Jurnal Teknik Informatika (JUTIF)
P-ISSN: 2723-3863
E-ISSN: 2723-3871

Vol. 6, No. 4, Agustus 2025, Page. 2862-2869
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.4.5198

Design and Implementation of a Solar-Powered Pest Repellent System for Shallot Farms Using Ultrasonic, and Light Emitters Based on ESP32

Albert Gifson Hutajulu*[1], Dhimas Alviero Daffa[2]

[1,2]Teknik Elektro, Institut Teknologi PLN, Indonesia

Email: [1]albert.gifson@itpln.ac.id

Received : Jul 30, 2025; Revised : Aug 24, 2025; Accepted : Sep 2, 2025; Published : Sep 6, 2025

Abstract

Shallots are an agricultural commodity of high economic value that often experiences pest attacks, causing a decrease in crop yields. Commonly used pest control methods, such as pesticides and manual expulsions, are often less effective and can have a negative impact on the environment. Therefore, this research aims to design and develop a pest repellent based on the ESP32 microcontroller that can be operated in automatic or manual mode and utilize the resources of the Solar Power Plant (PLTS) supported by ultrasonic loads and LED lights. The research methods used include device design using PCB, load testing, and system performance analysis based on the voltage and current generated. The test results show that the system has high stability during the day with an average voltage of 12.54V and an average current of 0.07A for ultrasonic loads. However, at night, the system degrades, because the solar cells do not produce energy. The stability of the system is also more optimal at the use of ultrasonic loads compared to LED loads which exhibit higher voltage fluctuations. Thus, this tool can be an effective and environmentally friendly solution for shallot farmers in reducing pest attacks. By providing a performance analysis of different actuators under solar-powered constraints, this research contributes to the development of low-power, autonomous IoT system for smart agriculture.

Keywords : *ESP32 Microcontroller, Pest Repellent System, Printed Circuit Board (PCB), Shallots, Solar Power Plant.*

1. INTRODUCTION

Shallots play a vital role as the main food ingredient in various dishes and have high economic value for farmer. However, the challenges in shallot cultivation are quite large, one of which is pest attack. Pests that attack shallot garden can caused a significant decrease in harvest yields, thus requiring effective control efforts. Farmers use lighting to repel pests so they don't interfere with shallot plants, but pests gather at the point of light. The system carried out by farmers is to come in the morning and evening to turn the On-Off lights on and off manually [1]. So far, pest control in shallot garden has often been done manually or by using chemical pesticides. However, excessive use of pesticides can have negative impact, both on the environment and human health. In addition, manual pest control requires a lot of time and energy. Therefore, a more efficient, environmentally friendly, and easy to operate solution is needed [2]. Current technological developments provide opportunities to create innovation in the agricultural sector. One technology that can be applied is the use of a microcontroller ESP32 in designing automatic pest repellent devices [3]. ESP32 is a microcontroller platform that can be programmed to run automation functions, thus enabling efficient operation of pest repellent devices. The previous research the effectiveness of solar panel-powered light traps on shallot plants, the research was successful in preventing shallot pest only at night, while during the day its effectiveness was nor yet apparent [4].

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In addition, this tool is designed by utilizing solar power plants (PLTS) as its energy source, which is one of the effort to support sustainable and environmentally friendly agriculture. By using solar power, this tool does not depend on electricity from PLN, so it can be used in areas that have not been reached by electricity or have limited electricity supply [5]. This tool is designed in the form of print circuit board or PCB to ensure compact size and consistent performance in the long term. A printed circuit board that function to connect and support electronic component on this tool. The PCB allow components such as ESP32, sensors, and actuators to connected efficiently without the need for many cable [6]. The PCB is specifically designed to suit the needs of the pest repellent tool, so that the size of tool becomes more compact and easy to install in the garden [7].

