International Journal Of Health, Engineering And Technology (IJHET) *E-ISSN 2829 - 8683*
Volume 5, Number 2, July 2026, *Page. 2810 - 2818*
Email : editorijhess@gmail.com

Design and Implementation Of An IoT-Based Rat Pest Monitoring System With Automatic Image Notification For Archive Rooms: A Case Study Of The Tulungagung Regency Transportation Agency

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Abstract

The presence of rats in archive storage rooms can cause damage to important documents, making an automatic monitoring system necessary for early detection. This study aims to design and develop a rat detection prototype based on the Internet of Things (IoT) using the You Only Look Once (YOLO) method. The research employed the Research and Development (R&D) approach, consisting of problem identification, data collection, product design, design validation, design revision, implementation, and product testing. The system utilizes a Logitech C270 HD webcam for image acquisition, a laptop for YOLO-based image processing, an ESP32 microcontroller, a relay, an ultrasonic speaker, Telegram notifications, and a web dashboard. The testing results showed that the system was able to detect rats in real time with an accuracy of 83.33% based on 24 testing scenarios using different viewing angles. The system also successfully sent notifications via Telegram, displayed detection results on the web dashboard, and automatically activated the ultrasonic speaker when a rat was detected. The validation results achieved an average score of 96% from experts and 90% from users, indicating that the prototype is highly valid and feasible for implementation in the archive room of the Tulungagung Regency Transportation Office. Future research is recommended to increase dataset diversity, use higher-resolution cameras, and develop a dedicated mobile application to improve detection accuracy and real-time monitoring.

Keywords: Internet Of Things (Iot), You Only Look Once (YOLO), ESP32, Rat Detection, Archive Room

INTRODUCTION

The rapid advancement of information technology has transformed administrative systems across both public and private organizations. An office serves as the central unit for administrative activities, information management, document processing, and decision-making support. It is not merely a physical workspace but also an integrated organizational system where planning, organizing, coordinating, and controlling activities are carried out using standardized procedures and supporting technologies (Yunisa & Martono, 2018). Consequently, the effectiveness of organizational operations is highly dependent on the proper management and preservation of archival records as essential sources of information.

Archives represent valuable organizational assets because they contain critical information such as administrative records, official correspondence, financial reports, policy documents, contracts, and strategic decisions. Proper archive management ensures administrative continuity, supports accountability, facilitates auditing processes, and provides reliable references for future policy formulation and organizational evaluation (Fathurrahman, 2018). Furthermore, effective records management contributes significantly to organizational efficiency by ensuring that information remains accessible, authentic, and secure throughout its lifecycle (Mulyapradana et al., 2023). Therefore, maintaining a secure archive storage environment is an essential component of organizational information management.

Despite their importance, archive storage rooms remain vulnerable to various environmental threats, particularly pest infestations. Among these pests, rats (*Rattus* spp.) are considered one of the most destructive due to their ability to gnaw on paper documents, cardboard, electrical cables, and other storage materials. Rats frequently inhabit enclosed, humid, and poorly monitored spaces such as archive rooms, where they can cause substantial physical damage to valuable documents and supporting infrastructure (Amsal et al., 2024). In addition to material destruction, rats are recognized as vectors of several zoonotic diseases, including leptospirosis, hantavirus infection, and salmonellosis, through their urine, feces, and saliva, thereby posing significant health risks within office environments (Gumay et al., 2020).

This issue has also been identified at the Archive Storage Room of the Tulungagung Regency Transportation Agency. Preliminary observations revealed that archive monitoring is still conducted manually through routine inspections performed by archive officers. Consequently, damage caused by rats is typically discovered only after archival documents have already been destroyed. Such a reactive monitoring approach is inefficient because it relies heavily on human supervision, requires considerable time and labor, and lacks an early warning mechanism capable of preventing document damage before it occurs (Ramadian et al., 2020). These limitations highlight the need for an automated monitoring system capable of detecting rat activity in real time.

The emergence of the Internet of Things (IoT) has created new opportunities for developing intelligent monitoring systems through the integration of sensors, microcontrollers, cameras, communication networks, and cloud-based notification services. IoT enables interconnected devices to collect, transmit, and process environmental data continuously, thereby improving monitoring efficiency and reducing human intervention (Atzori et al., 2010; Gubbi et al., 2013). One promising feature of IoT-based monitoring systems is auto-image notification, a mechanism that automatically captures an image whenever a predefined event is detected and instantly sends the captured image to users as visual evidence. When combined with computer vision techniques, particularly the YOLO (*You Only Look Once*) object detection algorithm, the system can accurately distinguish rats from other objects and pests, thereby reducing false detections and improving monitoring reliability (Redmon et al., 2016; Jocher et al., 2023).

