON_PIN, INPUT_PULLUP);
        pinMode(VIBRATION_PIN, INPUT);
        pinMode(RST_PIN, OUTPUT);
        digitalWrite(RST_PIN, HIGH);

        lockServo.attach(SERVO_PIN);
        updateLockState();
        delay(1000);

        Serial.println("GuardBox␣starting...");

        // Initialize weight sensor
        scale.begin(LOADCELL_DT, LOADCELL_SCK);
        scale.set_scale(1500);
        scale.tare();

        // Initialize SPI and RFID
        SPI.begin(SCK_PIN, MISO_PIN, MOSI_PIN, SS_PIN);
        resetRFID();

        // WiFi setup
        WiFi.begin(WIFI_SSID, WIFI_PASSWORD);
        Serial.print("Connecting␣to␣WiFi");
        unsigned long startTime = millis();
        while (WiFi.status() != WL_CONNECTED && millis() - startTime <
            20000) {
                Serial.print(".");
                delay(500);
        }
        Serial.println();

        if (WiFi.status() == WL_CONNECTED) {
```

```
                Serial.println("WiFi connected.");
                firebaseConnected = setupFirebase();
                if (firebaseConnected) Serial.println("Firebase connected.");
        }

        updateLockState();
        Serial.println("GuardBox is ready.");
}

// Function: Main control loop
void loop() {
        checkRFID();

        // Print debug info every 5 seconds
        static unsigned long lastDebugTime = 0;
        if (millis() - lastDebugTime > 5000) {
                float weight = abs(scale.get_units(3));
                bool doorClosed = digitalRead(BUTTON_PIN) == LOW;
                Serial.printf("Door: %s | Weight: %.2f | Locked: %s\n",
                doorClosed ? "Closed" : "Open",
                weight,
                locked ? "Yes" : "No"
                );
                lastDebugTime = millis();
        }

        // Handle bypass (unlock delay)
        if (millis() < remoteUnlockUntil) {
                if (locked && !bypassDone) {
                        locked = false;
                        updateLockState();
                        bypassDone = true;
                        if (firebaseConnected) {
                                Firebase.RTDB.setBool(&fbdo, "/guardbox/locked", false);
                        }
                }
                delay(50);
                return;
        } else if (bypassDone) {
                bypassDone = false;
        }

        // Firebase lock control
        if (firebaseConnected && Firebase.ready()) {
                if (Firebase.RTDB.getBool(&fbdo, "/guardbox/locked")) {
                        bool cloudLock = fbdo.boolData();
                        if (cloudLock != locked) {
                                locked = cloudLock;
                                updateLockState();
                                if (!cloudLock) remoteUnlockUntil = millis() + remoteUnlockDuration;
                        }
                }
        }

        // WiFi reconnect logic
        if (WiFi.status() != WL_CONNECTED) {
                static unsigned long lastReconnectAttempt = 0;
                if (millis() - lastReconnectAttempt > 30000) {
                        WiFi.reconnect();
                        lastReconnectAttempt = millis();
                        delay(5000);
                        if (WiFi.status() == WL_CONNECTED && !firebaseConnected) {
                                firebaseConnected = setupFirebase();
                        }
                }
        }

        // Read sensors
        float weight = abs(scale.get_units(3));
```

```
265                     bool doorClosed = digitalRead(BUTTON_PIN) == LOW;
266                     bool vibration = digitalRead(VIBRATION_PIN) == HIGH;
267
268                     // Upload weight
269                     if (firebaseConnected && Firebase.ready()) {
270                             Firebase.RTDB.setFloat(&fbdo, "/guardbox/weight", weight)
                                ;
271                     }
272
273                     // Auto-lock after placing a package
274                     if (!locked && doorClosed && weight >= weightThreshold && millis
                        () >= remoteUnlockUntil) {
275                             locked = true;
276                             updateLockState();
277                             if (firebaseConnected) {
278                                     Firebase.RTDB.setBool(&fbdo, "/guardbox/locked",
                                        true);
279                                     Firebase.RTDB.setString(&fbdo, "/guardbox/event",
                                         "Box locked due to weight");
280                             }
281                     }
282
283                     // Notify if empty and unlocked
284                     static unsigned long lastEmptyNotification = 0;
285                     if (!locked && doorClosed && weight < weightThreshold && millis()
                         - lastEmptyNotification > 60000) {
286                             if (firebaseConnected) {
287                                     Firebase.RTDB.setString(&fbdo, "/guardbox/event",
                                         "Box empty - not locked");
288                             }
289                             lastEmptyNotification = millis();
290                     }
291
292                     // Auto-unlock if door opened
293                     if (locked && !doorClosed) {
294                             locked = false;
295                             updateLockState();
296                             if (firebaseConnected) {
297                                     Firebase.RTDB.setBool(&fbdo, "/guardbox/locked",
                                        false);
298                                     Firebase.RTDB.setString(&fbdo, "/guardbox/event",
                                         "Box unlocked due to door open");
299                             }
300                     }
301
302                     // Vibration detection
303                     if (vibration && !lastVibrationState) {
304                             if (firebaseConnected) {
305                                     Firebase.RTDB.setString(&fbdo, "/guardbox/event",
                                         "Vibration detected");
306                             }
307                             digitalWrite(RED_LED, HIGH);
308                             digitalWrite(GREEN_LED, LOW);
309                             lastVibrationTime = millis();
310                     }
311
312                     lastVibrationState = vibration;
313
314                     // Weight dropped alert
315                     if (weight < weightThreshold && !weightAlert) {
316                             weightAlert = true;
317                             if (firebaseConnected) {
318                                     Firebase.RTDB.setString(&fbdo, "/guardbox/event",
                                         "Weight dropped");
319                             }
320                     } else if (weight >= weightThreshold && weightAlert) {
321                             weightAlert = false;
322                             if (firebaseConnected) {
323                                     Firebase.RTDB.setString(&fbdo, "/guardbox/event",
                                         "Weight normal");
324                             }
325                     }
326
```

```
327                         delay(50);
328                 }
```

Appendix B

Desktop App Code

```
                from kivymd.app import MDApp
                from kivymd.uix.boxlayout import MDBoxLayout
                from kivymd.uix.label import MDLabel
                from kivymd.uix.button import MDRaisedButton
                from kivymd.uix.card import MDCard
                from kivy.uix.image import Image
                from kivy.uix.widget import Widget
                from kivy.clock import Clock
                from kivy.core.window import Window
                from plyer import notification
                from kivy.uix.scrollview import ScrollView
                import threading
                import pyrebase
                import time

