

Design and Development of an ESP32-Based Bird Repellent Prototype with Dual Detection (PIR and Ultrasonic Sensors)

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ARTICLE INFORMATION	ABSTRACT
Received : 07 – 09 – 2026 Revised : 02 – 10 – 2026 Published : 05 – 11 – 2026	Attacks by seed-eating birds during the rice-ripening stage can reduce crop yields, while traditional repelling methods tend to be inconsistent. This study aims to design and evaluate an ESP32-based bird repellent prototype with dual detection using passive infrared and ultrasonic sensors with OR logic. The study adopts a design-and-development approach with applied experimentation in a controlled test room measuring 2 × 3 meters. The system integrates an HC-SR501 passive infrared sensor, an HC-SR04 ultrasonic sensor, an MG996R servo motor, an ISD1820 sound module, a speaker, and a reflective string as visual and audio actuators. Testing consisted of one test without birds and five sessions with test birds, with a maximum of seven birds. The results showed that the prototype was successfully implemented and all main system functions operated as designed. During testing with birds, the system recorded 171 triggers, with an average response time of 0.57 seconds and an average triggering distance of 232.14 cm. Following activation of the visual and audio actuators, the proportion of move-away responses was 68 percent. These results indicate that the developed prototype is suitable for preliminary validation of a bird repellent system in a controlled test environment.
Keywords: Bird Repellent ESP32 OR logic Controlled Test Room Dual Sensors	

I. Introduction

Attacks by seed-eating birds during the rice-ripening stage are among the factors that can reduce crop yields. The presence of birds in rice fields is related not only to food availability but also to visitation patterns at specific crop growth stages. Findings on the diversity of seed-eating birds in rice fields indicate that bird disturbance is a relevant factor in rice cultivation [1]. Bird visits to rice crops are also influenced by growth stages and specific periods of daily activity, so effective control requires a rapid and targeted response [2].

In practice, birds are still commonly repelled using traditional methods, such as manual guarding, simple noise-making devices, or conventional visual deterrents. These approaches are relatively easy to implement but tend to be inconsistent because they depend heavily on human presence and may not provide the same response under every disturbance condition. Several studies have proposed electronics- and microcontroller-based solutions, including the use of ultrasonic waves [3], Internet of Things-based integration of sensors and actuators [4], and ESP32-based automated systems to reduce bird pest disturbance on agricultural land [5]. Other studies have developed bird repellents using ultrasonic waves and LoRa communication [6], as well as systems incorporating PIR sensors and mechanical actuators to generate visual and acoustic disturbances [7]. Arduino-based approaches integrating sensors and sound actuators have also been used to support bird repelling in agricultural settings [8].

Nevertheless, previous studies still exhibit several limitations. Some designs rely on a single sensor or one type of stimulus, making the device response highly dependent on a single type of input [7], [8]. Several IoT-based studies use ESP32 or similar microcontrollers to control motion sensors, distance sensors, cameras, buzzers, and servos, and then transmit data to applications such as Blynk or cloud platforms [9], [10], [11]. These approaches offer strengths in remote monitoring and ease of control; however, testing is generally conducted in open fields without a fully controlled indoor experimental design. Meanwhile, IoT-based noise detection studies use sound sensors, recording modules, and speakers to issue warnings when noise thresholds are exceeded [12]. Such studies are relevant references for designing effective audio systems, but they have not specifically addressed bird repelling in a controlled test room.

Given these conditions, there remains a need for an offline prototype that can first be tested in a controlled environment before proceeding to field testing. This study proposes an ESP32-based bird repellent prototype with dual detection combining an HC-SR501 PIR sensor and an HC-SR04 ultrasonic sensor using OR logic. In

this approach, the repellent actuators are activated when either sensor detects a triggering condition. The system includes a visual actuator consisting of a reflective string moved by an MG996R servo motor and an audio actuator that produces repellent sounds through an ISD1820 module connected to a speaker. The entire system operates offline and is tested in a controlled room measuring 2×3 meters.

This study aims to design, implement, and evaluate the functional performance of an ESP32-based bird repellent prototype with dual detection in a controlled test room. Its contributions comprise the development of an offline prototype integrating two sensor types, the application of OR logic to increase detection opportunities, and the presentation of preliminary validation results through measurements of trigger counts, response times, triggering distances, and the tendency of birds to respond to visual and audio actuator activation.