Beyond detection, automated pest control is equally important to minimize archive damage. Ultrasonic technology has been widely adopted as an environmentally friendly rat repellent because rodents possess hearing capabilities that extend well beyond the upper frequency limit of human hearing. Previous studies have demonstrated that ultrasonic frequencies ranging from approximately 35 to 40 kHz effectively induce avoidance behavior in rats while remaining inaudible to humans (Baskoro et al., 2021). Therefore, integrating ultrasonic repellents with intelligent monitoring systems offers a proactive approach to protecting archival facilities from pest-related damage.

Several previous studies have explored electronic rat detection and repellent systems. Ahmad Nurfauzan et al. (2023) developed a rat repellent device utilizing a Passive Infrared (PIR) sensor, Arduino Uno, relay module, and ultrasonic speaker. Their findings indicated that ultrasonic frequencies between 35.4 and 40 kHz effectively caused panic and avoidance responses in rats, whereas frequencies below 26 kHz produced minimal behavioral effects. Similarly, Samudra et al. (2024) designed a microcontroller-based rat detection system using a PIR sensor and ultrasonic speaker. Their experimental results demonstrated that the PIR sensor achieved optimal detection performance within a distance of 1–3 meters, while its detection capability decreased significantly beyond 4 meters.

Although these studies have successfully demonstrated automatic rat detection and ultrasonic repelling mechanisms, most existing systems rely solely on motion sensors without incorporating intelligent visual recognition. Consequently, they cannot distinguish rats from other moving objects and do not provide visual evidence through real-time image notifications. Moreover, existing systems generally perform detection and repelling independently rather than integrating monitoring, visual verification, notification, and automated pest control into a unified IoT platform. This limitation represents an important research gap that warrants further investigation.

To address these limitations, this study proposes the Design and Development of an IoT-Based Rat Pest Monitoring System for Archive Rooms with Auto-Image Notification, using the Tulungagung Regency Transportation Agency as a case study. The proposed system integrates an ESP32 microcontroller, PIR sensor, camera module, YOLO-based object detection, cloud-based notification services, and an ultrasonic speaker into a single intelligent platform. When a rat is detected, the system automatically captures an image, sends a real-time notification accompanied by visual evidence to the user, and simultaneously activates the ultrasonic speaker to repel the pest. The integration of intelligent visual detection, automatic image notification, and active ultrasonic pest control within a unified IoT architecture constitutes the primary novelty of this research and is expected to provide a more effective solution for protecting archival documents compared with conventional monitoring approaches and previously developed systems.

RESEARCH METHODS

Research Design

This study employed a Research and Development (R&D) approach to design, develop, and evaluate an Internet of Things (IoT)-based rat pest monitoring system for archive rooms. The research was conducted between December 2025 and July 2026 at the Archive Room of the Tulungagung Regency Transportation Agency, East Java, Indonesia. The R&D methodology was adopted because it enables the systematic development, implementation, and evaluation of technological products through iterative design and testing (Sugiyono, 2017; Okpatrioka, 2023).

The proposed system integrates computer vision, IoT communication, and ultrasonic pest control into a single intelligent monitoring platform. The development process followed six major stages: (1) problem identification, (2) requirements analysis, (3) system design, (4) prototype development, (5) system validation and testing, and (6) product refinement.

Data Collection

Three complementary data collection techniques were employed.

1. Interviews were conducted with two key stakeholders, namely the Head of the General Affairs Division and the archive officer of the Tulungagung Regency Transportation Agency. The interviews explored existing archive management practices, current monitoring procedures, challenges in protecting archive documents, and user requirements for an automated monitoring system.
2. Field observations were carried out to investigate the physical conditions of the archive room, document storage arrangements, environmental characteristics, and evidence of rat activity. These observations provided practical information for designing an appropriate monitoring system.
3. Literature studies were conducted to establish the theoretical foundation of the research by reviewing previous studies related to Internet of Things (IoT), ESP32 microcontrollers, YOLO object detection, ultrasonic pest repellent technology, and intelligent monitoring systems.

System Architecture

The proposed monitoring system consists of four major components: a webcam for image acquisition, a laptop serving as the image processing unit, an ESP32 microcontroller for hardware control, and an ultrasonic speaker as the rat repellent device.

