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Development of an Internet of Things-Based Animal Trap Using Motion Sensors and Camera: A Case Study on Rat Traps

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Abstract

This research aims to develop and implement an Internet of Things (IoT)-based rat trap utilizing dual infrared motion sensors and an ESP32-CAM module. The system integrates infrared sensors calibrated as automated triggers for a servo-driven hatch door, with the ESP32-CAM providing remote visual validation, managed by a NodeMCU ESP8266 as the primary microcontroller. Telemetry data, real-time push notifications, and manual overrides are synchronized seamlessly through the Firebase Realtime Database and a custom Android application. Evaluated via black-box testing using white lab rats as test objects, the empirical results demonstrate that all integrated components operate effectively. The conditional automation sequence, including the 5-minute sensor masking and timeout safeguards, executed successfully without system failure. Furthermore, system integration proved highly stable, exhibiting an average control and data telemetry latency of 1–3 seconds, while mobile push notifications were delivered in less than 3 seconds. These findings confirm that the multi-sensor and camera infrastructure can be utilized optimally to deliver a responsive, reliable, and modern pest control solution.

Keywords: *ESP32-Cam; Firebase; Internet of Things; Infrared Motion Sensor; NodeMCU ESP8266*

1. Introduction

This Rats are one of the most common pests causing significant problems in various environments, including households, warehouses, agriculture, and the food industry. Irayanti et al. [1] state that rat infestations in residential areas can lead to substantial property damage, ranging from ruining food supplies, household appliances, and electrical wiring to destroying building structures such as roofs and walls. Furthermore, rats also serve as vectors for various infectious diseases that threaten human health, such as leptospirosis and salmonellosis. Meanwhile, the Ministry of Health [2] indicates that leptospirosis cases were still prevalent across several regions in Indonesia in 2024, with transmission predominantly occurring in residential environments due to direct contact with water or surfaces contaminated by rat urine.

Various methods have been used by the community to control rat populations, one of which is by installing conventional rat traps. However, Ramadhan et al. [3] point out that this method has several limitations, such as requiring manual inspection, being inefficient for mass trapping, and failing to provide real-time information to users. This condition renders rat pest control in households less than optimal.

The advancement of Internet of Things (IoT) technology has enabled the development of intelligent pest control systems capable of automating monitoring and containment processes. Several studies have proposed smart traps integrated with sensors and communication technologies. Alif et al. [4] developed an IoT-based automatic rat trap using five infrared obstacle sensors and an ultrasonic sensor integrated with Telegram notifications via an ESP8266 module. Aji Saputro et al. [5] designed an automatic rat trap utilizing infrared sensors, a servo motor, a buzzer, and the Blynk platform for IoT connectivity. Andriansyah et al. [6] proposed a rat trap system based on NodeMCU ESP8266 that integrates ultrasonic sensors and an ESP32-CAM module to provide real-time visual live streaming. Iqbal et al. [7] implemented a smart mouse trap using a seesaw mechanism activated by ultrasonic sensors and controlled via the Blynk application. Meanwhile, Bakti [8] developed a mobile Android-based mousetrap featuring an automated feeder control and an electronic execution mechanism.

Although previous studies have demonstrated the feasibility of automated pest control methods, several limitations remain in existing systems. Most current automated rat traps heavily rely on third-party messaging platforms with delayed response times, lack localized visual verification features to safely identify the trapped target, or fail to provide persistent data tracking and historical logging consolidated

within a single native interface. Therefore, there is still a need for an integrated and specialized pest control system that combines fast edge detection, real-time local streaming, and structured data tracking through a dedicated mobile application.
To address these limitations, this study proposes an IoT-based automatic rat trap using a NodeMCU ESP8266 microcontroller, infrared obstacle sensors, a motor servo, and an ESP32-CAM module. The proposed system utilizes calibrated infrared sensors inside a specialized trap structure to automatically trigger a high-torque servo door upon rat detection. To ensure secure data transmission and real-time visualization, all operational states, automated counting metrics, and capture histories are synchronized with the Firebase Realtime Database and displayed through a custom Android application. Additionally, the system features a remote-controlled video streaming and alert system via the integrated camera and buzzer modules.