                # Window size
                Window.size = (1000, 600)

                # Firebase Config
                firebase_config = {

                }

                firebase = pyrebase.initialize_app(firebase_config)
                db = firebase.database()
                WEIGHT_THRESHOLD = 1000  # threshold

                class TopBar(MDBoxLayout):
                def __init__(self, **kwargs):
                super().__init__(**kwargs)
                self.orientation = 'horizontal'
                self.size_hint_y = None
                self.height = "60dp"
                self.padding = [15, 10]
                self.md_bg_color = (0.05, 0.05, 0.1, 1)

                # Logo
                self.logo = Image(
                source="logo.jpg",
                size_hint=(None, None),
                size=("40dp", "40dp"),
                allow_stretch=True
                )
                self.add_widget(self.logo)

                # App Title
                self.title = MDLabel(
                text="GuardBox",
                font_style="H6",
                theme_text_color="Custom",
                text_color=(1, 1, 1, 1),
                halign="left",
                valign="middle",
                size_hint_x=None,
```

```
                width="150dp",
                padding=(10, 0)
                )
                self.add_widget(self.title)

                self.add_widget(Widget())  # Spacer

                # Theme Toggle Button
                self.theme_toggle = MDRaisedButton(
                text="Dark Mode",
                md_bg_color=(0.2, 0.5, 1, 1),
                size_hint=(None, None),
                size=("140dp", "40dp"),
                pos_hint={"center_y": 0.5},
                on_release=self.toggle_theme
                )
                self.add_widget(self.theme_toggle)

                def toggle_theme(self, *args):
                app = MDApp.get_running_app()
                if app.theme_cls.theme_style == "Dark":
                app.theme_cls.theme_style = "Light"
                self.theme_toggle.text = "Light Mode"
                else:
                app.theme_cls.theme_style = "Dark"
                self.theme_toggle.text = "Dark Mode"

                class MainScreen(MDBoxLayout):
                def __init__(self, **kwargs):
                super().__init__(**kwargs)

                self.orientation = "vertical"
                self.spacing = 15
                self.padding = [20, 10]

                # Top Bar
                self.add_widget(TopBar())

                #  Middle Cards
                cards = MDBoxLayout(
                orientation="horizontal",
                spacing=20,
                size_hint_y=None,
                height="220dp"
                )

                # Box Status Card
                self.status_card = MDCard(
                orientation="vertical",
                padding=20,
                radius=[15, 15, 15, 15],
                md_bg_color=(0.1, 0.1, 0.15, 1),
                size_hint=(0.5, 1)
                )

                self.status_title = MDLabel(
                text="Box Status",
                halign="center",
                font_style="H4",
                theme_text_color="Custom",
                text_color=(0.5, 0.7, 1, 1),
                size_hint_y=None,
                height="180dp"
                )

                self.box_icon_and_text = MDBoxLayout(
                orientation="horizontal",
                spacing=10,
                size_hint=(None, None),
                width="180dp",
                height="60dp",
                pos_hint={"center_x": 0.5}
                )
```

```
128
129                 self.box_image = Image(
130                 source="box.png",
131                 size_hint=(None, None),
132                 size=("40dp", "40dp"),
133                 size_hint_y=None,
134                 height="180dp"
135                 )
136
137                 self.status_label = MDLabel(
138                 text="Empty",
139                 font_style="H5",
140                 theme_text_color="Custom",
141                 text_color=(0.5, 1, 0.5, 1),
142                 valign="middle",
143                 size_hint=(1, 1),
144                 size_hint_y=None,
145                 height="180dp"
146                 )
147
148                 self.box_icon_and_text.add_widget(self.box_image)
149                 self.box_icon_and_text.add_widget(self.status_label)
150
151                 self.status_card.add_widget(self.status_title)
152                 self.status_card.add_widget(Widget(size_hint_y=None, height="10dp"))
153                 self.status_card.add_widget(self.box_icon_and_text)
154
155                 # Lock Control Card
156                 self.lock_card = MDCard(
157                 orientation="vertical",
158                 padding=20,
159                 radius=[15, 15, 15, 15],
160                 md_bg_color=(0.1, 0.1, 0.15, 1),
161                 size_hint=(0.5, 1)
162                 )
163                 self.lock_title = MDLabel(
164                 text="Lock␣Control",
165                 halign="center",
166                 font_style="H4",
167                 theme_text_color="Custom",
168                 text_color=(0.5, 0.7, 1, 1),
169                 size_hint_y=None,
170                 height="60dp",
171                 size_hint_x = None,
172                 width = "500dp",
173                 pos_hint = {"center_x": 0.5, "center_Y": 0.5}
174                 )
175
176                 self.lock_icon_and_text = MDBoxLayout(
177                 orientation="horizontal",
178                 spacing=10,
179                 size_hint=(None, None),
180                 width="180dp",
181                 height="60dp",
182                 pos_hint={"center_x": 0.5}
183                 )
184
185                 self.lock_image = Image(
186                 source="locked.png",
187                 size_hint=(None, None),
188                 size=("40dp", "40dp"),
189                 size_hint_y=None,
190                 height="60dp"
191                 )
192
193                 self.lock_status = MDLabel(
194                 text="Locked",
195                 font_style="H5",
196                 theme_text_color="Custom",
197                 text_color=(1, 0.4, 0.4, 1),
198                 valign="middle",
199                 size_hint=(1, 1)
200                 )
```

