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Development of an Ultrasonic Pest Repellent System Based on ESP32 and the Internet of Things (IoT)

Siti Fatimah[1], Inda Lestari[2], Cyndi Lestari[3], Nadia Putri Larita[4], Dini Milatul Husniyah[5], Arini Rosa Sinensis[6], Thoha Firdaus[7]
[1,2,3,4,5,6,7]Physics Education, Nurul Huda University, Indonesia
[1]sitifatimah@student.unuha.ac.id, [2]indalestari@student.unuha.ac.id, [3]cyndilestari@student.unuha.ac.id, [4]nadiaputri@student.unuha.ac.id, [5]dini@student.unuha.ac.id, [6]arini@unuha.ac.id, [7]thoha@unuha.ac.id

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ABSTRACT

Pest attacks on agricultural land often result in a significant decrease in crop yields. This study aims to develop an IoT-based pest repellent system integrating ultrasonic waves and remote control. The method involves an ESP32 microcontroller, a PIR sensor, and a PAM8403 amplifier with a piezoelectric tweeter. The system was evaluated through laboratory calibration and real-field implementation in East OKU. This device features automatic mode (ultrasonic triggers >20 kHz) and manual mode via the Blynk application. Quantitative results show a maximum detection range of 5 meters with a 110-degree coverage angle. The system achieves a stable 30 kHz output and real-time notifications with an average latency of less than 1 second. IoT integration enables farmers to monitor and control the device remotely, increasing crop protection efficiency in dynamic rice field environments.

A. INTRODUCTION

East Ogan Komering Ulu (OKU) Regency is one of the national food buffer zones, with the majority of its population dependent on the agricultural sector for their livelihood. According to data from the Central Bureau of Statistics (BPS) of OKU Timur Regency (2023),, agriculture is a leading sector supporting the local economy. However, the stability of harvest yields is often disrupted by fluctuating pest attacks, particularly rats and insects. This phenomenon is confirmed by a report from the official government portal, which recorded massive damage to rice crops due to attacks by hundreds of rats in several areas of East OKU, which directly threatens the welfare of farmers. In an interview, a farmer, Mr. Kasyanto, said that "There are many obstacles in the rice fields, one of which is the frequent pests such as rats, grasshoppers, planthoppers, and birds that can cause losses, even crop failure."

Current management methods mostly involve the continuous use of synthetic pesticides. As highlighted by Adiba (2015), this practice not only increases operational costs but also leads to the degradation of soil fertility and poses significant public health concerns due to chemical residues. Therefore, we are seeking effective, non-chemical, and sustainable pest control methods as an effective solution. This aligns with Nurfauzan (2023), who states that applying appropriate technology is essential to overcome inefficiencies in conventional agriculture and minimize the environmental impact of traditional farming methods. Therefore, innovative pest control tools are needed that are not only effective but also environmentally friendly and economical.

As pest repellent technology develops, there is an urgent need to integrate physical methods with automation and renewable energy to ensure long-term sustainability. The significance of this integration is highlighted by Ahmed and Hassan (2019), who emphasize that energy-efficient IoT nodes powered by solar energy are essential for modern agricultural pest management. Furthermore, Ghosal and Halder (2020) argue that IoT-based smart pest control using ultrasonic waves is a cornerstone for sustainable agriculture, as it minimizes human intervention while maximizing field protection. Locally, research by Fauzi and Setiawan (2021) and Akbar et al. (2022) demonstrates that combining ultrasonic waves with solar power and IoT significantly assists farmers in remotely monitoring field conditions and protecting rice plants more effectively than traditional methods.

The urgency of this study lies in providing a concrete, technology-driven solution for farmers in OKU Timur who still rely on hazardous chemical methods or inefficient manual guarding. Building on the work of Hidayat (2020), which utilizes PIR sensors for land security against animal pests, this research develops a Smart Ultrasonic Pest Repellent System specifically tuned to local pest characteristics. The novelty and significance of this study are found in the use of the ESP32 microcontroller to manage a dual-priority system (Automatic vs. Manual) through the Blynk platform. Unlike previous designs, this system leverages the high-speed PWM capabilities of the ESP32 to generate precise frequencies supported by Al Rasyid and Wardani (2024) as an effective deterrent while ensuring real-time accessibility for farmers, thus bridging the gap between advanced physics applications and practical agricultural needs.

