VOL. 21, NO. 10, MAY 2026 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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www.arpnjournals.com

DEVELOPMENT OF AN IOT-BASED SPEAR PEST TRAP DEVICE FOR RICE FIELDS INTEGRATED WITH A SOLAR POWER PLANT (PV SYSTEM)

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ABSTRACT

Rice farming is a strategic sector in supporting national food security. However, rice productivity is often threatened by brown planthopper infestations, which cause significant crop damage. Conventional pest control approaches, such as pesticide spraying, have various limitations, including negative impacts on the environment and farmers' health. Therefore, environmentally friendly and efficient technological innovations are needed to address this issue. This study aims to develop an Internet of Things (IoT)-based brown planthopper trap device integrated with a Solar Power Plant (PV system) as an independent energy source in rice fields. The system is designed to monitor and capture pests automatically, as well as transmit real-time pest attack data via wireless networks to user devices or a control center. The research method used is Research and Development (R&D), which includes the following stages: problem identification, device design, prototype development, functional testing, and field performance evaluation. The prototype will be tested in rice field areas to assess its effectiveness in trapping pests and the efficiency of energy consumption from the PV system. Evaluations are also conducted on data transmission quality and the reliability of the IoT system in open environments. The test results show that the system operates as designed. The inverter output voltage is relatively stable at 225-227 V, pump current is recorded between 0.6-0.9 A, electrical power ranges from 126-176 W, and the total daily energy consumption is 2.3 Wh. The low energy consumption demonstrates that this system can operate effectively solely with supply from the PV system.

Keywords: pest trap, brown planthopper, rice fields, renewable energy, PV system, IoT.

Manuscript Received 17 April 2026; Revised 7 May 2026; Published 20 July 2026

INTRODUCTION

Rice cultivation is a strategic agricultural sector that plays a pivotal role in ensuring national food security. In many Asian countries, including Indonesia, rice remains the primary staple food and contributes significantly to social and economic stability [1] [4]. As such, rice productivity serves as a crucial indicator for maintaining both food availability and societal welfare [5]. However, sustaining rice production continues to face major challenges, among which pest infestations represent one of the most critical threats. The brown planthopper (Nilaparvata lugens) is recognized as one of the most destructive rice pests, capable of causing substantial crop damage and yield loss [6] [8].

Conventional pest management strategies, particularly the widespread use of chemical pesticides, have long been employed to suppress brown planthopper populations. While chemical control methods often provide immediate results, their prolonged and excessive application poses several drawbacks. These include detrimental effects on the environment, negative impacts on farmer health, and the development of pest resistance over time. Such limitations highlight the urgent need for more sustainable, environmentally friendly, and technologically advanced approaches to pest control in rice farming systems. In the era of precision and smart agriculture, integrating modern technologies offers an opportunity to improve efficiency, sustainability, and resilience in agricultural production systems.

The advancement of digital technologies has enabled the adoption of the Internet of Things (IoT) in agriculture. IoT-based systems allow real-time monitoring, data collection, and decision-making processes, thereby enhancing both productivity and operational efficiency [9], [10]. IoT applications in agriculture have shown significant potential in areas such as irrigation management, crop health monitoring, and automated pest control. However, one of the challenges in implementing IoT technologies in remote or rural agricultural areas is the availability of a reliable and sustainable energy supply. Many rice fields are located far from centralized power grids, which creates limitations for the deployment of advanced electronic systems.

To overcome these challenges, renewable energy sources such as solar power offer a viable solution. Solar photovoltaic (PV) systems, in particular, provide clean, cost-effective, and reliable energy that can be integrated with IoT-based agricultural technologies. The integration of IoT with solar-powered systems creates a self-sufficient platform capable of operating in remote farming environments. This combination not only addresses the issue of energy availability but also contributes to reducing greenhouse gas emissions and promoting sustainable development in agriculture.

In light of these opportunities, the present research aims to develop an automatic IoT-based brown planthopper trapping system that is integrated with a solar power plant (PV system). The proposed system is

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designed to perform dual functions: first, to capture pests effectively using a physical trapping mechanism, and second, to transmit real-time data regarding pest population and infestation levels to farmers or central monitoring units via wireless networks. This real-time data flow enables farmers to make more informed decisions on pest control strategies, thereby reducing reliance on chemical pesticides and supporting environmentally friendly agricultural practices.

The research adopts a Research and Development (R&D) methodology, encompassing several phases: problem identification, system design, prototype development, functional testing, and field evaluation. The prototype is tested under real field conditions in rice paddies to assess its effectiveness in capturing brown planthoppers, its energy efficiency when powered solely by a PV system, and its reliability in transmitting data under open environmental conditions. By providing empirical evidence of system performance, this study contributes to the growing body of knowledge on IoT and renewable energy applications in agriculture. Furthermore, the integration of IoT and PV systems is expected to support sustainable rice farming, enhance productivity, and reduce the environmental footprint of pest management practices.

