

Intelligent and Secure Package Receiver System Utilizing Internet of Things (IoT) Technology

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ABSTRACT

The rapid expansion of e-commerce has increased the demand for secure and efficient package delivery solutions, particularly for recipients who are frequently away from home. This study presents the development of a Smart Package Receiver Box, an Internet of Things (IoT)-based system that integrates sensors and remote-control functionalities to enhance package security. The system incorporates an ESP32-CAM microcontroller, an ultrasonic sensor for courier detection, a PIR sensor for package counting, and a solenoid door lock for secure access control. These components are integrated with the Telegram messaging application, enabling real-time notifications, visual monitoring, and remote control of package deliveries. Experimental testing demonstrates that the system reliably detects couriers within a 5 cm to 30 cm range, accurately counts inserted packages, and ensures a secure locking mechanism with prompt response times. The collected data confirm stable system performance, minimal delays, and effective remote accessibility for users. Despite its advantages, the system presents certain limitations that warrant further improvements. The current implementation lacks encrypted communication, posing potential security vulnerabilities that could be mitigated by integrating AES-256 encryption and secure authentication protocols. Additionally, the system's reliance on Telegram makes it susceptible to disruptions in service availability, necessitating the incorporation of alternative communication channels such as SMS notifications or cloud-based APIs. Another limitation is that testing was conducted in a controlled environment, requiring further validation in real-world conditions to assess reliability across diverse network scenarios and environmental factors. Future enhancements will focus on strengthening data security, increasing system redundancy, and conducting comprehensive field testing to improve robustness and scalability for broader adoption in modern package delivery systems.

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1. INTRODUCTION

The rapid growth of e-commerce has simplified online shopping, but it has also introduced challenges in package delivery and receipt [1]. One common issue is when recipients are not at home during deliveries. Packages left in open areas are vulnerable to damage, loss, or theft [2]. To address this problem, this study proposes a Smart Package Receiver Box based on IoT technology [3].

The Smart Package Receiver Box system comprises several integrated components [4]. The ESP32-CAM acts as the control center, processing data from various sensors and controlling actuators. An ultrasonic sensor

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detects the presence of couriers in front of the box, while a PIR sensor detects motion and counts the number of package. The Solenoid Door Lock serves as an actuator, automatically locking and unlocking the box in response to commands from the ESP32-CAM. The entire system integrates with the Telegram application, enabling users to monitor box status and remotely control access remotely.

Previous studies have introduced various smart mailbox and package receiver systems; however, they present several limitations that this research aims to address [6] [7]. Some studies have focused on barcode-based smart mailboxes for tracking deliveries, but they have lacked real-time notifications via messaging applications [8] [9]. Other research developed IoT-based smart mailbox prototypes for package detection, but did not include features such as remote control through Telegram [10]. Additionally, IoT-based camera systems have been implemented for real-time patient indoor health monitoring [11] and smart building [12]. Automated locker systems with electronic locks exist, but they lack real-time notifications and camera integration [13] [14].

To bridge these gaps, this study introduces an innovative Smart Package Receiver Box that integrates real-time notifications, visual monitoring, and remote control via Telegram. Unlike previous research, this system enhances security and accessibility by enabling users to receive instant updates, visually verify package deliveries, and remotely operate the package box. This study contributes to the field by combining multiple essential security and convenience features into a single IoT-based package reception system, making it a practical solution for both residential and commercial applications [15].

By addressing these limitations, this research provides a more comprehensive and user-friendly approach to secure package delivery, ensuring greater reliability and usability for end-users.

2. METHOD

This study employs a lab-based research approach to design, develop, and evaluate the Smart Package Receiver Box system. The research methodology follows a structured process that includes problem identification, literature review, system design, component testing, and system integration. According to the research steps shown in Figure 1.