The webcam continuously captures images from the archive room and transfers them to the computer for processing. Object detection is performed using the YOLO (You Only Look Once) deep learning algorithm implemented with OpenCV. Once a rat is detected with a confidence score above the predefined threshold, the detection result is transmitted to the ESP32 through serial communication.

Upon receiving the detection signal, the ESP32 simultaneously activates an ultrasonic speaker via a relay module and sends a notification containing the captured image to users through the Telegram messaging platform. Consequently, archive officers receive immediate visual confirmation of rat activity while the ultrasonic device actively repels the detected pest.

Hardware and Software Components

The hardware configuration consists of:

- ESP32 microcontroller;
- USB webcam;

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- Relay module;
- Ultrasonic speaker (35–40 kHz);
- Personal computer/laptop;
- Power supply.

The software environment includes:

- Windows 10/11;
- Python programming language;
- YOLO object detection model;
- OpenCV library;
- Roboflow for dataset preparation and model training;
- Telegram Bot API for real-time notification.

System Development

The development procedure comprised the following steps:

1. Identification of archive room monitoring problems through interviews and field observations.
2. Collection of user requirements.
3. Hardware design, including electronic circuit construction and component integration.
4. Development of software for image acquisition, object detection, IoT communication, and notification services.
5. Training and deployment of the YOLO model for rat detection.
6. Integration of hardware and software into a complete IoT-based monitoring system.
7. Functional testing and validation of the developed prototype.

System Evaluation

The developed prototype was evaluated through three categories of testing.

Functional Testing

Each hardware component, including the webcam, ESP32, relay module, ultrasonic speaker, and Telegram notification service, was individually tested before complete system integration.

Expert Validation

Three experts in computer engineering and information technology evaluated the developed system using a five-point Likert scale. The evaluation covered system functionality, detection accuracy, response time, automatic notification performance, ultrasonic activation, usability, and implementation feasibility.

The validation score was calculated using:

[alidation\ Score=\frac{Observed\ Score}{Maximum\ Score}\times100%

The obtained percentages were interpreted according to the following criteria:

- 80–100% : Very Valid
- 61–80% : Valid
- 41–60% : Fair
- 21–40% : Less Valid
- <20% : Invalid

User Evaluation

User acceptance testing was conducted with archive personnel to evaluate system usability, ease of operation, effectiveness of Telegram notifications, dashboard readability, and the overall contribution of the system to archive security.

Performance Evaluation

The detection system was quantitatively evaluated using measurement error and detection accuracy.

The absolute error was calculated as

Error=|Y-X|

where (Y) represents the reference value and (X) denotes the measured value.

The percentage error was calculated by

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Error(%)=\frac{|Y-X|}{Y}\times100%
The detection accuracy was then computed as
Accuracy(%)=100-Error(%)

These evaluation metrics were used to assess the reliability of the proposed monitoring system in detecting rat activity and delivering real-time notifications within the archive environment.

RESULTS AND DISCUSSION

Developed IoT-Based Rat Monitoring System

An IoT-based rat monitoring system was successfully developed to improve archive room security by automatically detecting rat activity and providing real-time notifications. The proposed prototype integrates a webcam, a YOLO object detection model, an ESP32 microcontroller, a relay module, an ultrasonic speaker, a Telegram notification system, and a web dashboard into a single monitoring platform. The complete architecture of the developed system is presented in **Figure 1**.

Figure 1. Developed IoT-Based Rat Monitoring System Architecture

Figure 1 illustrates the workflow of the proposed monitoring system. The webcam continuously captures images from the archive room, which are processed using the YOLO object detection model. Once a rat is identified, the detection result is transmitted to the ESP32 microcontroller. The ESP32 subsequently activates the relay-connected ultrasonic speaker while simultaneously sending an image notification to the user through Telegram. In addition, all detection events are recorded and displayed on the web dashboard for monitoring purposes. This architecture enables continuous monitoring without requiring direct human supervision.

Functional Testing of System Components

After prototype development, each hardware and software component was evaluated individually to ensure correct operation before system integration. The functional testing results are summarized in **Table 1**.

Table 1. Functional Testing Results

Component	Expected Function	Result
Webcam	Capture real-time images	Successful
YOLO Model	Detect rat objects	Successful
ESP32	Receive detection signal	Successful
Relay Module	Activate ultrasonic speaker	Successful
Ultrasonic Speaker	Generate ultrasonic frequency	Successful
Telegram Bot	Send image notification	Successful
Web Dashboard	Display monitoring results	Successful

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As shown in Table 1, all hardware and software modules performed according to their intended functions. The webcam successfully acquired images in real time, while the YOLO model accurately identified rat objects. The ESP32 reliably received detection signals and activated the ultrasonic speaker via the relay module. Furthermore, Telegram notifications and dashboard visualization operated correctly, demonstrating successful integration of the entire IoT monitoring system.