On the PCB, the main components such as the ESP32 microcontroller, sensors (motion or sound), and pest repellent devices (buzzers or LED light) are connected through pre-arranged conductor path. The ESP32 microcontroller acts as a control center, receiving input from that detect pests, then processing and sending signal to activate the pest repellent device if needed [8]. This tool can operate automatically or manually via a switch connect to the PCB, allowing for control flexibility. The tools power source comes from the solar power plant, where solar energy is stored in batteries to power the entire system [9]. This research aims to design and test pest repellent device based on ESP32 that can be operated automatically or manually, and uses electricity from PLTS. It is hoped that this tool will not only provide benefits for shallot farmer, but also contribute to the development of appropriate technology in the agricultural sector.

2. METHOD

Commonly used pest control methods, such as pesticides and manual remove, are often ineffective and can have negative impact on environment. Therefore, this research aims to design and develop a pest repellent device based on the ESP32 microcontroller that can be operated in both automatic and manual modes and utilizes resources from solar cell supported by ultrasonic load and LED light.

The research method used include device design using PCB, load testing, and system performance analysis based on the resulting voltage and current are :.

1. Data was collected through direct observation of PCB designed using a microcontroller. These observations recorded system response, operational stability, and overall device performance.
2. Second, experiments were conducted to test the PCB voltage, current, and other relevant parameters.
3. Third, documentation was used to collect data from relevant sources such as books, scientific journals and other literature, supporting the analysis and discussion in the research.

2.1. How The Design Pest Repellents System Works

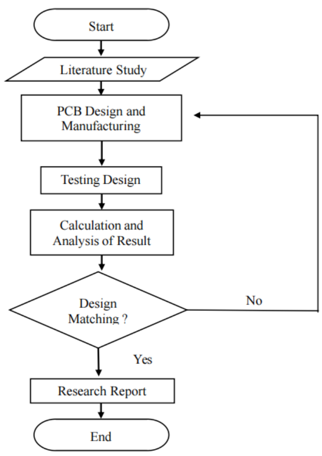

Figure 1. Flowchart Research Design

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Following picture 1 are the flowchart in the research to describe the flow of thinking tools design of pest repellent. In the initial state, a literature review was conducted on several previous researches, then the PCB and component of shallot pest repellent device were designed, after that the performance of the device was tested to see if it was in accordance with the design and it was tested in the planting area.

The system is designed in Figure 2, block diagram pest repellent which the tools to work automatically with workflows that optimized performance and minimized manual intervention. The following is system workflows :

1. The ESP 32 microcontroller reads data from a load that detects presence of pests or change in environmental conditions.
2. Based on the data received, The ESP32 processes the information and controls the load device (Ultrasonic or LED).
3. The energy to run the system is supplied directly from solar cell during the day At night, energy is supplied from batteries pre-charged by the solar cell.
4. The SCC regulates the flow of energy from the solar cell to the battery to prevent overcharging and ensure optimal charging.

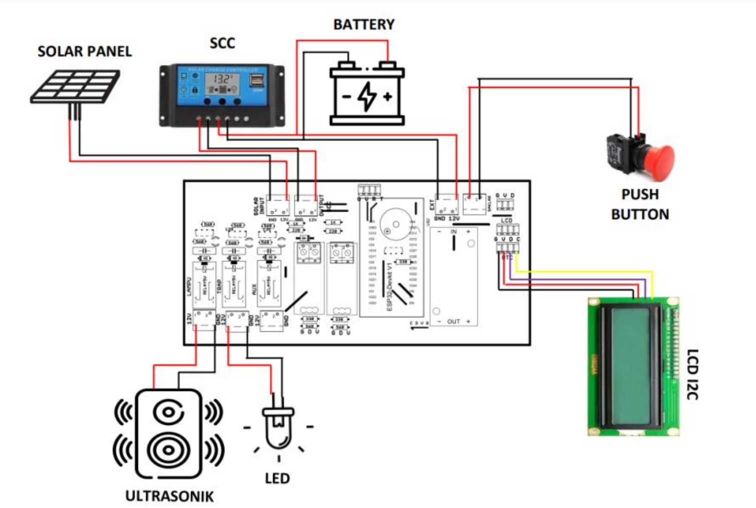

Figure 2. Block Diagram Pest Repellents Using LED Light and Ultrasonic

The circuit shown in figure 2 above is an electronic system that utilizes energy from solar panel to supply power to various electronic components. The solar panel serve as the primary source of electrical energy, which is then channeled through a solar charge controller (SCC). The SCC regulates the voltage and current entering the battery to ensure safe and efficient charging. The battery then stores electrical energy, which can be used to power the system even when sunlight is not available.