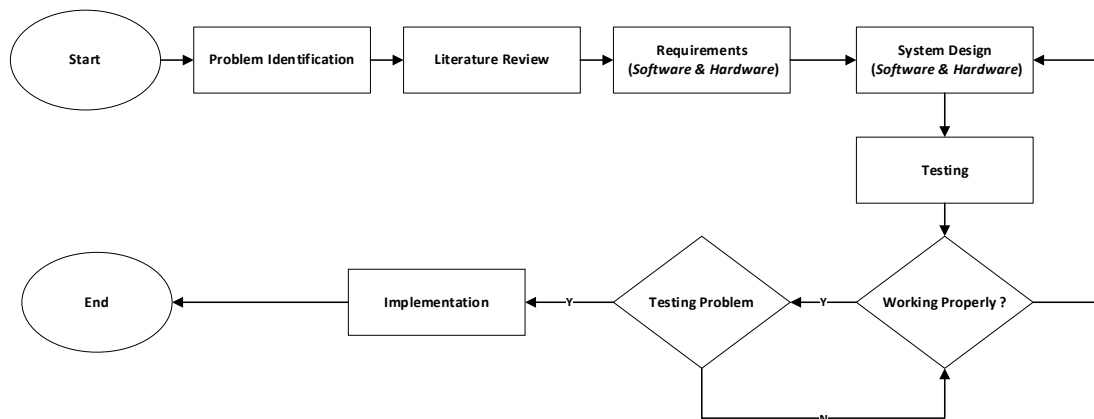


Figure 1. Research Stages

- The first stage is **Problem Identification**, which is done by conducting observations, reading literature, or conducting initial surveys.
- Literary Analysis:** This strategy is employed to gather information from various sources, including books, journals, and websites, relevant to the development of a tool for controlling and monitoring package receiving boxes (Smart Package Boxes) using the Internet of Things (IoT).
- Needs Analysis Phase:** The system encompasses the software, materials, and tools required to construct an Internet of Things-based imaginative package delivery box [16]. The selection of hardware components plays a crucial role in the functionality and efficiency of the Smart Package Receiver Box. The following justifications outline why specific components were chosen over alternative options:

- **ESP32-CAM vs. Raspberry Pi:**

The ESP32-CAM was chosen instead of the Raspberry Pi due to its lower power consumption, cost-effectiveness, and built-in camera module [17]-[19]. While Raspberry Pi provides more processing power, it is overqualified for a task that requires only basic image capture and real-time transmission [20]-[22]. The ESP32-CAM integrates Wi-Fi capability, making it ideal for IoT applications, whereas

the Raspberry Pi would require additional modules for wireless communication, increasing overall cost and complexity [23] [24].

- **Ultrasonic Sensor vs. Infrared Sensor:**

The ultrasonic sensor (HC-SR04) was selected over an infrared sensor because it offers more accurate distance measurements and performs reliably under varying lighting conditions [25]-[27]. Infrared detectors can be affected by ambient light, which reduces their accuracy in outdoor environments [28]-[31].

- **PIR Sensor for Package Counting:**

A PIR (Passive Infrared) sensor was used for package counting due to its ability to detect motion without direct contact [32] [33]. Unlike weight-based sensors, which may be affected by package placement, PIR sensors provide a more adaptable and scalable approach.

- **Solenoid Door Lock for Security:**

A solenoid door lock was chosen over traditional mechanical locks because it allows for electronic control via the ESP32-CAM, providing a seamless remote locking and unlocking mechanism through Telegram commands [34]-[36].

- This system is **designed** based on a block diagram that integrates the ESP32-CAM as the control unit, an ultrasonic sensor for detecting couriers, and a PIR sensor for counting packages. A solenoid door lock is incorporated for securing the package box, and the entire system is connected to the Telegram application for real-time monitoring and control [37].
- Subsequently, the **Instrument Testing Phase** involves a series of processes designed to verify and validate that the created or modified instrument or device functions as intended according to the specified requirements. The primary objective of this testing phase is to identify and rectify any defects or errors before widespread use of the instrument.
- Problem Testing, also commonly referred to as the **Problem Testing Phase**, is a systematic process of identifying, analyzing, and resolving issues that arise within a system, application, or software [38] [39]. It is a critical component of the software development life cycle and a fundamental aspect of general problem-solving. This phase involves a series of experiments to achieve optimal results.