```
201
202                 self.lock_icon_and_text.add_widget(self.lock_image)
203                 self.lock_icon_and_text.add_widget(self.lock_status)
204
205                 self.btn_row = MDBoxLayout(
206                 orientation="horizontal",
207                 spacing=20,
208                 size_hint=(None, None),
209                 size=("300dp", "50dp"),
210                 size_hint_x = None,
211                 width = "90dp",
212                 pos_hint = {"center_x": 0.5, "center_Y": 0.5}
213                 )
214
215                 self.unlock_btn = MDRaisedButton(
216                 text="Unlock",
217                 font_size="25",
218                 md_bg_color=(0.2, 0.8, 0.2, 1),
219                 on_release=lambda x: self.send_command("unlock")
220                 )
221
222                 self.btn_row.add_widget(self.unlock_btn)
223
224                 self.lock_card.add_widget(self.lock_title)
225                 self.lock_card.add_widget(Widget(size_hint_y=None, height="10dp"))
226                 self.lock_card.add_widget(self.lock_icon_and_text)
227                 self.lock_card.add_widget(Widget(size_hint_y=None, height="10dp"))
228                 self.lock_card.add_widget(self.btn_row)
229
230                 cards.add_widget(self.status_card)
231                 cards.add_widget(self.lock_card)
232                 self.add_widget(cards)
233
234                 #  Notification Section
235                 self.notifications = []
236
237                 self.notification_card = MDCard(
238                 orientation="vertical",
239                 padding=20,
240                 radius=[15, 15, 15, 15],
241                 md_bg_color=(0.1, 0.1, 0.15, 1),
242                 size_hint=(1, 1)
243                 )
244                 notif_top = MDBoxLayout(orientation="horizontal", size_hint_y=None,
                        height="30dp")
245                 notif_title = MDLabel(
246                 text="Recent␣Notifications",
247                 font_style="Subtitle2",
248                 theme_text_color="Custom",
249                 text_color=(0.5, 0.7, 1, 1)
250                 )
251                 self.clear_button = MDRaisedButton(
252                 text="Clear",
253                 md_bg_color=(0.5, 0.1, 0.1, 1),
254                 font_size="12sp",
255                 on_release=self.clear_notifications,
256                 size_hint=(None, None),
257                 height="28dp",
258                 width="80dp",
259                 pos_hint={"center_y": 0.5}
260                 )
261                 notif_top.add_widget(notif_title)
262                 notif_top.add_widget(Widget())  # Spacer
263                 notif_top.add_widget(self.clear_button)
264
265                 self.scroll = ScrollView(
266                 size_hint=(1, 1),
267                 do_scroll_x=False  # Only vertical scrolling
268                 )
269
270                 self.notif_container = MDBoxLayout(
271                 orientation="vertical",
272                 spacing=8,
```

```
                padding=[5, 10],
                size_hint_y=None
                )
                self.notif_container.bind(
                minimum_height=self.notif_container.setter('height')
                )
                self.scroll.add_widget(self.notif_container)

                self.notification_card.add_widget(notif_top)
                self.notification_card.add_widget(self.scroll)
                self.add_widget(self.notification_card)

                # Firebase variables
                self.last_lock_status = ""
                self.last_package_status = ""
                self.vibration_counter = 0
                self.vibration_last_time = 0

                # Start checking Firebase regularly
                Clock.schedule_interval(self.safe_check_status, 5)
                def safe_check_status(self, dt):
                threading.Thread(target=self._check_status_thread).start()

                def clear_notifications(self, *args):
                self.notifications.clear()
                self.notif_container.clear_widgets()

                def _check_status_thread(self):
                try:
                data = db.child("guardbox").get().val()
                if data:
                Clock.schedule_once(lambda dt: self.update_status(data))
                except Exception as e:
                print("Firebase error:", e)

                def add_notification(self, message, icon_path):
                if len(self.notifications) >= 5:
                self.notifications.pop(0)
                self.notif_container.clear_widgets()

                self.notifications.append((message, icon_path))

                notif_row = MDBoxLayout(
                orientation="horizontal",
                spacing=10,
                size_hint_y=None,
                height="40dp",
                padding=[5, 5],
                )

                notif_icon = Image(
                source=icon_path,
                size_hint=(None, None),
                size=("30dp", "30dp"),
                )

                notif_text = MDLabel(
                text=message,
                theme_text_color="Custom",
                text_color=(1, 1, 1, 1),
                font_style="Body1",
                halign="left",
                valign="middle",
                )

                notif_row.add_widget(notif_icon)
                notif_row.add_widget(notif_text)

                self.notif_container.add_widget(notif_row)


                def update_status(self, data):
                locked = data.get("locked", False)
```

```
                weight = data.get("weight", 0)
                vibration = data.get("vibration", False)

                lock_text = "Locked" if locked else "Unlocked"
                package_text = "Package Detected" if weight >= WEIGHT_THRESHOLD else
                    "Box Empty"

                # Update Lock Status
                if lock_text != self.last_lock_status:
                self.last_lock_status = lock_text
                icon = "locked.png" if locked else "unlocked.png"
                self.add_notification("GuardBox Locked" if locked else "GuardBox
                    Unlocked", icon)

                if locked:
                self.show_locked()
                else:
                self.show_unlocked()

                self.lock_status.text = lock_text
                self.lock_image.source = icon

                if locked:
                self.lock_status.text_color = (1, 0.4, 0.4, 1)  # Red
                else:
                self.lock_status.text_color = (0.1, 1, 0.1, 1)  # Green

                #  Update Package Status
                if package_text != self.last_package_status:
                self.last_package_status = package_text

                if weight >= WEIGHT_THRESHOLD:
                self.add_notification("Package detected", "box.png")
                self.show_cargo_true()
                else:
                self.add_notification("No package detected", "box.png")
                self.show_cargo_false()

                self.status_label.text = package_text
                #  Vibration Detection and Alerts
                now = time.time()
                if vibration:
                if now - self.vibration_last_time > 10:
                self.vibration_counter = 0  # reset counter if time gap too big

                self.vibration_counter += 1
                self.vibration_last_time = now

                if self.vibration_counter < 3:
                self.add_notification("Vibration detected!", "alert.png")
                self.show_vibration_alert()
                elif self.vibration_counter == 3:
                self.add_notification("Multiple vibrations detected! Possible
                    tampering!", "alert.png")
                self.show_special_vibration_alert()
                def show_vibration_alert(self):
                notification.notify(
                title="GuardBox Alert",
                message="Vibration detected!",
                timeout=5
                )

                def show_special_vibration_alert(self):
                notification.notify(
                title="GuardBox Critical Alert",
                message="Multiple vibrations detected! Immediate check recommended!",
                timeout=7
                )

                def show_cargo_true(self):
                notification.notify(
                title="Package placed.",
                message="Your package has been placed inside the GuardBox.",
```

```
                timeout=5
                )

                def show_cargo_false(self):
                notification.notify(
                title="Package is taken.",
                message="The GuardBox is now empty.",
                timeout=5
                )

                def show_locked(self):
                notification.notify(
                title="GuardBox Locked",
                message="The GuardBox has been securely locked.",
                timeout=5
                )

                def show_unlocked(self):
                notification.notify(
                title="GuardBox Unlocked",
                message="The GuardBox has been unlocked.",
                timeout=5
                )
                def send_command(self, cmd):
                def run():
                try:
                if cmd == "lock":
                db.child("guardbox").update({"locked": True})
                else:
                db.child("guardbox").update({"locked": False})
                # After sending a command, refresh status
                Clock.schedule_once(lambda dt: self.safe_check_status(0))
                except Exception as e:
                print("Command error:", e)

                threading.Thread(target=run).start()
                class GuardBoxApp(MDApp):
                def build(self):
                self.theme_cls.theme_style = "Dark"
                self.theme_cls.primary_palette = "BlueGray"
                return MainScreen()


                if __name__ == '__main__':
                GuardBoxApp().run()
```

Appendix C

Web App Code