The main contributions of this study are as follows: (1) the development of a smart pest control hardware system featuring localized fast-trigger automatic doors and responsive timeout failsafe; (2) the integration of Firebase Realtime Database and an Android application to streamline visual validation, manual device overrides, and persistent tracking of historical data; and (3) the deployment of a highly hygienic and efficient operational workflow that minimizes direct human exposure to captured biological pests.

2. Research Method

This study focuses on the implementation and development of motion sensors and cameras in an Internet of Things (IoT)-based animal trap system, with a specific case study on rat traps. The proposed system integrates multiple infrared obstacle sensors for movement detection, an ESP32-CAM module for visual validation, a high-torque servo motor for automated containment, cloud-based database storage, and a dedicated mobile monitoring and control application. The research methodology consists of system workflow planning, hardware and software integration based on the Waterfall model, and system evaluation through functional Black Box testing. The overall methodology adopted in this study is illustrated through the system architecture and operational workflow presented in the following subsections.

2.1. System Architecture

The proposed system consists of a NodeMCU ESP8266 microcontroller, an ESP32-CAM module, infrared obstacle sensors, a voltage sensor, a servo motor, a buzzer, a single-channel relay module, Firebase Realtime Database, and a custom Android application. The ESP8266 is a low-cost, highly integrated Wi-Fi microchip equipped with a Tensilica 32-bit RISC CPU Xtensa LX106, full TCP/IP stack capability, and built-in 802.11 b/g/n Wi-Fi support. It serves as the primary central controller responsible for executing localized automation logic, processing data from input sensors, managing peripheral actuators, and establishing bidirectional real-time data communication with the cloud database. The complete hardware layout, power distribution scheme, and data flow of the architecture are illustrated in Figure 1.

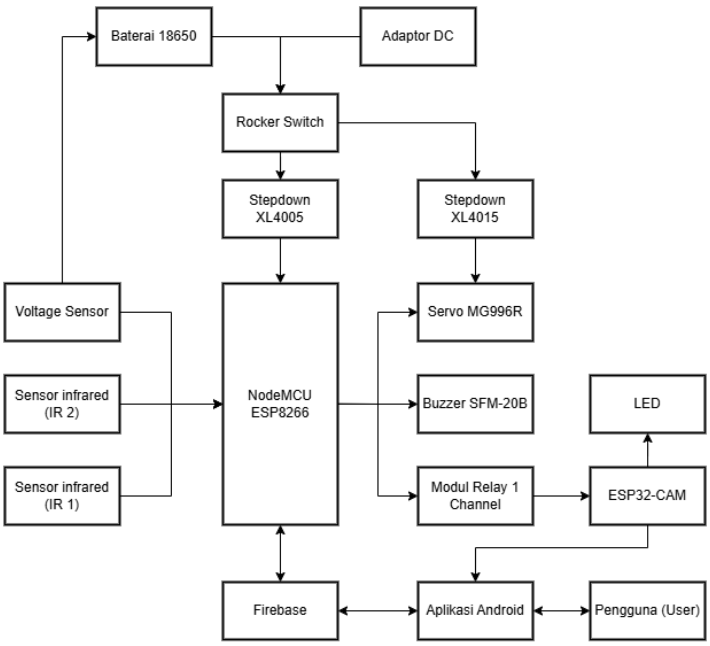

Figure 1: Architecture of the proposed system

An infrared obstacle sensor is used to detect the presence of animals entering the system. S, Arulananth et al. [9] explain that when the emitted infrared light hits an object, a portion of the rays reflects back and is captured by the receiver, thereby generating a signal that indicates the presence of an obstacle. According to the module's technical documentation, this reflected signal is processed through an on-board LM393 voltage comparator circuit, which immediately drives the digital output interface (OUT port) to output a low-level signal. In this architecture, two calibrated infrared obstacle sensors (IR 1 and IR 2) are utilized to manage the automated trapping logic. IR 1 is positioned at the entrance hatch to act as the primary trigger that prompts the servo door to close immediately upon rat detection. Meanwhile, IR 2 is placed further inside the secondary containment channel to verify and count if the rat has successfully moved into the main holding compartment.