The system is designed based on a block diagram that integrates the ESP32-CAM as the control unit, an ultrasonic sensor for detecting couriers, and a PIR sensor for counting packages. A solenoid door lock is incorporated for securing the package box, and the entire system is connected to the Telegram application for real-time monitoring and control. Figure 2 illustrates the system architecture of the IoT-Based Package Receiver Box, including three primary components: Input, Process, and Output. This is a comprehensive elucidation:

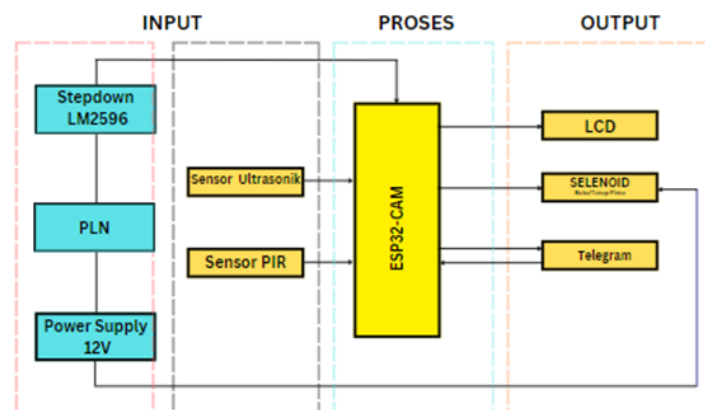


Figure 2. System Architecture

- Input Section

The input component serves as a resource and sensor that delivers preliminary data to the system:

1. Stepdown LM2596: Operates to reduce the voltage from the PLN electrical supply to a suitable level (5V) for utilisation by components such as the ESP32-CAM and other sensors.
2. Power Supply 12V: Supplies energy to components necessitating higher voltages, such as the Door Lock Solenoid.

3. Ultrasonic Sensor: Employed to ascertain the existence of a courier in proximity to the shipment box. This sensor quantifies the distance to an object by analysing the reflection of ultrasonic pulses.
4. PIR (Passive Infrared) Sensor: Operates to identify movement or variations in the quantity of products placed inside the box.
- b. Process Section
This part features the ESP32-CAM, serving as the primary controller of the system.
- c. ESP32-CAM: A microcontroller equipped with an integrated camera functionality, tasked with processing sensor data, capturing images, and transmitting instructions to the output section. The ESP32-CAM is linked to the network for communication with the Telegram application.
- d. Output Section
The output section represents the outcome of the procedure executed by the ESP32-CAM:
 1. LCD: Exhibits data including the quantity of products that have been placed in the box.
 2. Solenoid Door Lock: Operates as a box door locking mechanism, which is autonomously regulated to secure and release the door.
 3. Telegram: Serves as a notification and remote-control platform. The system transmits photographs and information to the owner over the Telegram bot and accepts orders, including door opening or locking.

Potential Integration with Smart Home Systems

The Smart Package Receiver Box has the potential to be integrated with smart home automation systems [40] [41]. By connecting with these platforms, users could automate package delivery notifications, enable voice-activated control, and integrate the system with existing innovative security solutions such as CCTV cameras and motion detectors.

Handling Network Failures

To ensure continuous operation during network failures, the system can be upgraded with local storage and fallback mechanisms. If the device loses Wi-Fi connectivity, sensor data and access logs can be stored locally on an SD card until the connection is reestablished. Additionally, an alternative communication method, such as GSM-based SMS alerts, could be implemented to notify users even when internet access is unavailable.

Future Expansions

Future improvements to the Smart Package Receiver Box could include:

1. Improved Image Processing: Enhancing image quality using AI-based object recognition to verify package deliveries more accurately.
 2. Biometric Authentication: Integrating fingerprint or facial recognition to allow secure access for authorized recipients.
 3. Extended Battery Backup: Adding an uninterruptible power supply (UPS) or solar-powered battery to keep the system running during power outages.
 4. Multi-User Access: Allowing multiple users to control and monitor the box through shared permissions.
- By implementing these expansions, the Smart Package Receiver Box can further enhance its functionality, reliability, and security, making it a more robust solution for modern package delivery challenges.

3. RESULTS AND DISCUSSION

This research adopts a multi-method approach integrating experimental and quasi-experimental techniques. The Smart Box unit, which has been developed, is the focus of the investigation. The device incorporates a variety of sensors, such as temperature, humidity, and motion sensors, to conduct a comprehensive data collection. Furthermore, a camera helps to document the activities that occur in the vicinity of the Smart Box. The system regularly records user activity and device performance data. The data are subsequently analyzed using descriptive statistics to characterize the general characteristics of the data, as well as inferential statistical tests to test the proposed hypothesis.