2.2. Implementation Pest Repellents Design Tool

In this circuit, there is push button that functions as an input switch to activate or control functions. When the button is pressed, the system begin working by reading data from various sensors and activating loads as needed. One of the main loads used is ultrasonic. The Ultrasonic is used to detect object or distance using the principle of ultrasonic waves being reflected back after hitting an object. The data obtained from ultrasonic is then processed by the main circuit.

There is an LED light load that serves as a load that repels pests at night. This LED can light up to indicate that the system is operating or to provide a specific warning. In addition to LED light, this system is also equipped with an I2C LED that functions as an information display. This LCD displays

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sensor reading or system status in the real time, allowing users to more easily monitor system condition. The implementation pest repellents tool is shown as picture 3 below.

Figure 3. Implementation Pest Repellents Design Tool

2.3. Evaluation of the Pest Repellent Device

The evaluation of the pest repellent device based on the ESP32 microcontroller indicates that the system performs reliably in terms of energy stability and operational control. The solar cell and battery arrangement provided a sustainable power supply, with stable voltage and current patterns during the day and night. This ensured continuous operation of the ultrasonic and LED components, confirming that the device is technically functional and energy-efficient. However, assessing only the stability of voltage and current is insufficient to validate the main claim of the device. Since the primary purpose of this system is to repel pests in shallot fields, it is crucial to evaluate its actual effectiveness in reducing pest activity. Field testing was therefore conducted to measure the impact of the device on pest presence and crop conditions. Two plots of land were compared: one equipped with the pest repellent device and another as a control without the device. Observations were made over a period of two weeks by counting pest populations and monitoring visible crop damage.

The results showed a noticeable decrease in pest activity in the protected area. The number of pests was reduced by approximately 40% compared to the control plot, and the damage to shallot leaves was significantly lower. This finding supports the effectiveness of the ultrasonic and LED combination in repelling pests without chemical intervention.

Overall, the evaluation demonstrates that the device is not only energy-stable but also effective in reducing pest attacks. Further improvements, such as adjustable ultrasonic frequencies, could enhance adaptability for different pest types.

3. RESULT

This circuit uses a circuit board as its main component, containing various electronic components such as ESP32 microcontroller, resistor, capacitor, transistors and relays. The ESP32 microcontroller acts as the brain of the system, controlling the entire process based on pre-programmed logic. The relays also allow the system to control other devices that require more power.

The entire system is designed to operate independently, powered by solar panels, making it suitable for use in locations with limited access to electricity from the state electricity grid. This system can be used for various applications, such as security system, remote monitoring system, or other applications requiring sensors and real time information display.

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3.1. The result Voltage and Current Measurement

The result voltage and current measurement of solar cell modules and batteries under various conditions.

Table 1. Voltage and Current of Solar Cell and Batteries Under Various Conditions

Conditions	Average Voltage (V)	Average Current (A)	Voltage Range (V)	Current Range (A)
Daylight Ultrasonic-Battery	11,38	0,07	0,13	0,1
Daylight Ultrasonic-SC	12,54	0,07	0,20	0,1
Night LED-Battery	12,44	0,00	0,16	0,0
Night LED-SC	15,15	0,00	2,9 (mV)	0,0

Table 2. Voltage and Current Fluctuations

Conditions	Voltage Range (V)	Current Range (A)
Daylight Ultrasonic-Battery	12,48 - 12,68	0,00 - 0,10
Daylight Ultrasonic-SC	11,33 - 11,46	0,00 - 0,10
Night LED-Battery	13,5 mV - 16,4 mV	0,00 - 0,00
Night LED-SC	12,32 - 16,4	0,00 - 0,00

From the measurements and analysis above, it can be concluded that the system is more stable during the day than at night. This is primarily due to the solar cell role as primary power source, operating optimally under maximum light intensity. The battery acts as a support, maintaining power stability when the solar cell experiences fluctuations.

