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ESP32-CAM Based IoT System for Bird Pest Monitoring on Rice Plants with Solar Energy Utilization

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Abstract

Introduction: The problem of bird pest attacks is still a big challenge in rice cultivation in Indonesia because it can significantly reduce crop yields. This condition shows the need for a pest control system that can work automatically and sustainably.
Objective: This study aims to design and test an Internet of Things (IoT)-based bird pest detection and control system that can be operated independently in rice field areas.
Method: The development method is carried out through a prototyping approach, which integrates ESP32-CAM modules, solar panels, solar charge controllers, batteries, step-down converters, gearbox motors, sirens, and automatic notifications. The system was tested on 6 × 5-meter land with a variety of detection distances ranging from 10 cm to 140 cm to determine the detection and response performance of the device.
Results: The test results showed that the system was able to identify the presence of 1–10 birds with an average accuracy of 92%. When an object is detected, the driving motor and siren activate automatically as a form of expulsion. In addition, the system also sends real-time detection images and notifications through the LINE app. Stable performance as well as expulsion effectiveness exceeding 85% indicate that this device can work consistently in the field environment.
Conclusion: Overall, the developed system has the potential to be an energy-efficient, easy-to-operate, and effective smart farming solution in helping farmers reduce losses due to bird pests in rice fields.

Keywords: ESP32-CAM, *Internet of Things, Smart Farming.*

Introduction

Advances in digital technology in the last decade have changed the way agricultural systems are run, especially through the use of *the Internet of Things* (IoT) which enables automation processes, monitoring of land conditions, and data-driven control in real time [1], [2]. The integration of intelligent sensors in IoT systems has also been shown to improve monitoring accuracy and decision-making effectiveness in precision agriculture [3]. In this context, IoT is an important foundation for developing smart farming concepts that aim to reduce manual work and increase productivity [1].

On the other hand, rice farmers in Indonesia are still facing bird pest attacks that result in significant crop losses. The Agriculture Department notes that bird pest attacks can reduce potential crop yields by 20-30% in each planting season if not handled seriously. IoT technology is considered to have the potential to provide more effective monitoring and control solutions, although its application in rural areas is still constrained by infrastructure and costs [4]. Recent studies show that IoT systems for field monitoring and pest control can significantly reduce these losses [5].

Efforts to develop pest control devices have been carried out using various microcontrollers, such as WeMos ESP8266-based systems and PIR sensors that only recognize movements without visual ability [6], as well as solar-powered Arduino-based tools that do not yet provide remote monitoring [7]. Another approach uses alternative energy or PIR sensors but still does not come with automatic notifications or web monitoring [8], [9]. Ultrasonic and siren-based systems also remain dependent on conventional power sources and do not yet support real-time monitoring [10], [11].

Seeing these limitations, this study developed an ESP32-CAM-based system that utilizes solar energy and is able to detect bird pests through visual identification. The system is equipped with automatic notifications through the LINE app and a web server to monitor the condition of the land remotely. This approach is designed to provide a more self-sustaining, efficient, and relevant solution to the needs of modern agriculture.

This study focuses on the design and evaluation of IoT systems for the detection, expulsion, and monitoring of bird pests in rice plants. The goal is to produce an automated system that supports the implementation of smart farming.

Method

This type of research is Research and Development (R&D) which aims to develop a prototype of an IoT system for monitoring and eradicating bird pests. The method of developing the Internet of Things (IoT) system because it allows iterative processes, repeated evaluations, and design improvements from the initial stage [12], [13]. This approach is also widely applied to the development of microcontroller-based systems that require flexibility in hardware and software settings during field testing [14].

The research location is in Durian Village, Aceh Tamiang Regency, in January-March 2024, coinciding with the phase of formation and ripening of rice grains, which is a period prone to bird pest attacks. Previous studies have shown that bird infestations at this stage can cause panicle damage of more than 40% if not effectively controlled [15]. These conditions make the location and time of the research representative to assess system performance.