Rat Detection Performance

The detection capability of the proposed system was evaluated using 24 testing scenarios representing different rat positions and viewing angles. The objective was to assess the robustness of the YOLO model under varying visual conditions. Examples of the detection results are shown in **Figure 2**, while the quantitative performance is summarized in **Table 2**.

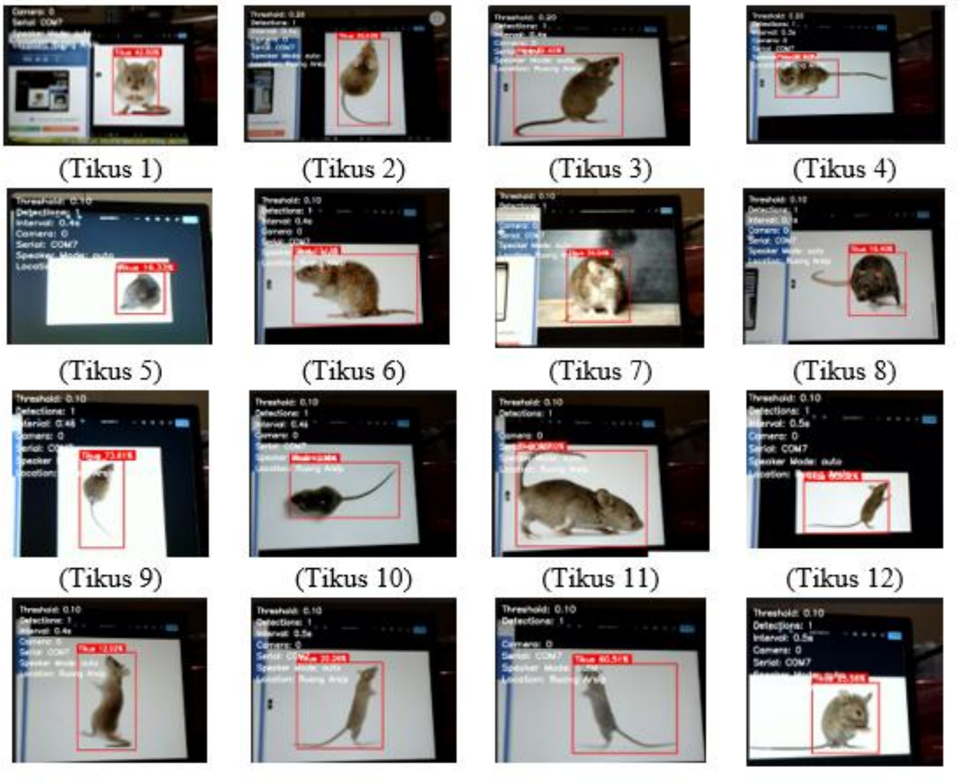

Figure 2. Examples of Rat Detection Using YOLO

Figure 2 demonstrates that the developed YOLO model successfully identified rats under various viewing angles. Most testing scenarios resulted in successful detection, whereas several images failed because of unfavorable object orientation or limited visibility.

Table 2. Detection Performance

Parameter	**Value**
Total testing scenarios	24
Successfully detected	20
Undetected	4
Detection accuracy	**83.33%**

As presented in Table 2, the proposed system successfully detected rats in 20 of the 24 testing scenarios, achieving an overall detection accuracy of **83.33%**. Detection failures primarily occurred when the rat was partially occluded or positioned at extreme viewing angles, reducing the visibility of distinguishing features required by the YOLO model.

Automatic Notification and Monitoring Interface

Following successful object detection, the system automatically generated notifications and stored the detection history on the monitoring dashboard. The monitoring interface is illustrated in **Figure 3**.