3.1 Hardware Evaluation

The hardware is composed of two components: PIR and Ultrasonic Sensor Circuits, and Solenoid Lock Door Circuits.

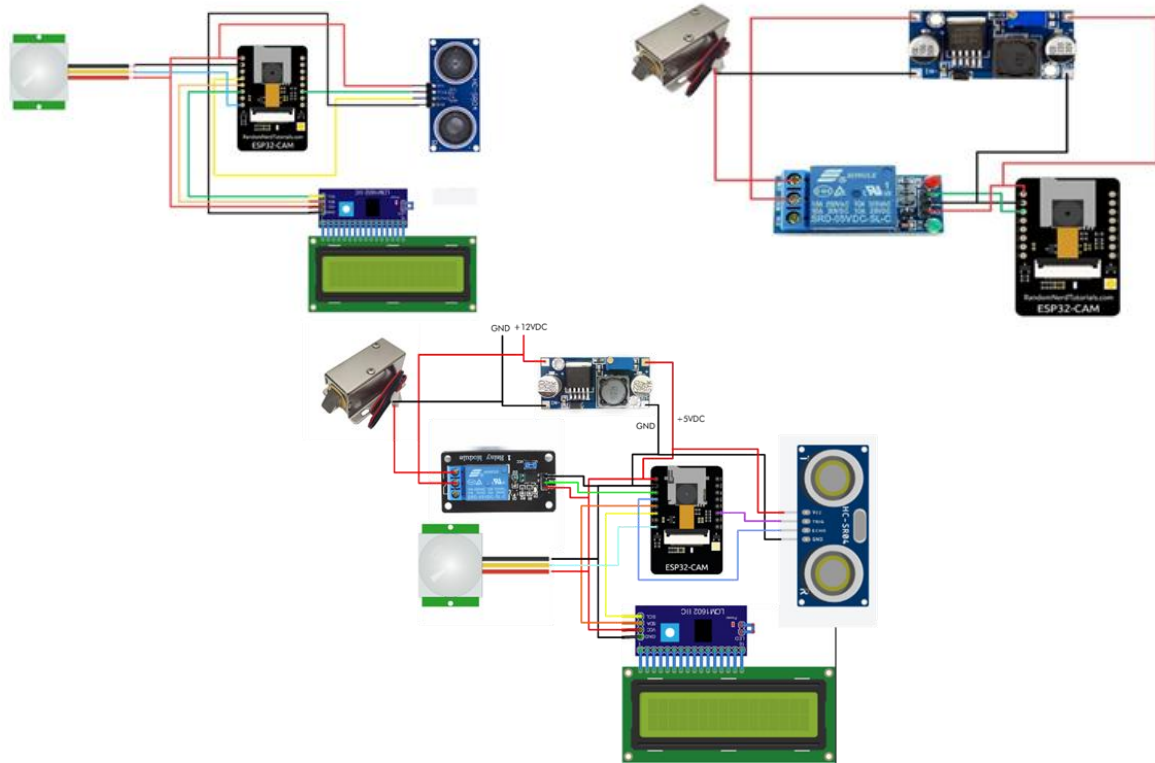


Figure 3. Comprehensive Circuit

In the Ultrasonic Sensor circuit, the VCC pin is linked to the power pin (5V), the Out pin is connected to the GPIO 03 pin, and the GND pin of the sensor is attached to the GND pin of the ESP32-CAM. The VCC pin of the PIR sensor is connected to the power supply (5V), the GND pin of the PIR sensor is linked to the GND pin of the ESP32-CAM, and the output pin of the PIR sensor is connected to the GPIO13 pin of the ESP32-CAM.

In the solenoid door lock circuit, the IN pin of the relay is linked to GPIO 12 on the ESP32-CAM, the VCC pin of the relay is connected to the 5V power pin on the ESP32-CAM, and the GND pin of the relay is attached to the GND pin on the ESP32-CAM. The relay has a Normally Closed contact connected to a 12V supply from the Step Down LM2596, while the Common Contact of the relay is linked to the solenoid door lock. Pengujian Sensor Ultrasonik

The ultrasonic sensor (HC-SR04) is used to ascertain the existence of items in front of the package receiving box. Testing is conducted at several distances: 5 cm, 10 cm, 25 cm, and 30 cm. Each time the sensor identifies an item, the ESP32-CAM captures an image. It transmits a notice to the Telegram bot, stating "A Courier is Sending a Package," accompanied by the captured image.