II. Methods

A. Research Type and Approach

This study is a design-and-development study using an applied experimental approach in a controlled environment. It focuses on developing an ESP32-based bird repellent prototype, followed by testing the functional performance of the system in a room measuring 2×3 meters. This approach was selected because the study not only produces a conceptual design but also implements a physical device and evaluates its performance through staged testing. A similar sequence of design, implementation, testing, and analysis has been used in studies of microcontroller- and Internet of Things-based automated system prototypes [13], [14].

B. System Design

The developed system consists of input, processing, and output blocks. The input block includes an HC-SR501 passive infrared sensor and an HC-SR04 ultrasonic sensor. The passive infrared sensor detects movement, while the ultrasonic sensor detects the presence of objects based on distance. The processing block uses an ESP32 microcontroller as the main controller to read sensor inputs and execute OR logic. With this logic, the system activates the actuators when either sensor detects a triggering condition. The output block consists of a visual actuator, an MG996R servo motor that moves a reflective string, and an audio actuator, an ISD1820 module connected to a speaker. The system is powered by a 12 V adapter, with an LM2596 module stepping down the voltage to meet the operating requirements of the components. In general, the configuration linking sensors, a microcontroller, and visual and audio actuators in this prototype is consistent with the architecture of ESP32-based automated systems and mechanical actuators used in previous IoT prototype studies [15], [16].

Table 1. Main System Components and Their Functions

No.	Component	Function
1	ESP32	Main microcontroller that reads sensor data, executes OR logic, and controls the actuators.
2	HC-SR501 PIR sensor	Detects bird movement around the feeding area.
3	HC-SR04 ultrasonic sensor	Measures object distance to support target presence detection.
4	MG996R servo motor	Moves the reflective string as a visual bird repellent actuator.
5	Reflective string	Creates a visual disturbance when moved by the servo.
6	ISD1820 module	Stores and plays repellent sounds when the system is active.
7	Speaker	Produces audio output as a repellent actuator.
8	12 V adapter	Serves as the main power supply for the system.
9	LM2596	Steps down the adapter voltage to meet component requirements.

Table 1 lists the main prototype components used in this study: the ESP32, HC-SR501 passive infrared sensor, HC-SR04 ultrasonic sensor, MG996R servo motor, ISD1820 module, speaker, 12 V adapter, LM2596 module, and reflective string as the visual repellent element. This component summary illustrates the relationships among the input devices, controller, and actuators in the developed system.

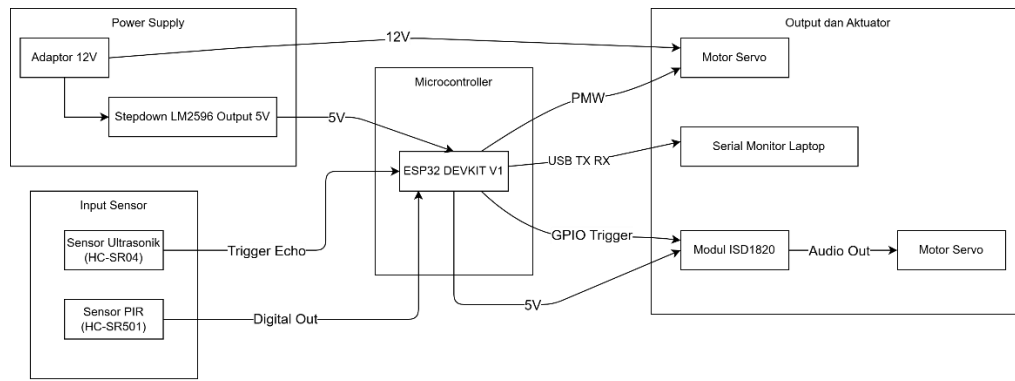


Figure 1. System block diagram

Figure 1 shows the relationships among the system components, with sensors serving as inputs, the ESP32 as the processor, and visual and audio actuators as outputs. This block diagram clarifies the overall system workflow before it is further explained through the software flowchart.

During operation, the system remains in standby mode and repeatedly reads the sensors. When either sensor detects a triggering condition, the ESP32 activates servo movement and audio output for 5 seconds. Once the activation period ends, the system returns to standby mode without an additional cooldown period. This configuration is intended to increase detection opportunities in a relatively small test room while maintaining a rapid system response to the presence of birds around the feeding area. The simultaneous use of visual and audio actuators is also based on previous research approaches that combine mechanical movement and sound output to enhance the repellent effect [4], [7], [8], [12].