The trapping and verification mechanisms utilize an MG996R servo motor, an SFM-20B buzzer, and a single-channel relay module. The high-torque digital servo motor, featuring metal gears capable of delivering a stall torque up to 11kg/cm at 6V [10] , executes the rapid physical isolation of the entry hatch. To streamline power management, the system employs dual XL4015 step-down buck converters; one regulates a stable 5V line for the logic components, while the other supplies an isolated 5.5V track explicitly to handle the inductive load spikes of the servo. The active piezo buzzer acts as a local acoustic indicator. Furthermore, the single-channel relay module applies a tri-state open-drain switching approach, effectively cutting or supplying 5V power to the ESP32-CAM and its illuminating LED array only when invoked. All state transitions, calculated capture metrics, and persistent log indexes are transmitted to the Firebase Realtime Database and synchronistically displayed through the custom Android application, allowing for low-latency remote monitoring and device overrides.

2.2. System Workflow

The operational workflow of the proposed system begins with the initialization of all hardware and software components, including the NodeMCU ESP8266 microcontroller, infrared obstacle sensors, servo motor, and the connection setup to the Firebase Realtime Database. After initialization, the system enters a continuous monitoring loop to detect animal presence. The calibrated infrared obstacle sensors stand by to register any physical entry at the trap gate.

When an animal trips the first sensor (IR 1) at the entrance hatch, the automated containment process is immediately initiated. The NodeMCU ESP8266 processes this digital state-change and signals the high-torque MG996R servo motor to rotate, pulling the mechanical hatch to close the trap door instantly. Once the door is secured, a 5-minute software countdown (timeout failsafe) begins. During this critical window, the secondary sensor (IR 2) inside the containment channel actively monitors the animal's movement. If the animal moves deeper into the main holding compartment and triggers IR 2 within the 5-minute period, the system classifies the event as a successful capture, logs the metric, increments the automated capture counter, and updates the state. However, if the countdown reaches zero without a trigger from IR 2, the system logs a timeout anomaly event, indicating that the target might have backed out or failed to trigger the secondary gate properly.