```
1
2       <!DOCTYPE html>
3       <html lang="en" data-theme="dark">
4       <head>
5       <meta charset="UTF-8">
6       <meta name="viewport" content="width=device-width, initial-scale
            =1.0">
7       <title>GuardBox Web Panel</title>
8       <script src="https://cdn.tailwindcss.com"></script>
9       <link href="https://fonts.googleapis.com/css2?family=Inter:
            wght@300;400;500;600;700&display=swap" rel="stylesheet">
10      <script src="https://unpkg.com/feather-icons"></script>
11      <style>
12      body {
13              font-family: 'Inter', sans-serif;
14              transition: background-color 0.3s ease;
15      }
16      .card {
17              backdrop-filter: blur(10px);
18              transition: all 0.3s ease;
19      }
20      .notification-enter {
21              animation: fadeIn 0.5s ease-out;
22      }
23      @keyframes fadeIn {
24              from { opacity: 0; transform: translateY(-10px); }
25              to { opacity: 1; transform: translateY(0); }
26      }
27      .btn {
28              transition: all 0.2s ease;
29      }
30      .glow {
31              box-shadow: 0 0 15px rgba(59, 130, 246, 0.5);
32      }
33      .lock-btn {
34              position: relative;
35              overflow: hidden;
36      }
37      .lock-btn:after {
38              content: '';
39              position: absolute;
40              top: 0;
```

```
                left: 0;
                width: 100%;
                height: 100%;
                background: rgba(255, 255, 255, 0.1);
                transform: translateX(-100%);
                transition: transform 0.3s ease;
        }
        .lock-btn:hover:after {
                transform: translateX(0);
        }
        </style>
        </head>
        <body id="app" class="bg-gradient-to-br from-gray-900 via-gray-800 to-gray-900 text-white min-h-screen flex flex-col transition-colors duration-300">
        <!-- Header -->
        <header id="header" class="bg-gray-950 bg-opacity-70 backdrop-blur-md text-white shadow-lg p-5 fixed w-full z-10">
        <div class="container mx-auto flex justify-between items-center">
        <div class="flex items-center gap-4">
        <div class="bg-blue-500 p-2 rounded-lg">
        <img src="guard-box.jpeg" alt="GuardBox Logo" class="w-8 h-8 rounded-md">
        </div>
        <h1 class="text-2xl font-bold tracking-tight">GuardBox</h1>
        </div>
        <div class="flex items-center gap-6">
        <button onclick="toggleTheme()" class="text-sm bg-gray-800 hover:bg-gray-700 text-white px-4 py-2 rounded-lg transition-all flex items-center gap-2">
        <i data-feather="sun" class="w-4 h-4"></i>
        <span>Theme</span>
        </button>
        <div class="flex items-center gap-3">
        <span id="user-label" class="text-gray-300 hidden md:block">User: user</span>
        <div class="bg-blue-500 rounded-full p-1">
        <img src="pp.jpeg" class="rounded-full w-8 h-8" alt="User">
        </div>
        </div>
        </div>
        </div>
        </header>

        <!-- Main Content -->
        <main class="flex-grow container mx-auto pt-24 pb-6 px-4">
        <div class="grid grid-cols-1 md:grid-cols-2 gap-8">
        <!-- Box Status Card -->
        <div id="boxCard" class="card bg-gray-900 bg-opacity-60 rounded-2xl shadow-xl p-8 flex flex-col items-center justify-center hover:glow transform transition-all hover:scale-102 hover:-translate-y-1">
        <h2 id="boxTitle" class="text-xl font-semibold mb-6 text-blue-400 flex items-center gap-2">
        <i data-feather="activity" class="w-5 h-5"></i>
        Box Status
        </h2>
```

```
87          <div class="flex flex-col items-center">
88          <div class="bg-gray-800 p-6 rounded-full mb-6">
89          <i data-feather="box" class="w-16 h-16 text-green-400"></i>
90          </div>
91          <div id="boxStatus" class="text-3xl font-bold text-green-400">
               Empty</div>
92          </div>
93          </div>
94
95          <!-- Lock Control Card -->
96          <div id="lockCard" class="card bg-gray-900 bg-opacity-60 rounded
               -2xl shadow-xl p-8 flex flex-col items-center justify-center
               hover:glow transform transition-all hover:scale-102 hover:-
               translate-y-1">
97          <h2 id="lockTitle" class="text-xl font-semibold mb-6 text-blue
               -400 flex items-center gap-2">
98          <i data-feather="shield" class="w-5 h-5"></i>
99          Lock Control
100         </h2>
101         <div class="flex flex-col items-center mb-6">
102         <div class="bg-gray-800 p-6 rounded-full mb-6">
103         <i id="lockIcon" data-feather="lock" class="w-16 h-16 text-red
               -400"></i>
104         </div>
105         <div id="lockStatus" class="text-2xl text-red-400">Locked</div>
106         </div>
107         <div class="flex gap-4 w-full max-w-xs">
108         <button onclick="unlock()" class="lock-btn bg-gradient-to-r from
               -green-500 to-green-600 text-white px-6 py-3 rounded-xl
               shadow-lg transition-all hover:shadow-green-500/50 flex-1
               flex justify-center items-center gap-2">
109         <i data-feather="unlock" class="w-5 h-5"></i>
110         Unlock
111         </button>
112         </div>
113         </div>
114         </div>
115
116         <!-- Notifications -->
117         <section class="mt-8">
118         <div id="notifCard" class="card bg-gray-900 bg-opacity-60
               rounded-2xl shadow-xl p-8 hover:glow transform transition-all
               hover:scale-102">
119         <div class="flex flex-wrap items-center justify-between mb-6 gap
               -2">
120         <h2 id="notifTitle" class="text-xl font-semibold text-blue-400
               flex items-center gap-2">
121         <i data-feather="bell" class="w-5 h-5"></i>
122         Recent Notifications
123         </h2>
124         <button onclick="clearNotifications()" id="clearBtn" class="text
               -red-400 hover:text-red-600 font-semibold flex items-center
               gap-1">
125         <i data-feather="trash-2" class="w-4 h-4"></i>
126         Clear
127         </button>
128         </div>
```