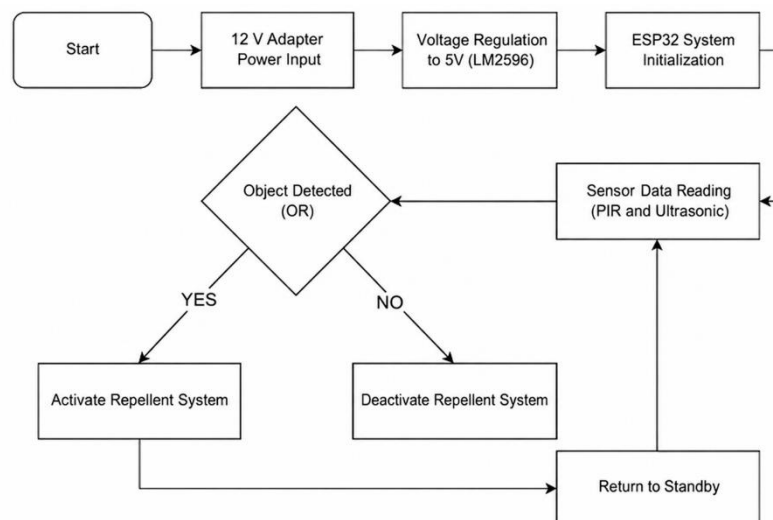


Figure 2. System flowchart

Figure 2 illustrates the software workflow on the ESP32, from system initialization and sensor readings to OR logic-based decision-making, activation of the visual and audio actuators, and the return to standby mode. This flowchart explains the sequence of control processes used during testing.

C. Test Environment and Scenarios

Testing was conducted in a controlled room measuring 2×3 meters. The prototype was positioned facing a feeding area on the floor of the test room. Testing was carried out in two stages. The first stage consisted of a single functional test without birds to ensure that all main system functions operated as designed. The second stage involved testing with birds over five sessions. The numbers of birds in the respective sessions were 3, 5, 7, 5, and 5, with a maximum of 7 birds in a single session. This staged testing approach is also commonly used in studies of microcontroller-based automated system prototypes [15], [17].

D. Data Collection

Research data were collected through direct observation during testing. The observed parameters included the number of system trigger events, the system response time from target detection to actuator activation, the distance between the object and the ultrasonic sensor at the first trigger, and the birds' reactions after actuator activation. Bird reactions were classified into two categories: moving away and not moving away from the

feeding area. Response times and distances were recorded with the assistance of serial monitor output, while bird reactions were assessed through visual observation and video recordings.

E. Data Analysis

The data were analyzed using descriptive quantitative methods by calculating the trigger count, average response time, average triggering distance, and percentage of move-away responses among the total number of birds observed. The percentage of move-away responses was calculated using Equation (1).

$$P = \frac{J_m}{J_t} \times 100\% \quad (1)$$

where:

P = percentage of move-away responses (%)

J_m = number of birds that moved away

J_t = total number of birds observed across all test sessions

These calculations were used to describe the tendency of birds to respond to device activation in the controlled test room. The average response time and triggering distance were then used to assess the functional performance of the prototype based on the results from all sessions.

III. Results and Discussion

The ESP32-based bird repellent prototype with dual detection was successfully implemented as designed. The system integrates an HC-SR501 PIR sensor and an HC-SR04 ultrasonic sensor as inputs, the ESP32 as the main controller, an MG996R servo motor to move the reflective string, and an ISD1820 module and speaker as audio actuators. All components operate within a single offline system using OR logic, so the actuators are activated when either sensor detects a triggering condition. The functional test without birds also showed that all main system functions operated as designed, including the power supply, sensor readings, OR logic, servo activation, audio output, a 5-second activation period, and the return to standby mode after each activation cycle. These findings indicate that the prototype was not only physically realized but also functioned according to the intended workflow.

During testing with birds in the controlled room measuring 2 × 3 meters, the system was tested in five sessions involving 3, 5, 7, 5, and 5 birds, respectively. The device position, test room, and device orientation toward the feeding area were maintained to ensure consistent test conditions. The system response results for each test session are summarized in Table 2.

Table 2. System Response Results for Each Test Session

Session	Triggers	Dominant sensor	Average distance (cm)	Average response time (seconds)
1.	21	Ultrasonic	232.39	0.5
2.	21	Ultrasonic	231.86	0.3
3.	30	PIR	233.53	0.5
4.	39	PIR	230.58	0.6
5.	60	Ultrasonic	232.48	0.7

As shown in Table 2, the number of system triggers varied across sessions: 21 in session 1, 21 in session 2, 30 in session 3, 39 in session 4, and 60 in session 5. The dominant sensor triggering the system also varied, with the ultrasonic sensor dominant in sessions 1, 2, and 5, and the PIR sensor dominant in sessions 3 and 4. The average triggering distance in each session ranged from 230.58 to 233.53 cm, while the average response time ranged from 0.3 to 0.7 seconds. Overall, these data indicate that the prototype provided measurable responses throughout all test sessions.