The novelty of this research lies in its integrated dual-system priority architecture, which distinguishes it from previous static designs. While earlier studies, such as Alamsyah and Nurhilal (2017), focused on standalone devices with fixed triggers, this study introduces a dynamic management system that synchronizes sensor-driven automation with real-time manual overrides. By utilizing the high-speed PWM capabilities of the ESP32 microcontroller, the system generates a precise 30 kHz frequency specifically calibrated to the auditory sensitivities of local pests as identified by Nurfauzan (2023). This approach bridges the gap between IoT connectivity and bio-acoustic physics, offering a more adaptive solution than traditional, non-integrated devices.

Consequently, the objective of this research is to design, construct, and test a Smart Ultrasonic Pest Repellent System Based on IoT to provide a concrete technological solution for farmers in East OKU. This study aims to evaluate the effectiveness of the ESP32-based frequency generation and the reliability of the PIR sensor in triggering the system, while ensuring seamless remote monitoring and control through the Blynk platform. By achieving these objectives, the research seeks to offer an efficient, non-chemical alternative to conventional pest management, thereby improving harvest stability and supporting sustainable agricultural practices.

B. METHODS

This research uses a Research and Development (R&D) approach with the ADDIE model, which includes the stages of Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was chosen because it provides a systematic development flow for producing educational technology and applied engineering products, from needs analysis to comprehensive product performance evaluation (Sanatang & FB, 2021). This approach is suitable for the development of pest repellent systems based on applied physics and the Internet of Things (IoT), which require hardware and software integration (Sari, 2015).

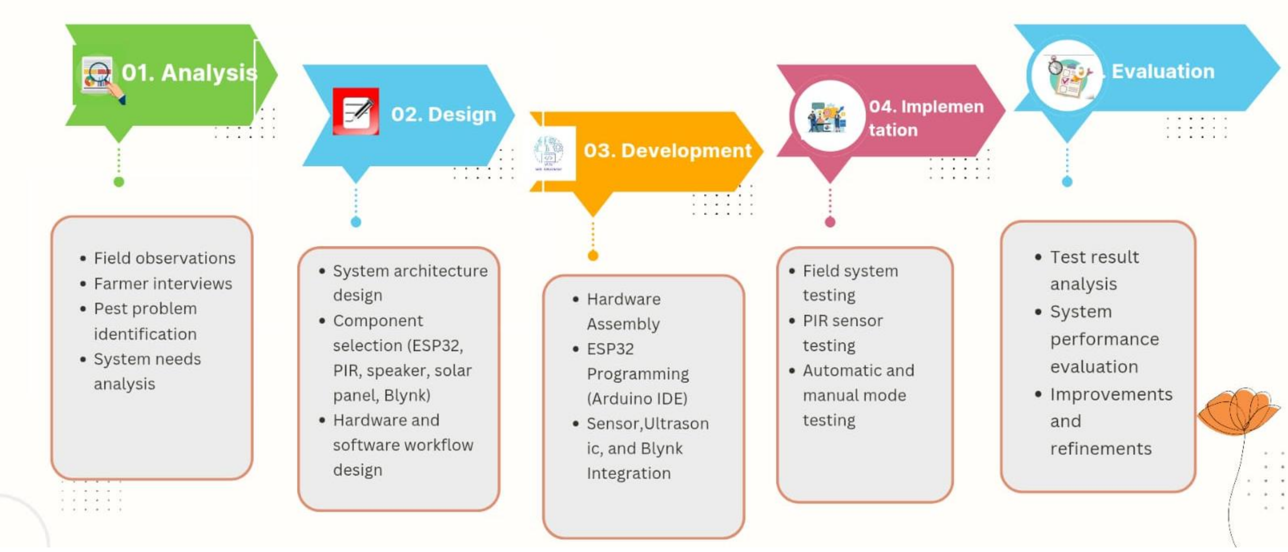

Figure 1. Flowchart with ADDIE Method

a. Analysis

The analysis phase was conducted to identify problems and user needs as the basis for system development. The analysis was conducted through field observations and interviews with farmers in East OKU Regency who were facing pest attacks such as rats, grasshoppers, planthoppers, and birds. Previous research has shown that pest attacks, especially rats, are a major factor in reducing crop yields on agricultural land (Pusparini & Suratha, 2018). Furthermore, the excessive use of chemical pesticides is considered ineffective, expensive, and has a negative impact on the environment, necessitating alternative solutions that are environmentally friendly and sustainable (Nurfauzan et al., 2023).