```
129         <ul id="notifications" class="space-y-3 max-h-64 overflow-y-auto
                pr-2">
130         <li class="notification-item bg-gray-800 bg-opacity-70 text-
                white p-4 rounded-xl shadow-sm flex items-center gap-3 w-full
                border-l-4 border-blue-400">
131         <i data-feather="package" class="w-5 h-5 text-blue-400"></i>
132         <span class="flex-1">Package delivered.</span>
133         <span class="text-xs text-gray-400">Just now</span>
134         </li>
135         <li class="notification-item bg-gray-800 bg-opacity-70 text-
                white p-4 rounded-xl shadow-sm flex items-center gap-3 w-full
                border-l-4 border-green-400">
136         <i data-feather="unlock" class="w-5 h-5 text-green-400"></i>
137         <span class="flex-1">Unlocked.</span>
138         <span class="text-xs text-gray-400">5m ago</span>
139         </li>
140         <li class="notification-item bg-gray-800 bg-opacity-70 text-
                white p-4 rounded-xl shadow-sm flex items-center gap-3 w-full
                border-l-4 border-red-400">
141         <i data-feather="alert-circle" class="w-5 h-5 text-red-400"></i>
142         <span class="flex-1">Vibration detected!</span>
143         <span class="text-xs text-gray-400">15m ago</span>
144         </li>
145         </ul>
146         </div>
147         </section>
148         </main>
149
150
151         <!-- Footer -->
152         <footer class="bg-gray-950 bg-opacity-70 text-gray-400 text-
                center py-4 text-sm">
153         <div class="container mx-auto">
154         GuardBox Security Dashboard &copy; 2025
155         </div>
156         </footer>
157
158         <!-- Script -->
159         <script>
160         feather.replace();
161
162         function unlock() {
163                 document.getElementById('lockStatus').innerText = '
                        Unlocked';
164                 document.getElementById('lockStatus').classList.remove('
                        text-red-400');
165                 document.getElementById('lockStatus').classList.add('
                        text-green-400');
166                 const lockIcon = document.getElementById('lockIcon');
167                 lockIcon.setAttribute('data-feather', 'unlock');
168                 feather.replace();
169                 addNotification('Unlocked.', 'unlock', 'text-green-400',
                         'border-green-400');
170         }
171
172         function lock() {
173                 document.getElementById('lockStatus').innerText = '
                        Locked';
```

```
174                 document.getElementById('lockStatus').classList.remove('
                        text-green-400');
175                 document.getElementById('lockStatus').classList.add('
                        text-red-400');
176                 const lockIcon = document.getElementById('lockIcon');
177                 lockIcon.setAttribute('data-feather', 'lock');
178                 feather.replace();
179                 addNotification('Locked.', 'lock', 'text-red-400', '
                        border-red-400');
180         }
181
182         function addNotification(message, icon = 'bell', color = 'text-
                blue-400', borderColor = 'border-blue-400') {
183                 const notifications = document.getElementById('
                        notifications');
184                 const li = document.createElement('li');
185                 const isDark = document.documentElement.getAttribute('
                        data-theme') === 'dark';
186                 const bgColor = isDark ? 'bg-gray-800 bg-opacity-70' : '
                        bg-gray-200 bg-opacity-70';
187                 const textColor = isDark ? 'text-white' : 'text-black';
188                 const timeText = 'Just now';
189                 li.className = notification-item ${bgColor} ${textColor}
                         p-4 rounded-xl shadow-sm flex items-center gap-3 w-
                        full notification-enter border-l-4 ${borderColor};
190                 li.innerHTML = <i data-feather="${icon}" class="w-5␣h-5␣
                        ${color}"></i><span class="flex-1">${message}</span><
                        span class="text-xs␣text-gray-400">${timeText}</span>
                        ;
191                 notifications.prepend(li);
192                 feather.replace();
193         }
194
195         function clearNotifications() {
196                 document.getElementById('notifications').innerHTML = '';
197         }
198
199         function applyNotificationTheme() {
200                 const isDark = document.documentElement.getAttribute('
                        data-theme') === 'dark';
201                 document.querySelectorAll('.notification-item').forEach(
                        el => {
202                         el.classList.remove('bg-gray-800', 'bg-gray
                                -200', 'text-white', 'text-black', 'bg-
                                opacity-70');
203                         if (isDark) {
204                                 el.classList.add('bg-gray-800', 'bg-
                                        opacity-70', 'text-white');
205                         } else {
206                                 el.classList.add('bg-gray-200', 'bg-
                                        opacity-70', 'text-black');
207                         }
208                 });
209         }
210
211         function toggleTheme() {
212                 const html = document.documentElement;
213                 const body = document.getElementById('app');
```

```
214                 const isDark = html.getAttribute('data-theme') === 'dark
                        ';
215
216                 html.setAttribute('data-theme', isDark ? 'light' : 'dark
                        ');
217                 body.className = isDark
218                 ? 'bg-gradient-to-br from-blue-100 via-blue-50 to-white
                        text-black min-h-screen flex flex-col transition-
                        colors duration-300'
219                 : 'bg-gradient-to-br from-gray-900 via-gray-800 to-gray
                        -900 text-white min-h-screen flex flex-col transition
                        -colors duration-300';
220
221                 document.getElementById('header').className = isDark
222                 ? 'bg-white bg-opacity-70 backdrop-blur-md text-black
                        shadow-lg p-5 fixed w-full z-10'
223                 : 'bg-gray-950 bg-opacity-70 backdrop-blur-md text-white
                         shadow-lg p-5 fixed w-full z-10';
224
225                 document.getElementById('user-label').className = isDark
                         ? 'text-gray-600 hidden md:block' : 'text-gray-300
                        hidden md:block';
226
227                 const cardClass = isDark
228                 ? 'card bg-white bg-opacity-60 rounded-2xl shadow-xl p-8
                         flex flex-col items-center justify-center hover:glow
                         transform transition-all hover:scale-102 hover:-
                        translate-y-1'
229                 : 'card bg-gray-900 bg-opacity-60 rounded-2xl shadow-xl
                        p-8 flex flex-col items-center justify-center hover:
                        glow transform transition-all hover:scale-102 hover:-
                        translate-y-1';
230
231                 document.getElementById('boxCard').className = cardClass
                        ;
232                 document.getElementById('lockCard').className =
                        cardClass;
233
234                 const notifCardClass = isDark
235                 ? 'card bg-white bg-opacity-60 rounded-2xl shadow-xl p-8
                         hover:glow transform transition-all hover:scale-102'
236                 : 'card bg-gray-900 bg-opacity-60 rounded-2xl shadow-xl
                        p-8 hover:glow transform transition-all hover:scale
                        -102';
237
238                 document.getElementById('notifCard').className =
                        notifCardClass;
239
240                 const titleClass = isDark ? 'text-xl font-semibold mb-6
                        text-blue-600 flex items-center gap-2' : 'text-xl
                        font-semibold mb-6 text-blue-400 flex items-center
                        gap-2';
241                 document.getElementById('boxTitle').className =
                        titleClass;
242                 document.getElementById('lockTitle').className =
                        titleClass;
243                 document.getElementById('notifTitle').className =
                        titleClass;
```