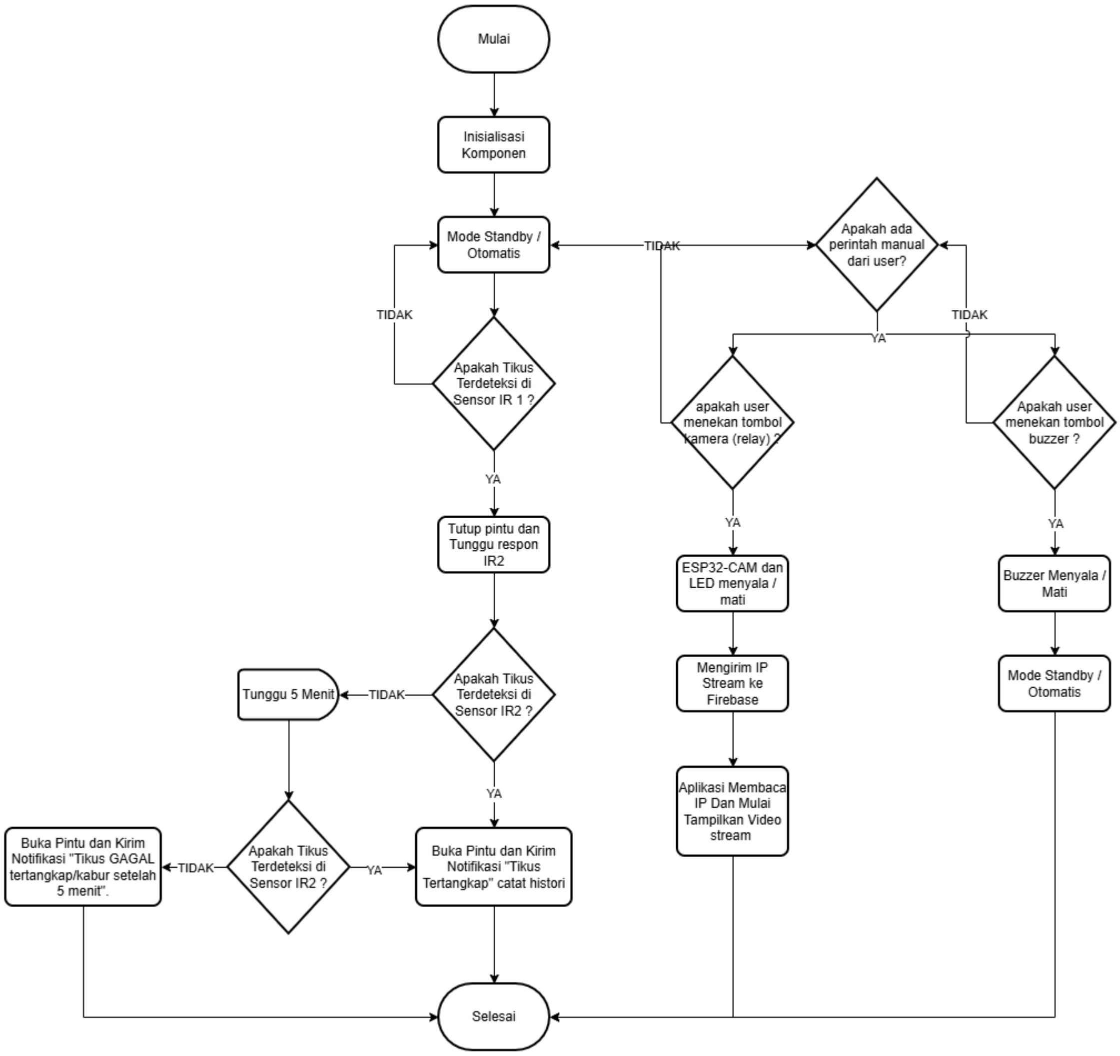

Figure 2: Workflow of the proposed system

After the logical evaluation of the trap state is concluded, the system records the precise timestamps and operational logs, then transmits this data to the Firebase Realtime Database. Concurrently, a push notification is routed to the custom Android application to immediately alert the user. Through the mobile interface, the user can review the updated capture metrics, cross-check the remaining battery telemetry, and remotely invoke a command to power up the ESP32-CAM via the 1-channel relay module for real-time video streaming. This visual confirmation workflow allows the user to safely inspect the trap interior from a hygienic distance. Once the automated or manual tracking cycles finish, the system loops back to its initial monitoring state and awaits the next detection loop.

3. Result and Discussion

3.1. Prototype Implementation

The proposed automatic animal trap system was successfully developed by integrating a NodeMCU ESP8266 microcontroller, infrared obstacle sensors, a high-torque servo motor, an ESP32-CAM module, Firebase Realtime Database, and a custom Android application. The ESP8266 serves as the central controller responsible for processing sensor data, executing the automated trapping logic, controlling servo movements based on a localized timeout mechanism, and transmitting system logs to the cloud database.