b. Design

The design stage is carried out based on the results of the needs analysis by compiling a comprehensive ultrasonic pest repellent system design.This system is designed using an ESP32 microcontroller as the main control center that integrates a PIR sensor on GPIO 14 pin to detect pest movement with a range of 110°. Ultrasonic sound output is generated through a Pulse Width Modulation (PWM) mechanism on GPIO 25, which is then amplified by a PAM8403 amplifier to vibrate a piezoelectric tweeter speaker. The system's power supply is self-contained, using solar panels and a Solar Charge Controller (SCC) to charge a 12V battery, whose voltage is reduced to 5V via a step-down converter. All components are protected by a weatherproof housing. On the software side, the firmware was developed in C++ on the

Arduino IDE that supports priority management between automatic (sensor) mode and manual mode through the Blynk application for real-time monitoring and remote control.IoT-based (Sari, 2015; Tjandi, 2022).

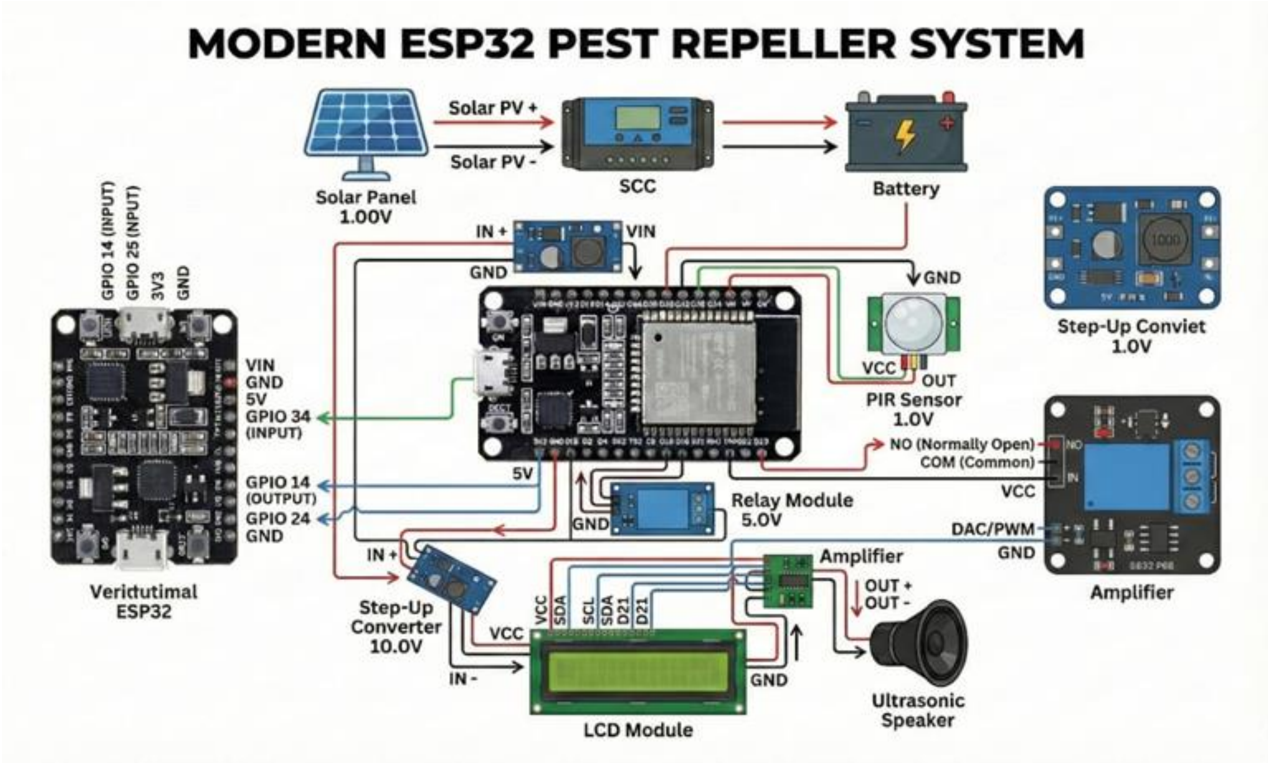

Figure 2. Pest Repellent Circuit SketchESP32 and IoT Based Ultrasonic

c. Development

The development phase is the process of turning the design into a prototype of an intelligent ultrasonic pest repellent system. This phase involves assembling the hardware, which includes an ESP32, a PIR sensor, a PAM8403 amplifier, a piezoelectric tweeter speaker, and a solar panel-based power supply system.The tool manufacturing process is carried out through six systematic phases, starting with component preparation and circuit assembly using soldering techniques to ensure connectivity between GPIO pins and minimize signal noise. The process continues with writing and flashing the program code for ultrasonic frequency configuration and synchronizing Wi-Fi credentials with the Blynk server. After successful IoT integration, the entire circuit is placed in a weatherproof enclosure to protect the device from extreme conditions in the field. The final stage involves comprehensive functional testing and calibration to validate the tool's automatic response to movement, the stability of smartphone control, and ensure the resulting frequency falls within the desired ultrasonic range.(Nurfauzan et al., 2023).