1. Test 1: At a distance of 5 cm, the sensor identifies the item, the ESP32-CAM captures an image, and the Telegram bot gets a notice.
2. Test 2: Distance 10 cm, findings similar to the first test.
3. Test 3: At a distance of 25 cm, detection operates seamlessly, with alerts and images sent over Telegram.
4. Test 4: At a distance of 30 cm, the sensor continues to identify objects and transmit data as anticipated.

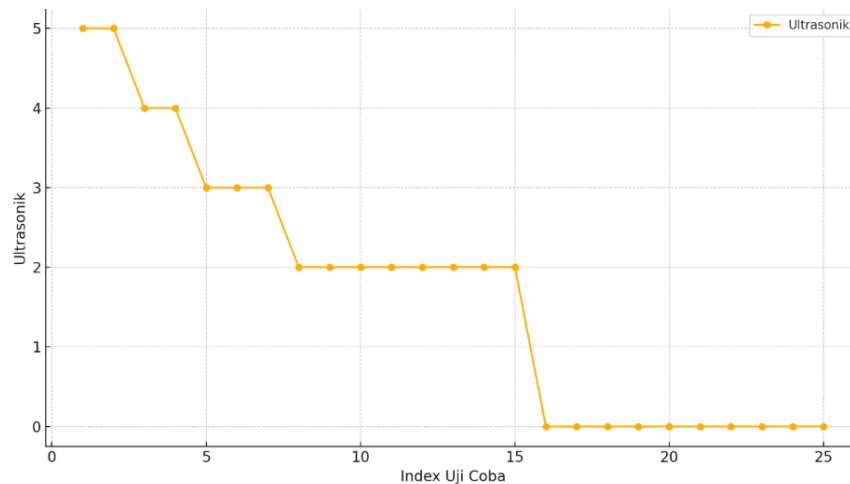


Figure 4. Ultrasonic Liner Testing

In Figure 4, loss in Value: The Ultrasonic graph illustrates a progressive decline in value from the 1st to the 11th test, signifying a reduction in the performance or sensitivity of the ultrasonic sensor over time. Stability: Following the 11th test, the value stabilizes around 1, suggesting that, after initial adjustment, the sensor may achieve a minimum performance level. Abrupt Decline: A significant reduction in value is observed in the 15th test, necessitating further investigation to determine whether this is a testing error or a sensor malfunction.

3.1.1 Testing of Door Lock Solenoid

The door lock solenoid is evaluated to confirm that the door's opening and locking mechanism operates as commanded by the Telegram bot.

1. Test 1: The instruction "/bukakunci" is sent over the Telegram bot. The solenoid door lock effectively unlocks the box door.
2. Test 2: Upon package insertion, the door automatically relocks when it senses no further activity in front of the box.

The test demonstrates that the Telegram bot's management of the solenoid door lock works seamlessly, enhancing security for package deliveries.