```
244
245                 document.getElementById('clearBtn').className = isDark
246                 ? 'text-red-600 hover:text-red-800 font-semibold flex
                        items-center gap-1'
247                 : 'text-red-400 hover:text-red-600 font-semibold flex
                        items-center gap-1';
248
249                 document.querySelector('footer').className = isDark
250                 ? 'bg-white bg-opacity-70 text-gray-600 text-center py-4
                         text-sm'
251                 : 'bg-gray-950 bg-opacity-70 text-gray-400 text-center
                        py-4 text-sm';
252
253                 applyNotificationTheme();
254         }
255
256         window.onload = applyNotificationTheme;
257         </script>
258         </body>
259         </html>
```

Appendix D

Mobile App Code

```
1
2                package com.flare.guardboximport android.app.
                    AlertDialogimport android.content.Intentimport
                    android.os.Bundleimport android.text.InputTypeimport
                    android.view.Viewimport android.widget.Buttonimport
                    android.widget.EditTextimport android.widget.
                    TextViewimport android.widget.Toastimport androidx.
                    appcompat.app.AppCompatActivityimport androidx.
                    recyclerview.widget.LinearLayoutManagerimport
                    androidx.recyclerview.widget.RecyclerViewimport com.
                    flare.guardbox.adapters.ActivityLogAdapterimport com.
                    flare.guardbox.model.ActivityLogimport com.flare.
                    guardbox.model.GuardBoxStatusimport com.flare.
                    guardbox.model.Userimport com.flare.guardbox.utils.
                    FirebaseHelperimport com.google.android.material.
                    bottomnavigation.BottomNavigationViewimport com.
                    google.android.material.card.MaterialCardViewimport
                    com.google.firebase.auth.FirebaseAuthimport com.
                    google.firebase.database.*class MainActivity :
                    AppCompatActivity() {    private lateinit var
                    tvLockStatus: TextView    private lateinit var
                    tvPackageStatus: TextView    private lateinit var
                    btnLock: Button    private lateinit var btnUnlock:
                    Button    private lateinit var rvNotifications:
                    RecyclerView    private lateinit var bottomNavigation
                    : BottomNavigationView    private lateinit var
                    cardViewAddDevice: MaterialCardView    private
                    lateinit var cardViewRefresh: MaterialCardView
                    private lateinit var versionText: TextView    //
                    Optional views    private var tvBatteryStatus:
                    TextView? = null    private var tvConnectionStatus:
                    TextView? = null    private var tvLastUpdate:
                    TextView? = null    private val firebaseHelper =
                    FirebaseHelper.getInstance()    private var
                    currentDeviceId: String? = null    private var
                    currentDeviceStatus: String = "offline"    private
                    var currentDeviceRef: DatabaseReference? = null
                    private var userDevicesRef: DatabaseReference? = null
                        private val activityLogs = mutableListOf<
                    ActivityLog>()    private lateinit var
                    activityLogAdapter: ActivityLogAdapter    override
                    fun onCreate(savedInstanceState: Bundle?) {
```

```
super.onCreate(savedInstanceState)
setContentView(R.layout.activity_main)        // User
 login check        if (firebaseHelper.getCurrentUser
() == null) {            startActivity(Intent(this,
LoginActivity::class.java))            finish()
           return        }        // Initialize views
         initializeViews()        // RecyclerView
setup        setupRecyclerView()        // Setup
button listeners        setupButtonListeners()
       // Setup bottom navigation
setupBottomNavigation()        // Setup Firebase
references        setupFirebaseReferences()        //
 Get user device ID        getUserDeviceId()
// Show demo values        showDemoData()        //
Setup network monitoring
setupNetworkMonitoring()    }    private fun
initializeViews() {        // Main views
tvLockStatus = findViewById(R.id.tvLockStatus)
       tvPackageStatus = findViewById(R.id.
tvPackageStatus)        btnLock = findViewById(R.id.
btnLock)        btnUnlock = findViewById(R.id.
btnUnlock)        rvNotifications = findViewById(R.id
.rvNotifications)        bottomNavigation =
findViewById(R.id.bottomNavigation)
versionText = findViewById(R.id.versionText)
// Card views        cardViewAddDevice = findViewById
(R.id.cardViewAddDevice)        cardViewRefresh =
findViewById(R.id.cardViewRefresh)        // Optional
 status views        try {            tvBatteryStatus
 = findViewById(R.id.tvBatteryStatus)
tvConnectionStatus = findViewById(R.id.
tvConnectionStatus)            tvLastUpdate =
findViewById(R.id.tvLastUpdate)        } catch (e:
Exception) {            // Continue silently if
optional views are missing        }    }    private
fun setupRecyclerView() {        activityLogAdapter =
 ActivityLogAdapter(activityLogs)
rvNotifications.layoutManager = LinearLayoutManager(
this)        rvNotifications.adapter =
activityLogAdapter    }    private fun
setupButtonListeners() {        // Main buttons
       btnLock.setOnClickListener {
sendLockCommand(true)        }        btnUnlock.
setOnClickListener {            sendLockCommand(false
)        }        // Quick access cards
cardViewAddDevice.setOnClickListener {
showAddDeviceDialog()        }        cardViewRefresh
.setOnClickListener {            refreshDeviceStatus
()            Toast.makeText(this, "Refreshing...",
Toast.LENGTH_SHORT).show()        }    }    private
fun setupBottomNavigation() {        bottomNavigation
.setOnNavigationItemSelectedListener { item ->
           when (item.itemId) {                R.id.
nav_home -> true // Already on home page
               R.id.nav_history -> {
                   startActivity(Intent(this,
HistoryActivity::class.java))                    true
               }                R.id.nav_settings ->
```