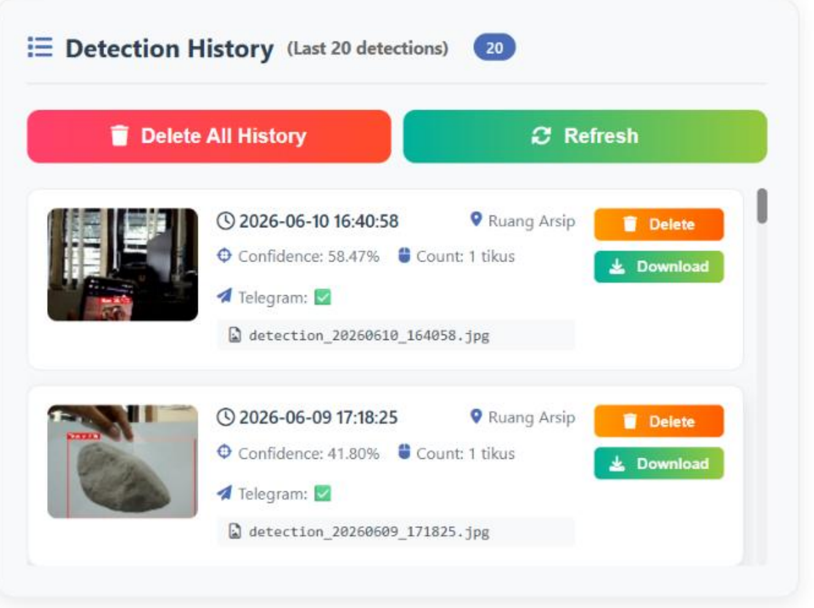

Figure 3. Web Dashboard Display

The dashboard displays the detected image together with the detection timestamp, enabling archive personnel to monitor rat activity remotely. Simultaneously, the Telegram Bot delivers an instant notification containing the captured image, allowing users to verify detection events without physically inspecting the archive room.

Expert Validation

To evaluate the feasibility of the developed prototype, expert validation was conducted involving specialists in computer systems and information technology. The evaluation focused on system functionality, detection capability, notification performance, usability, and implementation feasibility. The results are summarized in Table 3.

Table 3. Expert Validation Results

Validator	**Score**	**Category**
Expert 1	96%	Highly Valid
Expert 2	96%	Highly Valid
Average	**96%**	**Highly Valid**

The expert assessment yielded an average validation score of **96%**, indicating that the developed system satisfies the functional and technical requirements for archive room monitoring. The experts also confirmed that the integration between the YOLO detection model, ESP32 microcontroller, ultrasonic control module, Telegram notification service, and web dashboard functioned effectively.

User Evaluation

User acceptance testing was carried out with archive personnel to evaluate the usability of the proposed monitoring system under real operational conditions. The evaluation results are presented in Table 4.

Table 4. User Evaluation Results

Evaluation Aspect	**Score**
Ease of use	High
Dashboard readability	High
Notification effectiveness	High
Monitoring effectiveness	High
Overall user acceptance	**90%**

The average user evaluation score reached 90%, indicating that the developed prototype was considered practical and easy to operate. Users reported that the automatic Telegram notification and dashboard significantly improved monitoring efficiency compared with conventional manual inspection.

Overall System Performance

To summarize the experimental findings, the overall system performance is presented in Table 5.

Table 5. Overall Performance of the Proposed System

Performance Indicator	Result
Detection Accuracy	**83.33%**
Expert Validation	**96%**
User Validation	**90%**
Telegram Notification	Successful
Dashboard Monitoring	Successful
Ultrasonic Activation	Successful

Overall, the proposed IoT-based rat monitoring system successfully integrated real-time object detection, automatic image notification, dashboard visualization, and ultrasonic pest deterrence into a unified intelligent monitoring platform. The detection accuracy of 83.33%, combined with expert validation of 96% and user acceptance of 90%, demonstrates that the developed prototype is technically feasible and suitable for deployment in archive room environments to support early detection and prevention of document damage caused by rat infestations.

CONCLUSION

This study successfully designed and developed an Internet of Things (IoT)-based rat pest monitoring system for archive rooms integrated with automatic image notification. The proposed system combines a Logitech C270 HD webcam, the YOLO object detection algorithm, an ESP32 microcontroller, a relay module, an ultrasonic speaker, a Telegram notification service, and a web-based dashboard into a unified monitoring platform. The system enables real-time rat detection, automatically sends image notifications to users, records detection events on the dashboard, and activates an ultrasonic speaker to repel rats without requiring manual intervention.

Experimental results demonstrated that the proposed system achieved a rat detection accuracy of 83.33% under 24 testing scenarios with different viewing angles. Functional testing confirmed that all hardware and software components operated as intended, while expert and user evaluations yielded validation scores of 96% and 90%, respectively, indicating that the developed prototype is highly feasible for practical implementation. These findings demonstrate that the proposed IoT-based monitoring system provides an effective and reliable solution for protecting archival documents through continuous monitoring, early detection, and automated pest deterrence. Furthermore, the integration of computer vision, real-time notification, and ultrasonic control offers a practical contribution to intelligent archive management systems and can be further extended to other indoor monitoring applications.

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