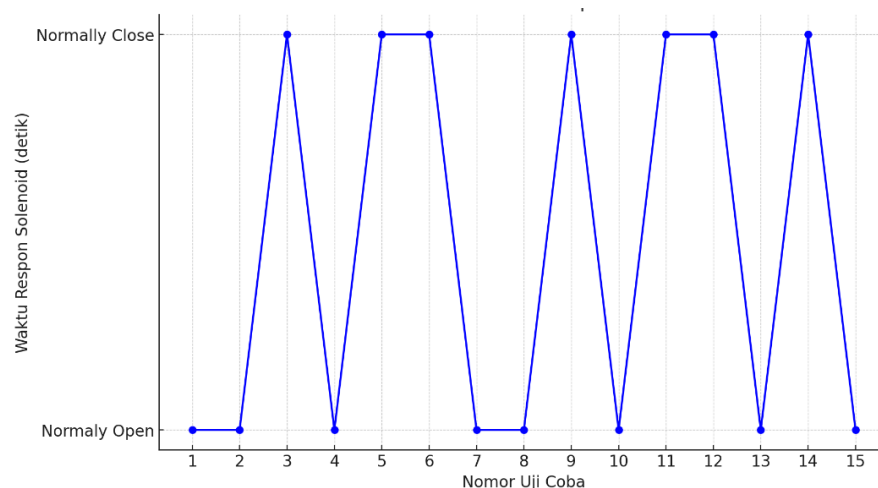


Figure 5. Solenoid Response Outcomes for Each Test Problem

Figure 5 illustrates that the solenoid's reaction time exhibits remarkable consistency. The solenoid promptly and reliably reacts to the order to open or shut in every test. There is no notable delay or considerable variation in reaction time. This indicates that the solenoid's internal mechanism functions properly and is reliable. The rapidity and reliability of this reaction time render the solenoid highly suitable for situations that necessitate a responsive and consistent actuator. This solenoid has shown reliability in performing its functions efficiently and consistently within a short timeframe.

[illegible]

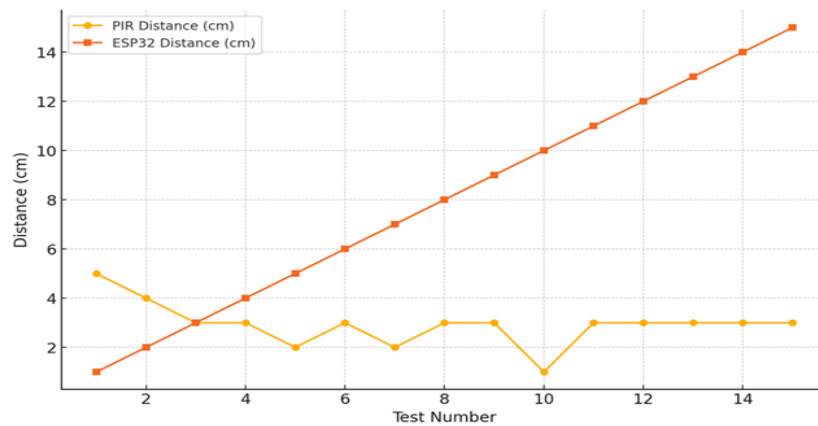


Figure 7. Response to Object Distance

Table 1 explains the following observations:

a. Data Distribution:

The data for the Solenoid sensor appears stable during several tests, with consistent responses. However, from tests 16 to 25, the response dropped to zero, which may indicate sensor failure or specific conditions that failed to trigger the sensor. The PIR sensor exhibited greater response variation compared to the Solenoid. This suggests that the PIR sensor reacts more dynamically to test variables, possibly being more sensitive to environmental changes or experimental setups.

b. Response to Distance:

The Solenoid sensor response shows a decreasing trend, eventually reaching zero as the distance increases, assuming the test sequence corresponds to increasing distance. This may indicate a maximum operating range or other factors limiting detection. For the PIR sensor, the response remained relatively stable at higher levels during the final tests, suggesting it is less affected by distance variations within the tested range.

The PIR sensor appears more effective in maintaining consistent response levels across different distances compared to the Solenoid sensor, which loses detection capability at greater distances.

Figure 7 compares the detection ranges between the PIR sensor and the ESP32 in various trials. The PIR sensor exhibited slight fluctuations in its detection range, maintaining an average distance of less than 6 cm. Meanwhile, the ESP32, utilizing a camera, demonstrated a more linear and stable increase in detection range. This indicates that the ESP32 can detect objects with improved accuracy as the distance increases. The differences highlight the specific roles of each sensor: the PIR sensor is more sensitive to small changes near the box, whereas the ESP32 provides more accurate detection at greater distances.