The system uses ESP32-CAM as a detection unit, solar panels as an energy source, and actuators in the form of gearbox motors and siren. The series of block diagrams and system workflows are shown in Figure 1 and Figure 2.

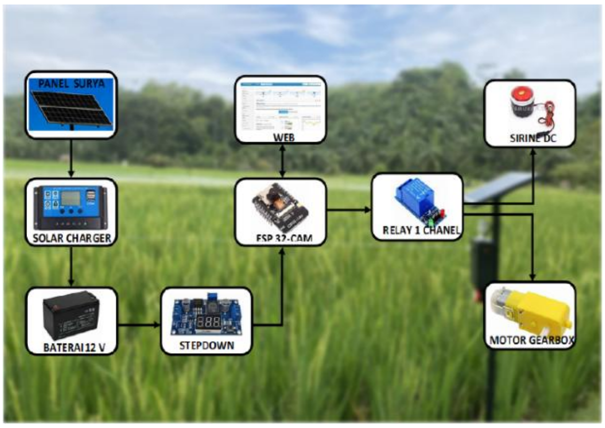


Figure 1. System Block Diagram

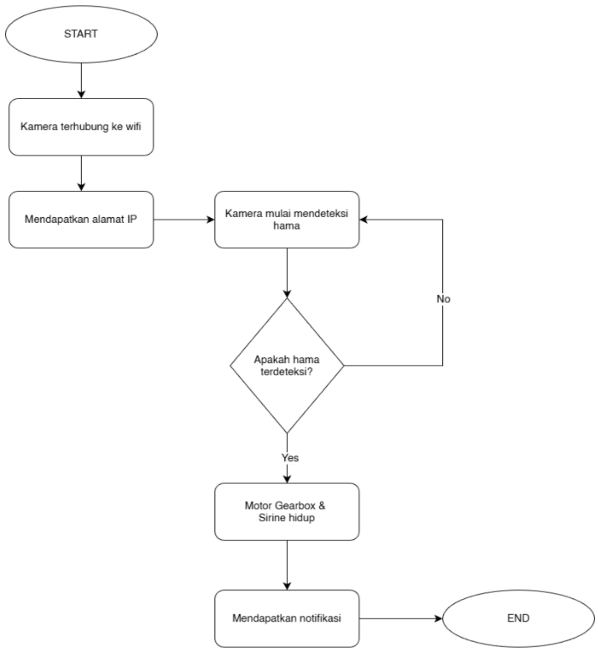


Figure 2. System Flowchart

The test aims to obtain performance data based on technical parameters such as effective detection distance, system response time, success rate of sending notifications through the LINE app, and stability of system operation under variations in environmental conditions, such as light intensity and hotspot signal strength. Calculation of detection accuracy using Equation (1).

$$Accuracy\% = \frac{Number\ of\ Correct\ Detections}{Total\ Test\ Count} \times 100 \qquad (1)$$

All tests were carried out without causing injury to the birds. The system only utilizes sound and movement for expulsion, following *the principles of animal welfare* in field research [16], [17], [18].

Results and Discussion

Results

1. System Test Results

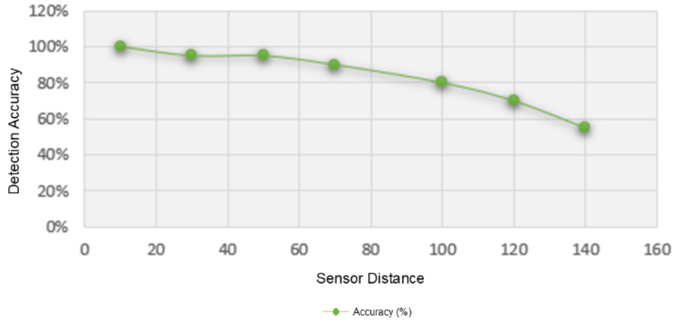
Table 2 presents system performance data based on the variation in detection distance. Testing was carried out 20 times for each distance interval.