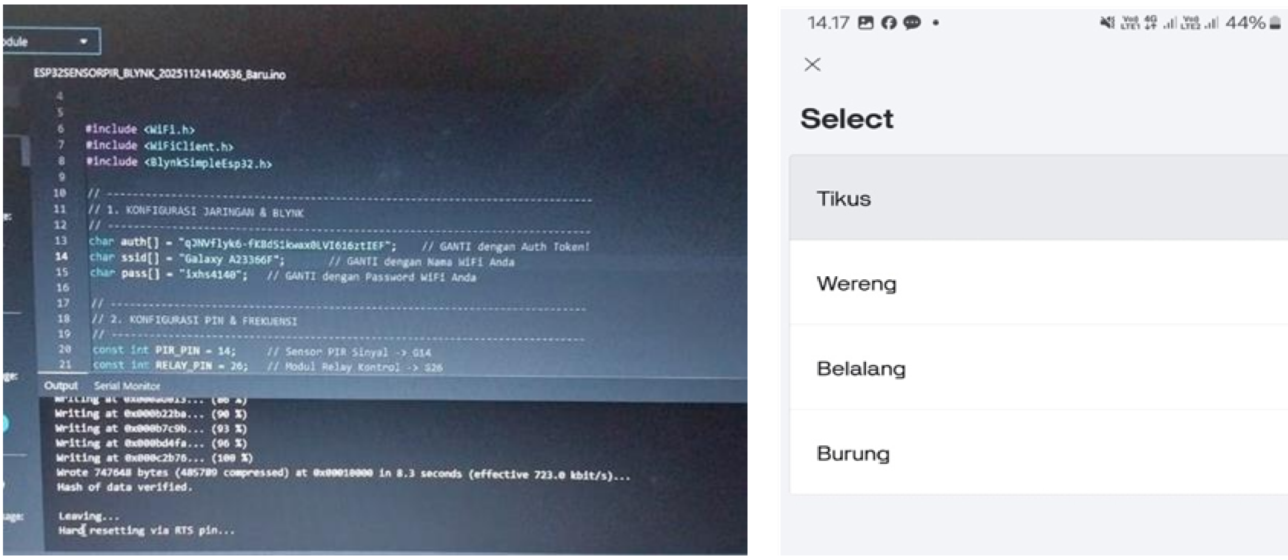

Figure 2. Arduino ide Coding Display and Blynk Application on Mobile

d. Implementation

The implementation phase was carried out by testing the system prototype under operational conditions. Testing included the PIR sensor's ability to detect pest movement, the system's response to activating ultrasonic waves, and the performance of the remote control system via the Blynk application. This phase was conducted to validate the prototype's technical performance through three main parameters. First, the functionality test ensured that the PIR sensor was able to detect movement within a radius of 1-6 meters and that the ESP32 could execute control commands accurately. Second, validation of physical parameters was conducted to ensure frequency stability in the ultrasonic range (30 kHz), to ensure effective pest repellent without causing audiosonic sound leakage that disturbs humans.

Third, IoT connectivity and latency tests were conducted using the Blynk application to measure the remote control's response speed. The evaluation focused on the stability of data transmission from the cloud to the device and the robustness of the Wi-Fi connection when the device was operated in rice fields with limited signal conditions. This is crucial to ensure the system remains reliable in providing real-time notifications and control. This implementation aims to ensure the system performs as designed and operates stably in a dynamic agricultural environment (Tjandi, 2022).

e. Evaluation

The evaluation phase showed that this pest repellent system works optimally with a stable ultrasonic frequency at 30 kHz which effectively disturbs pests without noise pollution for humans. Technical validation confirmed that the PIR sensor is able to detect movement within a radius of 1–5 meters with a data transmission latency to the Blynk application of under 1 second, thus ensuring real-time remote control response. In addition, the use of a solar power system ensures 24-hour power continuity, while the implementation of dual modes (automatic and manual) has been proven to increase the operational efficiency of farmers in protecting their land independently and sustainably.