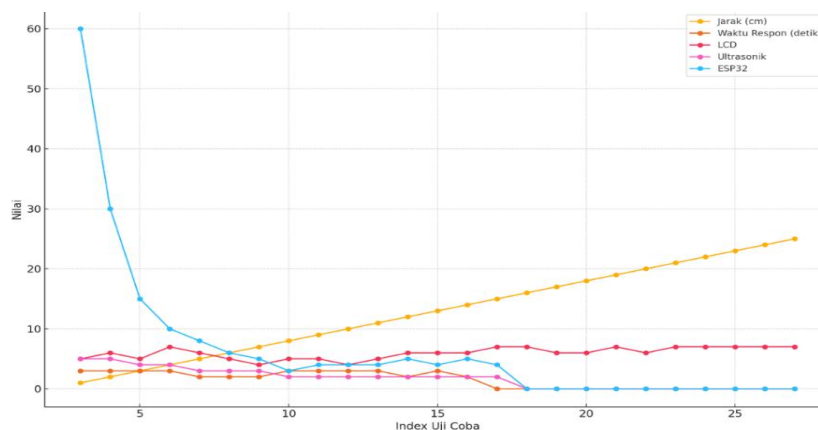


Figure 8. Combined Linear Visualization of Smart Box Package Testing

The explanation and analysis of Figure 8 are as follows: The ESP32 initially recorded very high values (around 60) that then dropped sharply to nearly zero during the first few observations. Afterward, the values tended to stabilize at lower levels. This suggests that the ESP32 may have a very high initial response, which stabilizes over time.

The distance (cm) shows a constant and significant upward trend. This may indicate that the distance continuously increases over time or as the test progresses, which could be relevant in the context of measuring physical distance or changes in position.

Response Time initially remained relatively constant but experienced a slight drop in the middle phase before returning to its initial value. This indicates relatively stable response times with minor fluctuations. LCD readings displayed small variations and tended to stabilize around a particular value. These small fluctuations may reflect minor changes in readings or test conditions. Stability: Attributes such as "Response Time," "LCD," and "Ultrasonic" demonstrated stability during most of the trials, indicating reliability under given conditions. Variability: The ESP32 exhibited significant initial variations but quickly stabilized, which is an important consideration in both hardware and software testing, as it helps understand initial reactions and long-term stability. Consistent Growth: The steady increase in distance (cm) may reflect a test condition designed to measure changes in distance or movement over time.

3.3 Comparison to Alternative Solutions

Compared to traditional mailbox systems and alternative innovative package solutions, the proposed Smart Package Receiver Box offers enhanced security, real-time monitoring, and remote access control. Unlike barcode-based mailboxes, which only provide delivery confirmation upon scanning, this system allows for immediate verification through live camera feeds. Similarly, conventional locker-based solutions require physical retrieval codes, whereas this IoT-enabled system provides seamless remote access, reducing operational complexities.

3.4 Potential Hacking Risks and Security Enhancements

As an IoT-based system, cybersecurity threats such as unauthorized access, data interception, and device hijacking must be taken into consideration. To mitigate these risks, several encryption and security protocols are proposed:

1. End-to-End Encryption: Implementing AES-256 encryption for all communication between the ESP32-CAM and the Telegram bot to prevent data interception.
2. Secure Authentication: Using multi-factor authentication (MFA) for access control to ensure only authorized users can interact with the system.
3. Firmware Security Updates: Regularly updating the firmware to patch vulnerabilities and enhance system protection against evolving cyber threats.
4. Intrusion Detection System (IDS): Monitoring network traffic for suspicious activity and deploying automated countermeasures if unauthorized access is detected.

4. CONCLUSION AND LIMITATION

The research findings indicate that the Smart Package Receiver Box, based on the Internet of Things (IoT), demonstrates effective and efficient performance. The system successfully integrates the ESP32-CAM, ultrasonic sensor, and PIR sensor with the Telegram application to facilitate package reception. The ultrasonic sensor accurately detects couriers within a range of 5 cm to 30 cm, while the PIR sensor effectively counts the number of inserted packages. The Solenoid Door Lock provides quick and consistent responses for locking and unlocking the box. The system's stability and fast response times allow users to conveniently monitor and control the package box via Telegram, even when they are not at home.

However, the system has some limitations that need to be addressed in future research. The current implementation relies on unencrypted communication, posing significant security risks; therefore, future iterations should incorporate AES-256 encryption and secure authentication mechanisms. The system's dependency on Telegram means any downtime or service interruption could render it ineffective, highlighting the need for alternative communication channels. Additionally, the system has only been tested in a controlled environment; real-world deployment is required to validate its long-term reliability and effectiveness. Future enhancements should focus on improving security measures, increasing system redundancy, and conducting extensive real-world testing to ensure robustness under varying conditions.

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