In addition to system responses, bird behavior was observed after the visual and audio actuators were activated. In session 1, 2 birds moved away and 1 did not; in session 2, 3 moved away and 2 did not; in session 3, 5 moved away and 2 did not; in session 4, 4 moved away and 1 did not; and in session 5, 3 moved away and 2 did not. Overall, 17 move-away responses and 8 non-move-away responses were observed over a total testing duration of 12 hours, 31 minutes, and 52 seconds. The overall test results are summarized in Table 3.

Table 3. Summary of Overall Test Results

Parameter	Result
Number of test sessions	5 sessions
Total system triggers	171
Overall average triggering distance (cm)	232.14
Overall average response time (seconds)	0.57
Total move-away responses	17
Total non-move-away responses	8
Percentage of birds that moved away (%)	68%
Total testing duration	12 hours 31 minutes 52 seconds

As shown in Table 3, the system recorded 171 triggers over five test sessions, with an overall average triggering distance of 232.14 cm and an overall average response time of 0.57 seconds. Bird behavior observations yielded 17 move-away responses and 8 non-move-away responses, resulting in a move-away proportion of 68%. This summary indicates that the developed prototype functioned in the controlled test room and produced measurable repellent outcomes based on system response parameters and the reactions of the test subjects.

These results indicate that dual detection using OR logic makes an important contribution to system performance. Variations in the dominant sensor across sessions suggest that the two sensors do not operate identically but complement each other according to their detection characteristics. The PIR sensor is more sensitive to changes in movement, while the ultrasonic sensor detects object presence based on distance. With OR logic, the system can activate the actuators as soon as either sensor detects a triggering condition, thereby providing more detection opportunities than a single-sensor configuration. In the context of the 2×3 -meter test room, this approach is relevant because targets may move in different directions and patterns. The combination of PIR and ultrasonic sensors in this study can therefore be understood as an approach that increases detection opportunities while maintaining a rapid system response in a confined test environment.

In terms of operating speed, the overall average response time of 0.57 seconds indicates that the system responds quickly between detecting a triggering condition and activating the actuators. This value indicates that sensor readings, OR logic processing by the ESP32, and actuator activation occur without significant delays. In addition to being rapid, actuator activation exhibited a stable operating pattern. The functional test showed that the MG996R servo moved as instructed, the ISD1820 module played repellent sounds through the speaker, activation lasted 5 seconds, and the system returned to standby mode afterward. Thus, the developed prototype was not only responsive but also consistent in repeatedly performing its repellent function during testing.

Regarding the behavior of the test subjects, observations showed that activation of the visual and audio actuators tended to encourage birds to move away from the feeding area. Across the five test sessions, 17 move-away responses and 8 non-move-away responses were recorded, yielding a move-away proportion of 68%. This finding indicates that system activation was not only technically successful but also elicited behavioral responses in the birds. In this study, servo-driven movement of the reflective string served as a visual disturbance, while sound from the speaker reinforced the startle effect around the feeding area. The combination of these stimuli supports the idea that bird repelling is more promising when it does not rely on a single type of stimulus. However, because 8 non-move-away responses were still observed, these findings are more appropriately interpreted as preliminary validation that combined visual and audio actuators are promising in a controlled test room, rather than as a basis for claiming absolute effectiveness under more complex field conditions.

IV. Conclusion

This study successfully designed and implemented an ESP32-based bird repellent prototype with dual detection using PIR and ultrasonic sensors and OR logic. The developed prototype integrates detection, data processing, and visual and audio actuator activation into a single offline system that operates as designed. The functional test also showed that all main system functions, including sensor readings, OR logic, servo activation, audio output, a 5-second activation period, and the return to standby mode, operated properly.

During testing in a controlled room measuring 2×3 meters, the system recorded 171 triggers, with an average response time of 0.57 seconds and an average triggering distance of 232.14 cm. Following activation of the visual and audio actuators, the proportion of move-away responses was 68%. These results indicate that the developed prototype has good functional performance as a preliminary validation of a bird repellent device in a controlled test environment.

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