Table 1. Results of the Monitoring System

Distance (cm)	Number of Tests	Number of Correct Detections	Accuracy (%)	Response Time (seconds)
10	20	20	100%	0.86
30	20	19	95%	0.96
50	20	19	95%	1.14
70	20	18	90%	1.40
100	20	16	80%	1.54
120	20	14	70%	1.77
140	20	11	55%	2.05

Based on Table 2, the system shows optimal performance at close range. At a distance of 10 cm, the system successfully detected objects 20 times (100% accuracy) with the fastest response time of 0.86 seconds. As the distance increases to 70 cm, the accuracy decreases slightly to 90% with a response time of 1.40 seconds. A significant drop in performance began to be seen at a distance of 140 cm, where accuracy dropped to 55% and response time slowed down to 2.05 seconds.

Furthermore, the decreasing trend of accuracy with respect to detection distance can be seen visually in Figure 4.



Gambar 3. Detection Accuracy vs Sensor Distance Graph

Figure 4 shows the inverse relative relationship between sensor distance and detection accuracy. The graph shows a trend line that slopes gradually from a distance of 10 cm to 100 cm, then swoops sharply after passing a distance of 120 cm.

Discussion

The ESP32-CAM-based bird pest monitoring and control system was tested on 6 × 5 meter rice fields with 20 experiments under various lighting conditions, ranging from morning to evening, and at a distance between 10 to 140 cm from the detection point. The system is able to detect the presence of birds with high accuracy at a distance of 10–100 cm, with an average accuracy of about 92% and a success rate of more than 85% for sending LINE notifications. The data showed that the accuracy and success rate of the system gradually decreased as the distance increased, while the response time increased from 0.86 seconds at a distance of 10 cm to 2.05 seconds at a distance of 140 cm. This trend corresponds to the characteristics of the ESP32-CAM camera module, where objects that are farther away occupy fewer pixels on the sensor, so detection becomes more challenging and requires longer image processing.

The decrease in performance at distances of more than 100 cm is also affected by variations in light intensity in open areas. As the lighting decreases, the contrast of the bird object against the background decreases, so the detection accuracy decreases. The system is still able to send notifications along with camera captured images at an effective distance, confirming network stability and data transmission reliability. The utilization of solar energy through the main panel provides a continuous power supply to the system, allowing the device to operate independently for up to eight hours without the need for recharging, while maintaining the continuity of the monitoring process in the field.

Although the ESP32-CAM was used in this study due to its low cost and ease of integration, similar systems can be improved using more powerful platforms such as the Raspberry Pi. The platform enables the use of higher-resolution cameras, faster image processing, and the integration of more complex detection algorithms, so that the effective detection distance can be extended and accuracy improved in low-light conditions. As such, the results on the ESP32-CAM prototype remain relevant as a proof of concept, while a full-scale implementation can leverage a more powerful platform for optimal performance.

These findings are in line with previous reports that showed a decrease in the effectiveness of optical sensors at long distances [19] and the importance of using renewable energy for autonomous farming devices [8], [20] The system also offers real-time monitoring and automatic notification integrations that have not been fully integrated in previous studies [6], [7]. With optimal performance at a distance of 10–100 cm, this system is suitable for small to medium rice fields, where effective detection and expulsion are crucial to prevent significant crop damage. Overall, the ESP32-CAM system enables effective, sustainable bird pest control and is ready for further development with a more robust platform.

Conclusion

The ESP32-CAM system has proven to be effective for the detection and removal of bird pests at distances of 10–100 cm with an average detection accuracy of about 92%, a response time of less than 1.5 seconds, and a success rate of more than 85% of LINE notification delivery. The system operates independently using solar energy, providing real-time monitoring, as well as effective bird removal. These results support the hypothesis that IoT systems can detect and respond to birds in real-time with high accuracy, network stability, and energy efficiency. In addition, the system can be further developed using more powerful platforms such as the Raspberry Pi to improve effective distances and detection accuracy, thus providing a sustainable and field-ready agricultural solution. In the later stages, the integration of vision-based AI algorithms can be the focus of development to optimize system performance under varying lighting conditions.

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