C. RESULTS AND DISCUSSION

1. Results

a. Product Results

The results of this research represent the physical embodiment of the developed intelligent pest control system. The primary focus of the results phase was the effectiveness of sensor detection over distance and the successful transmission of data to an IoT platform. This system is a development of a previous Arduino Uno R3-based device, now enhanced with ESP32 to support Internet of Things (IoT) features.

Figure 4. Ultrasonic Pest Repeller Based on ESP32 and IoT

b. Trials

1. Trial Results

The following is the integrated test result data which includes object distance, generated frequency, sensor response, and synchronization in the Blynk application:

Table 1. Prototype Tool Test Results

Object Distance (Meters)	Output Frequency (kHz)	PIR Sensor Detection	Tool Response Status	Blynk Notifications & Controls
1 Meter	30 kHz	Detected	Very fast	Distributed (Active)
2 Meter	30 kHz	Detected	Fast	Distributed (Active)
3 Meter	30 kHz	Detected	Stable	Distributed (Active)
4 Meter	30 kHz	Detected	A Little Slow	Distributed (Active)
5 Meter	30 kHz	Detected	Less Stable	Distributed (Active)
6 Meter	30 kHz	Not detected	Standby	Connected (Idle)

Based on Table 1, the device works optimally within a range of 1-4 meters. At a distance of 5 meters, the PIR sensor begins to experience a decrease in detection stability, and at a distance of 6 meters the sensor is no longer able to detect infrared radiation from objects (pests), so the system remains in idle mode. Several ultrasonic frequency options can be utilized in pest repellent systems. In this study, a frequency of 30 kHz was selected because it falls within the effective ultrasonic range for disrupting rodent auditory responses while remaining inaudible to humans.

2. Discussion

Based on the test results in Table 1, the resulting frequency was stably at 30 kHz. This frequency selection has proven effective in disrupting pests. This is supported by the findings of Nurfauzan et al. (2023) who stated that at a frequency of 22.2 kHz, rats, monitored by infrared cameras, began to exhibit confusion, while at a frequency of 30.0 kHz, the intensity of the disturbance increased significantly, effectively repelling pests from the crop area. The use of this frequency is an appropriate physical solution because it is above the threshold of human hearing but is highly disruptive to the auditory nervous system of rat pests.

The development of this tool represents a modernization step from a manual system based on Arduino Uno R3 to an intelligent system based on ESP32. This integration allows the use of wireless features for remote monitoring. In accordance with Sari's theory (2015), the use of a wireless embedded system provides convenience in monitoring field conditions in real-time. The data in Table 1 shows that the notification status on the Blynk application is always "Channeled" as long as the sensor detects movement, which proves that data communication between the microcontroller and smartphone via the Wi-Fi network runs reliably.

Test data shows that the PIR sensor has an effective detection range of up to 5 meters in a rice field environment. The decrease in accuracy at a distance of 5-6 meters is influenced by the characteristics of the sensor that detects infrared radiation from the object's body temperature. This control mechanism aligns with the concept of a relay-based control tool prototype by Tjandi (2022), which emphasizes the importance of a fast system response to input triggers. In this tool, the ESP32 successfully processes PIR input and provides sound output and notifications in less than 1 second, providing a solution to Mr. Kasyanto's constraints regarding limited manpower in manual field monitoring.

Compared to biological pest control methods such as the use of owls, whose effectiveness depends on the predator population in the area (Pusparini & Suratha, 2018), the use of this ultrasonic repellent offers more certain and consistent control. Furthermore, because this tool works based on the principles of wave physics, no chemical residue is left in the soil, thus maintaining the environmental health of the rice fields in East OKU. The use of a dual system (Automatic and Manual) ensures the tool remains flexible in use according to the dynamics of pest attacks in the field.

D. CONCLUSION

This study successfully developed an IoT-based ultrasonic pest repellent system using the ESP32 microcontroller. The system integrates a PIR sensor for motion detection and produces ultrasonic waves with a stable frequency of 30 kHz.

The test results show that the device operates effectively within a detection range of 1–5 meters and is able to send real-time notifications through the Blynk application with a latency of less than 1 second. The use of solar power also allows the device to operate continuously in agricultural environments. Overall, this system provides an environmentally friendly and efficient alternative to chemical pesticides and helps farmers monitor and control pest repellent devices remotely.

SuggestionsFor further research, it is recommended that this system be equipped with an Artificial Intelligence (AI)-based pest identification feature using a camera module (ESP32-CAM) so that the ultrasonic frequency emitted can be specifically tailored to the type of pest detected. Furthermore, increasing the number of sensor points (nodes) in a mesh network can be considered to cover a wider rice field area.

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