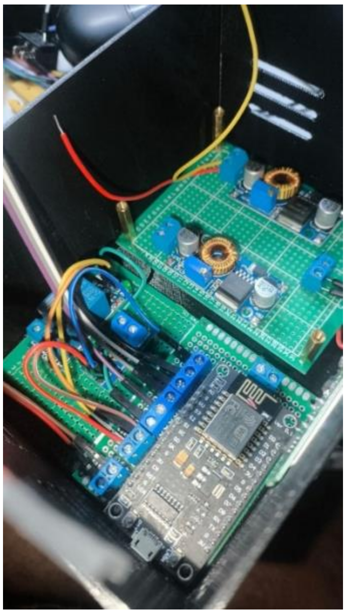

Figure 3: Prototype PCB implementation of the main control circuit

The hardware implementation was assembled using a modular perfboard PCB approach to streamline manual component deployment and circuit evaluation. The main control board houses the primary NodeMCU ESP8266 microcontroller and the first XL4015 step-down buck converter to provide a stable 5V power rail for the logic circuits. To simplify wiring distribution inside the trap chassis, the architecture extends to a secondary peripheral expansion board using a separate dot-matrix matrix. This sub-board acts as a dedicated junction hub to route the isolated 5.5V power tracks and data lines directly to the MG996R servo motor and the input infrared obstacle sensors. Meanwhile, the secondary ESP32-CAM module, configured as an isolated visual validation node controlled via a 1-channel relay, is strategically positioned at a separate elevated camera housing to achieve an optimal wide-angle field of view inside the main holding compartment.

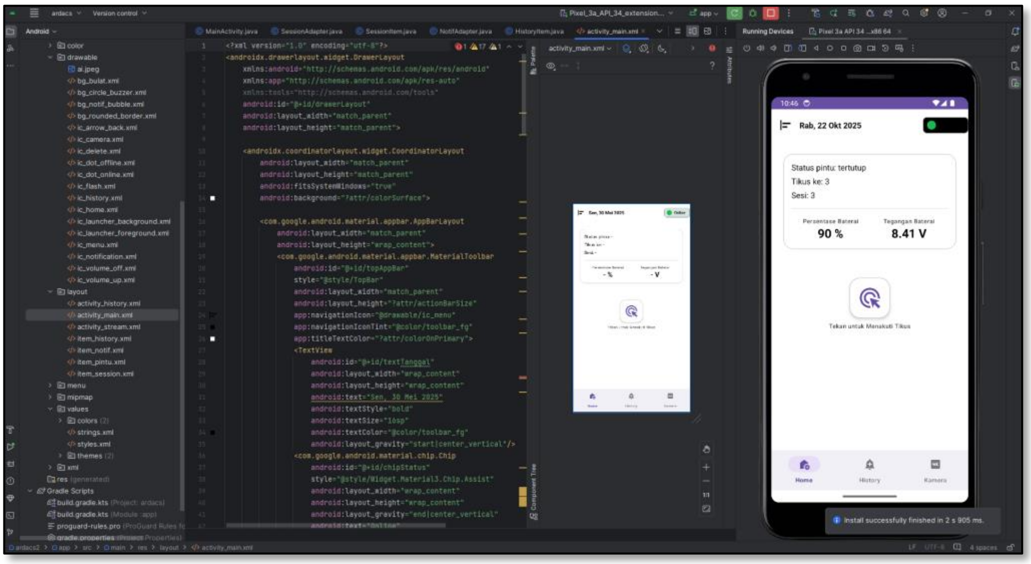

Figure 4: Android Studio IDE integrated development environment showing XML source layout and application interface preview

Furthermore, a mobile monitoring and control application was developed using Android Studio and connected to Firebase Realtime Database. The application enables users to monitor animal trapping activities, check battery status, and access live video streaming in real time. Through the main interface, the dashboard provides a continuous display of capture statistics, operational sessions, and precise voltage metrics. This real-time visibility ensures that users can manage the active status of the system efficiently from a distance. The successful integration of hardware and software components demonstrates the feasibility of implementing an IoT-based intelligent animal trap system.

3.2. Infrared Obstacle Sensor Testing

The infrared obstacle sensor was tested to determine its effective detection range for various objects. The sensor must reliably detect the presence of a target animal to ensure the automated trapping mechanism triggers correctly.