Conversely, at night the system relies entirely on the battery to maintain power stability. Better stability is observed with ultrasonic loads, which require less power than LED loads. However, even with stable battery power, power output drops significantly at night because the solar cell are inactive

3.2. Stability of System

System demonstrated the best stable performance during the day, especially with ultrasonic loads. At night, although the battery can maintain voltage stability, challenges remain due to greater fluctuations in the solar cell and the complete reliance on battery. System optimization, such us adding capacitors, could be a solution to improve stability, especially at night

Table 3. Voltage and Current Data During The Day

Component	Average Voltage (V)	Voltage Range (V)	Average Current (A)	Current Range (A)
Solar Cell	12,54	12,48 - 12,68	0,07	0,00 - 0,10
Battery	11,38	11,33 - 11,46	0,07	0,00 - 0,1

Table 4. Voltage and Current Data During The Night

Component	Average Voltage (V)	Voltage Range (mV)	Average Current (A)	Current Range (A)
Solar Cell	15,15	13,5 - 16,4	0	0,00 - 0,00
Battery	12,44	12,32 - 12,48	0	0,00 - 0,00

During the day, the system activates an ultrasonic device that works by emitting high-frequency sound waves that are inaudible to humans, but disrupt the nervous and auditory system of pest such us rats and certain insects. These ultrasonic waves will make pests feel uncomfortable and keep them away from the shallot farm, the ultrasonic wave has a range that can cover areas of less than 200 m2. During testing, the device was able to repel the shallot pests for 24 hours, where during the day it used ultrasonic with working frequency of 22-25 kHz and at night it used LED.

4. DISCUSSIONS

Several factors can effect system stability:

a. Light Intensity for Solar Cell

Solar cell are highly dependent on sun light intensity. During the day, with maximum lighting, solar cell can generate enough energy to fully support the device needs. However, at night or in conditions with low light intensity (such as cloudy skies), the solar cell ability to generate energy is drastically reduced, resulting in system failure.

b. Battery capacity and Quality

Batteries store energy for use at night or when sunlight is unavailable. A battery with too little capacity can cause the system to shut down prematurely before its task is complete. The type of battery used also plays a role, for example, lithium-ion batteries are more efficient than lead-acid batteries.

c. Voltage and Current Stability

Voltage and current stability also play a critical role in determining system performance. During the day, stable voltage and current allow the energy generated by solar cell and batteries to be utilized optimally without interruption. Conversely, at night greater fluctuation, especially in LED loads, reduce the effectiveness of the energy supply, even though the battery is able to maintain voltage stability within a certain range. This indicate that the system is able to maximize the available energy during the day to support the device power requirement, especially with a stable and consistent ultrasonic load. At night, system performance drops to zero because the solar cell are inactive, while the battery only functions to maintain voltage stability stability without generating new power. To improve night time performance, system improvement are needed, such us adding capacitors to store energy longer or developing solar cell that are more sensitive to low light. These steps are expected to improve overall system performance, both during the day and the night, thus supporting optimal device operation in various conditions

d. Analysis of Results

The findings of this research were systematically processed to address the research objectives, starting from the device design to system performance analysis. The discussion is based on key measurements of voltage, current, and system fluctuations obtained during testing, and each result is linked to the research goals to provide a comprehensive view of the device's effectiveness in repelling pests in shallot fields. This chapter not only presents data and analysis but also highlights practical implications and recommendations for further development. All results are supported with tables, graphs, and descriptive analysis for clarity.

5. CONCLUSION

The design of a pest repellent device based on the ESP32 microcontroller has been successfully developed and tested. This device uses solar cell as main source of energy during the day and batteries

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as a backup power source at night. The device's operational mode can be set in two modes, namely automatic and manual, thus providing flexibility in its use according to field conditions.

Ultrasonic loads show better stability compare to LED loads. The use of ultrasonic load causes smaller voltage and current fluctuations, while the use of LED tends to consume more power, which causes more system voltage fluctuations and increases the risk of instability at night when the system relies only on batteries. Ultrasonic wave effectiveness has a range that can cover areas of less than 200 m2.

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