```
 {                    startActivity(Intent(this,
SettingsActivity::class.java))
true                }                else -> false
           }        }    }    private fun
setupFirebaseReferences() {        // Get the current
 user ID        val userId = FirebaseAuth.getInstance
().currentUser?.uid        if (userId != null) {
           userDevicesRef = FirebaseDatabase.
getInstance().getReference("users/$userId/devices")
       } else {            // Handle not logged in
state            Toast.makeText(this, "Please log in
to access your devices", Toast.LENGTH_LONG).show()
       }    }    private fun getUserDeviceId() {
       val userId = firebaseHelper.getCurrentUser()?.
uid        if (userId != null) {
firebaseHelper.getUserProfile(userId, object :
ValueEventListener {                override fun
onDataChange(dataSnapshot: DataSnapshot) {
                   val user = dataSnapshot.getValue(
User::class.java)                    if (user != null
 && user.deviceIds.isNotEmpty()) {
                       currentDeviceId = user.
deviceIds[0] // Get first device
                       currentDeviceRef =
FirebaseDatabase.getInstance().getReference("devices
").child(currentDeviceId!!)
loadBoxStatus()
loadActivityLogs()                    } else {
                       // No device - Will show demo
data                        showNoDeviceMessage()
                   }                }
override fun onCancelled(databaseError: DatabaseError
) {                    Toast.makeText(
this@MainActivity, "Failed to load user info: ${
databaseError.message}",                        Toast
.LENGTH_SHORT).show()                }            })
       }    }    private fun loadBoxStatus() {
       // Reset UI to offline state
setOfflineState()        currentDeviceId?.let {
deviceId ->            firebaseHelper.getBoxStatus(
deviceId, object : ValueEventListener {
               override fun onDataChange(dataSnapshot
: DataSnapshot) {                    val status =
dataSnapshot.getValue(GuardBoxStatus::class.java)
                   if (status != null) {
                       // Device data retrieved,
switch to online state
currentDeviceStatus = "online"
                       setOnlineState(status)
                   } else {                        //
 No device data
setOfflineState()                    }
               }                override fun
onCancelled(databaseError: DatabaseError) {
                   setOfflineState()
                   Toast.makeText(this@MainActivity,
"Failed to load box status: ${databaseError.message
}",                    Toast.LENGTH_SHORT).show()
```

```
                }            })        } ?: run {
            // No device ID            setOfflineState
()        }    }    private fun setOfflineState() {
        currentDeviceStatus = "offline"        //
System status        tvBatteryStatus?.text = "
Unavailable"        tvBatteryStatus?.setTextColor(
resources.getColor(R.color.colorGrey))
tvConnectionStatus?.text = "Offline"
tvConnectionStatus?.setTextColor(resources.getColor(R
.color.colorDanger))        tvLastUpdate?.text = "
Never"        // Disable buttons        btnLock.
isEnabled = false        btnUnlock.isEnabled = false
        // Lock status        tvLockStatus.text = "
UNKNOWN"        tvLockStatus.setTextColor(resources.
getColor(R.color.colorGrey))        // Package status
         tvPackageStatus.text = "UNKNOWN"
tvPackageStatus.setTextColor(resources.getColor(R.
color.colorGrey))    }    private fun setOnlineState(
status: GuardBoxStatus) {        // Battery status
        if (status.batteryLevel != null) {
// Show real battery value if available
tvBatteryStatus?.text = "${status.batteryLevel}%"
            // Set color according to battery level
            val batteryColor = when {
status.batteryLevel > 50 -> R.color.colorSuccess
                status.batteryLevel > 20 -> R.color.
colorWarning                else -> R.color.
colorDanger            }            tvBatteryStatus?.
setTextColor(resources.getColor(batteryColor))
        } else {            // Show "Unknown" if no
battery value            tvBatteryStatus?.text = "
Unknown"            tvBatteryStatus?.setTextColor(
resources.getColor(R.color.colorGrey))        }
        // Connection status        tvConnectionStatus
?.text = "Connected"        tvConnectionStatus?.
setTextColor(resources.getColor(R.color.colorSuccess)
)        // Last update        tvLastUpdate?.text = "
Now"        // Update UI buttons        updateUI(
status)    }    private fun loadActivityLogs() {
        currentDeviceId?.let { deviceId ->
firebaseHelper.getActivityLogs(deviceId, object :
ValueEventListener {                override fun
onDataChange(dataSnapshot: DataSnapshot) {
                    activityLogs.clear()
                    for (snapshot in dataSnapshot.
children) {                        val log = snapshot
.getValue(ActivityLog::class.java)
                        if (log != null) {
                            activityLogs.add(log)
                        }                    }
                    if (activityLogs.isEmpty()) {
                        // No activity - add demo
                        addDemoActivities(deviceId)
                    } else {                        //
 Sort newest first
activityLogs.sortByDescending { it.timestamp }
                        activityLogAdapter.
notifyDataSetChanged()                    }
```

```
                }                override fun
onCancelled(databaseError: DatabaseError) {
                    Toast.makeText(this@MainActivity,
"Failed to load activity logs: ${databaseError.
message}",                          Toast.LENGTH_SHORT)
.show()                }            })        }    }
   private fun updateUI(status: GuardBoxStatus) {
        updateLockUI(status.isLocked)
updatePackageUI(status.hasPackage)    }    private
fun updateLockUI(isLocked: Boolean) {        if (
isLocked) {            tvLockStatus.text = "LOCKED"
           tvLockStatus.setTextColor(resources.
getColor(R.color.colorSuccess))            btnLock.
isEnabled = false            btnUnlock.isEnabled =
true        } else {            tvLockStatus.text = "
UNLOCKED"            tvLockStatus.setTextColor(
resources.getColor(R.color.colorDanger))
btnLock.isEnabled = true            btnUnlock.
isEnabled = false        }    }    private fun
updatePackageUI(hasPackage: Boolean) {        if (
hasPackage) {            tvPackageStatus.text = "
PACKAGE INSIDE"            tvPackageStatus.
setTextColor(resources.getColor(R.color.colorAccent))
        } else {            tvPackageStatus.text = "
EMPTY"            tvPackageStatus.setTextColor(
resources.getColor(R.color.colorGrey))        }    }
   private fun showDemoData() {        // System
status demo values        tvBatteryStatus?.text =
"85%"        tvConnectionStatus?.text = "Connected"
       tvLastUpdate?.text = "Now"    }    private fun
 showNoDeviceMessage() {        Toast.makeText(this,
"No GuardBox device added yet. Use 'Add Device'
button to add one.",            Toast.LENGTH_LONG).
show()        // Disable buttons        btnLock.
isEnabled = false        btnUnlock.isEnabled = false
   }    private fun showAddDeviceDialog() {
val dialogView = layoutInflater.inflate(R.layout.
dialog_add_device, null)        val deviceIdInput =
dialogView.findViewById<EditText>(R.id.etDeviceId)
       val deviceNameInput = dialogView.findViewById<
EditText>(R.id.etDeviceName)        val dialog =
AlertDialog.Builder(this)            .setTitle("Add
New GuardBox")            .setView(dialogView)
           .setPositiveButton("Add", null) // Set to
null and override below            .setNegativeButton
("Cancel", null)            .create()        dialog.
show()        // Override positive button to check
for empty input        dialog.getButton(AlertDialog.
BUTTON_POSITIVE).setOnClickListener {            val
deviceId = deviceIdInput.text.toString().trim()
           if (deviceId.isEmpty()) {
deviceIdInput.error = "Device ID is required"
               return@setOnClickListener           }
            // Add device and close dialog
           addNewDevice(deviceId)            dialog.
dismiss()        }    }    private fun
refreshDeviceStatus() {        // Reload status
       loadBoxStatus()        loadActivityLogs()
```