Table 1: Infrared Obstacle Testing Result Sensor

Test Distance (cm)	Fur ball Detection	PVC Sheet (Reflective) Detection	Hand Detection
2 cm	Detected	Detected	Detected
4 cm	Detected	Detected	Detected
6 cm	Detected	Detected	Detected
8 cm	Detected	Detected	Detected
10 cm	Detected	Detected	Detected
12 cm	Not Detected	Detected	Not Detected
14 cm	Not Detected	Not Detected	Not Detected
16 cm	Not Detected	Not Detected	Not Detected
18 cm	Not Detected	Not Detected	Not Detected
20 cm	Not Detected	Not Detected	Not Detected

The testing results indicate that the infrared obstacle sensor operates consistently across all object types within a range of 2 to 10 cm. Once the distance exceeds 10 cm, variations in detection occur based on the object's properties. The PVC sheet maintains the longest detection threshold, remaining detectable up to 14 cm due to its larger surface reflectivity. Meanwhile, both the fur ball and hand tracking parameters drop off immediately after 10 cm. These baseline measurements define the operational boundaries of the sensor before it is integrated into the structural layout of the system.

3.3. Servo Motor Endurance and Stress Testing

To evaluate the mechanical durability and thermal stability of the MG996R metal-gear servo motor under continuous load, a progressive stress test was conducted. The actuator was subjected to repeated, nonstop open-close cycles to ensure that high-frequency operations do not cause gear misalignment, torque degradation, or microcontroller resets

Table 2: Servo Motor Endurance and Stress Testing Result

Progressive Cycles	Observed Mechanical Behavior	Status
10 Cycles	Smooth rotation, torque delivery is stable	Pass
20 Cycles	Stable performance, motor housing exhibit moderate heat	Pass
30 Cycles	Stable performance, motor housing exhibit moderate heat	Pass
40 Cycles	Stable performance, motor housing exhibit moderate elevated heat	Pass
50 Cycles	Stable performance, motor housing exhibit moderate elevated heat	Pass

The endurance results indicate that the MG996R servo motor can handle high-frequency stress scenarios successfully. Although the motor housing exhibited moderate to moderately elevated heat during the later progressive cycles (20 to 50 cycles), the overall torque delivery remained stable without any mechanical lag or gear stuttering.

3.4. Video Streaming Endurance and Stability Testing

To evaluate the operational stability and data transmission reliability of the ESP32-CAM module under prolonged use, a continuous live streaming test was conducted. The camera feed was monitored constantly over a fixed duration of 30 minutes to ensure that continuous wireless data transmission does not cause severe network disconnections, packet loss, or extreme thermal throttling.

Table 3: Video Streaming and Stability Testing Result

Video Stream Duration	Observed Mechanical Behavior	Status
5 Minutes	Clear video feed, data transmission is stable and smooth	Pass
10 Minutes	Temporary frame freezing occurs due to minor network buffering	Pass
15 Minutes	Stream recovers, frame rate stabilizes as module housing begins to warm up	Pass
20 Minutes	Continuous streaming, module housing exhibits moderate heat	Pass
25 Minutes	Continuous streaming, module housing exhibits moderate heat	Pass
30 Minutes	Noticeable frame stuttering occurs, module housing exhibits moderate heat	Pass

The testing results demonstrate that the ESP32-CAM module is capable of maintaining an active live video feed during extended deployment windows. A temporary frame freezing event was observed at the 10-minute mark due to localized network buffering, but the stream recovered promptly by the 15-minute interval. As the test progressed past 15 minutes, the compact camera housing accumulated moderate heat. By the 30-minute mark, this thermal buildup combined with prolonged Wi-Fi data transmission caused noticeable frame stuttering (lagging). However, the connection remained active without experiencing a total system crash or disconnection, proving the system's overall resilience for short-to-medium operational monitoring sessions.

3.5. System Integration Testing

The overall system integration testing evaluated the seamless operation and coordination between the dual infrared obstacle sensors, the MG996R servo motor, and the ESP32-CAM video streaming module. The testing ensured that automated physical responses and manual application overrides occurred correctly under various tracking and detection scenarios.