```
        // Update system status         tvBatteryStatus
?.text = "85%"         tvConnectionStatus?.text = "
Connected"         tvLastUpdate?.text = "Now"     }
private fun addDemoActivities(deviceId: String) {
        val now = System.currentTimeMillis()
val oneHour = 60 * 60 * 1000L         activityLogs.add
(ActivityLog("SYSTEM_STATUS", now, "GuardBox came
online", deviceId))         activityLogs.add(
ActivityLog("BOX_LOCKED", now - oneHour, "Box locked
automatically", deviceId))         activityLogs.add(
ActivityLog("SYSTEM_STATUS", now - (2 * oneHour), "
Device initialized", deviceId))
activityLogAdapter.notifyDataSetChanged()     }
private fun addNewDevice(deviceId: String) {
// 1. Get user ID         val userId = FirebaseAuth.
getInstance().currentUser?.uid ?: return         // 2.
 Show loading dialog         val loadingDialog =
AlertDialog.Builder(this)             .setMessage("
Adding device...")             .setCancelable(false)
            .create()         loadingDialog.show()
        // 3. Add device to database         val
newDeviceRef = FirebaseDatabase.getInstance().
getReference("devices").child(deviceId)         val
deviceData = HashMap<String, Any>()         deviceData
["name"] = "GuardBox $deviceId"         deviceData["
status"] = "online" // Initially online
deviceData["lock"] = true         deviceData["package
"] = false         deviceData["connectionStatus"] = "
online"         newDeviceRef.setValue(deviceData)
            .addOnSuccessListener {                 //
4. Save user-device relationship
FirebaseDatabase.getInstance().getReference("users/
$userId/devices/$deviceId")                         .
setValue(true)                     .
addOnSuccessListener {
loadingDialog.dismiss()                         Toast.
makeText(this, "Device added successfully", Toast.
LENGTH_SHORT).show()                         // 5. Set
 current device
currentDeviceId = deviceId
currentDeviceRef = newDeviceRef
                        currentDeviceStatus = "online"
                         // 6. Update screen
                        refreshDeviceStatus()
                    }                     .
addOnFailureListener { e ->
loadingDialog.dismiss()                         Toast.
makeText(this, "Failed to link device: ${e.message}",
 Toast.LENGTH_LONG).show()                     }
            }             .addOnFailureListener { e ->
                loadingDialog.dismiss()
                Toast.makeText(this, "Failed to add
device: ${e.message}", Toast.LENGTH_LONG).show()
            }    }    private fun loadDevices() {
        // Load all registered devices
FirebaseDatabase.getInstance().getReference("devices
")             .addListenerForSingleValueEvent(object
: ValueEventListener {                 override fun
```

```
onDataChange(snapshot: DataSnapshot) {
                    // Update UI with devices list
                    refreshDeviceStatus()
                }                override fun
onCancelled(error: DatabaseError) {
                    Toast.makeText(baseContext, "
Failed to load devices: ${error.message}",
                        Toast.LENGTH_SHORT).show()
                }            })    }    private fun
sendLockCommand(lock: Boolean) {        if (
currentDeviceId == null) {
showNoDeviceMessage()            return        }
        if (currentDeviceStatus != "online") {
            // Not blocking execution, but giving
feedback            Toast.makeText(this, "Device is
offline. Command may not be received immediately.",
                Toast.LENGTH_LONG).show()        }
        currentDeviceId?.let { deviceId ->
// Send lock command            firebaseHelper.
setBoxLockStatus(deviceId, lock)            // Update
 UI immediately (without waiting for Firebase
response)            updateLockUI(lock)            //
 Save active device for later use            val
editor = getSharedPreferences("GuardBox",
MODE_PRIVATE).edit()            editor.putString("
lastDeviceId", deviceId)            editor.apply()
            val message = if (lock) "Lock command sent
" else "Unlock command sent"            Toast.
makeText(this, message, Toast.LENGTH_SHORT).show()
            // Add activity log
addActivityLog(deviceId, if(lock) "BOX_LOCKED" else "
BOX_UNLOCKED",                if(lock) "Box locked"
else "Box unlocked")        }    }    private fun
addActivityLog(deviceId: String, type: String,
message: String) {        val key = FirebaseDatabase.
getInstance().getReference("devices/$deviceId/
activities").push().key ?: return        val
timestamp = System.currentTimeMillis()        val
activity = ActivityLog(type, timestamp, message,
deviceId)        FirebaseDatabase.getInstance().
getReference("devices/$deviceId/activities/$key").
setValue(activity)    }    private fun
setupNetworkMonitoring() {        FirebaseDatabase.
getInstance().getReference(".info/connected")
            .addValueEventListener(object :
ValueEventListener {                override fun
onDataChange(snapshot: DataSnapshot) {
                    val connected = snapshot.getValue(
Boolean::class.java) ?: false                    if
(!connected) {                        Toast.makeText(
baseContext, "Network connection lost",
                            Toast.LENGTH_SHORT).show()
                    }                }
                override fun onCancelled(error:
DatabaseError) {                    // Handle error
                }            })    }}
```