Table 4: Overall System Integration Testing Result

No	Testing Scenario	Hardware and Camera Response	Android App UI and Notification	Status
1	Standby mode (Trap empty)	Servo states Open, ESP32-CAM stream is OFF	UI displays Pintu "Terbuka", Video feed is inactive	Pass
2	Entrance Triggered (Animal trips IR1)	IR 1 temporarily disables for 5 mins	UI displays Pintu "Tertutup" and notifications “Pintu menutup, tikus masuk!”	Pass
3	False Alarm Timeout (Triggering IR1 but leaves before trap closed)	After 5 mins, IR1 re-enabled and Servo changed to open	After 5 mins UI Display Pintu “Terbuka” and notification:“Tikus kabur, Pintu terbuka kembali”	Pass
4	Successful Trap (Animal bypasses IR1 to IR2)	Servo states Closed and after get signal from IR2 Servo states Open	UI Display Pintu “Terbuka” after get notification: “Pintu terbuka kembali, tikus ke-n”	Pass
5	Manual Camera Control ON (User turns on feed via app button)	Servo maintains its current state, ESP32-CAM stream turns ON	UI displays current door status, Live video feed stream activates	Pass
6	Manual Camera Control OFF (User turns off feed via app button)	Servo maintains its current state, ESP32-CAM stream turns OFF	UI displays current door status, Video feed stops streaming	Pass
7	System Reset (User presses Reset Session in app)	Servo returns to Open state, IR1 and IR2 re-arm to standby mode	UI resets to Pintu "Terbuka", Sesi terbaru dimulai	Pass
8	Network Re-sync (Wi-Fi temporarily disconnects and reconnects)	Microcontroller holds its last physical state (Open or Closed)	UI shows temporary "Offline" state then automatically resynchronizes data with Firebase	Pass

The integration testing confirms that the end-to-end communication loop between the dual-sensor infrastructure, the Firebase Realtime Database telemetry, and the Android mobile application operates exactly as designed. The system successfully executes a conditional logic sequence where the entrance sensor (IR 1) is temporarily masked upon initial trigger, granting a 5-minute tracking window. If the timeout expires without an inner trigger from IR 2, the system automatically re-arms IR 1 while keeping the hatch open. To optimize power consumption and data efficiency, the ESP32-CAM module operates under dedicated manual control from the application interface, allowing the user to toggle the live feed independently without altering the mechanical gate states. Furthermore, the system demonstrates strong network resilience by safely maintaining its physical lock state during temporary Wi-Fi dropouts and re-synchronizing smoothly upon reconnection, proving high operational reliability for active field deployment.

4. Conclusion

This study successfully implemented and developed an Internet of Things (IoT)-based animal trap system tailored as an automated rat trap. The proposed system integrated multiple infrared obstacle sensors with a high-torque servo motor actuator to perform automated containment sequences, all managed via a NodeMCU ESP8266 and synchronized in real-time through the Firebase Realtime Database to a dedicated Android mobile application.

Experimental results from functional black-box testing using white lab rats demonstrated that the conditional automation logic operated with high reliability. The system successfully executed the 5-minute sensor masking sequence, ensuring that the entrance sensor (IR 1) was temporarily disabled upon initial trigger to allow the target to advance to the inner chamber without causing data loops. The overall hardware infrastructure proved stable, managing successful mechanical gate closures immediately upon the triggering of the inner sensor (IR 2).

Furthermore, the end-to-end integration between the physical prototyping hardware and the mobile software interface enabled stable remote monitoring and control. The bidirectional telemetry loop achieved high performance, maintaining a minimal control and data latency of 1–3 seconds, while mobile push notifications were delivered seamlessly in less than 3 seconds. Although minor operational limitations were observed, such as the ESP32-CAM module requiring manual power control from the application interface to optimize data and power efficiency, the overall system operated reliably and achieved the core objectives of the study.

Future work may focus on integrating an independent solar-panel charging infrastructure for long-term outdoor deployment, implementing passive thermal cooling grids around the camera module to mitigate streaming stress, and embedding lightweight edge AI computer vision models directly onto the ESP32-CAM for automated animal classification.

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