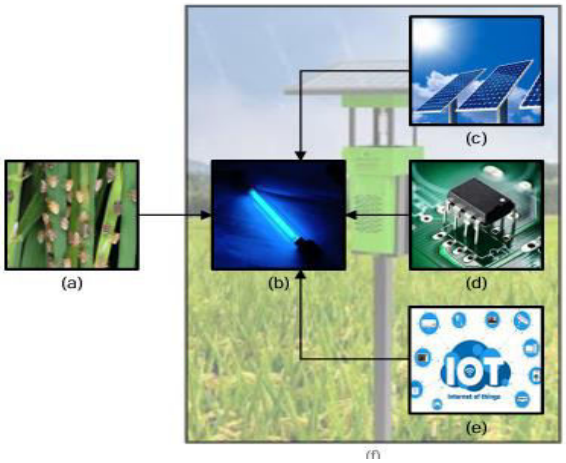


Figure-1. Illustration of the research background. (a) Brown planthopper (*Nilaparvata lugens*); (b) UV lamp as an attractant for phototactic pests; (c) Solar photovoltaic (PV) system;(d) System control unit; (e) IoT system;(f) Pest trap system.

The IoT system block diagram represents the overall sequence of operations in a system. Its purpose is to simplify the understanding of the processes that take place within the developed system. A block diagram carries a specific meaning by providing descriptions within each block. Each block is connected by a line that indicates the direction of operation, illustrating the interconnection and relationship among the components in a rice pest control system with IoT.

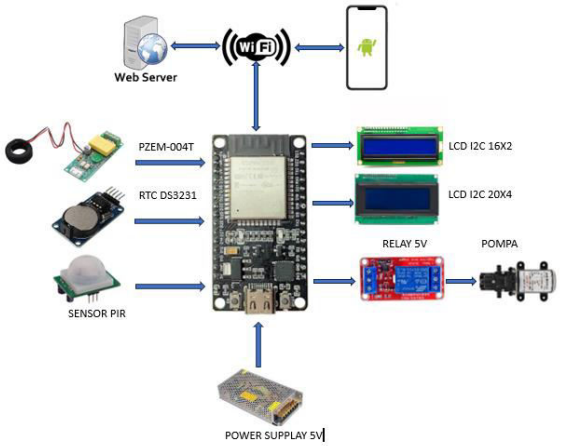


Figure-2. IoT System block diagram.

The Figure-2. illustrates the design of an IoT-based control and monitoring system utilizing an ESP32 microcontroller integrated with multiple sensors, actuators, and communication modules. All components within this IoT control system are supplied with a 5-volt power source, where the ESP32 functions as the central controller, distributing voltage to the sensors, modules, and the pump used for pesticide spraying. The entire system is powered by a solar photovoltaic (PV) system.
The ESP32 microcontroller serves as the core data processor and system controller, interfacing with all sensors on its input side and controlling the pump, connected to its output, for spraying operations. The collected data are transmitted to a web server via a Wi-Fi network, enabling real-time monitoring through a smartphone or PC. On the input side, a PIR sensor is connected to detect the movement of rice pests, sending digital signals to the ESP32. The RTC DS3231 (Real-Time Clock) provides accurate time and date information, allowing the ESP32 to schedule automatic operations of the UV lamp at night and to automate the pesticide spraying process. Meanwhile, the PZEM-004T module measures electrical parameters such as voltage, current, and power consumption, with the data recorded by the ESP32.

On the output side of the controller, a 5-volt relay acts as an electronic switch to control both the pump and UV lamp according to commands from the ESP32. The pump, connected through the relay, is activated or deactivated based on signals from the RTC or PIR sensor processed by the microcontroller. An LCD module is also connected to the ESP32 output, serving as a local monitoring interface to display sensor data, relay status, RTC time, and other system information. This LCD uses an I2C interface to optimize the use of microcontroller pins.

The IoT system based on the ESP32 is equipped with a Wi-Fi module, which processes data from the PIR sensor, PZEM-004T, and RTC, then transmits it to the

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web server. This enables farmers or users to remotely monitor the system in real-time via smartphones.

In brief, the workflow of the rice pest control system is as follows:

a. The ESP32 receives power from the power supply.
b. The RTC DS3231 provides time data ; the ESP32 determines the operating mode (day/night).
c. The PIR sensor detects motion ; the ESP32 decides whether to activate or deactivate the actuators.
d. The 5V relay is triggered by the ESP32 turning on the pump or lamp according to the program logic.
e. The I2C LCDs system information locally.
f. The PZEM-004T records power consumption → the data are transmitted to the server.
g. All information is sent to the web server → accessible via smartphone monitoring.

EXPERIMENTAL METHOD

Conceptual Research

This study employs a Research and Development (R&D) approach, which includes the design, development, testing, and evaluation of an IoT-based pest trap system integrated with a Solar Power Plant (PLTS). In the initial stage, a literature review was conducted on journals, scientific articles, research reports, and government regulations related to rice pest control, light trap technology, the application of IoT in agriculture, and the use of renewable energy, particularly solar power systems. This literature study was complemented with a descriptive study approach through direct interviews with farmers in the target area (partners) to explore the main problems associated with brown planthopper pests and the need for modern supporting tools.

The process of this research is shown in a flow diagram in the form of a conceptual framework.

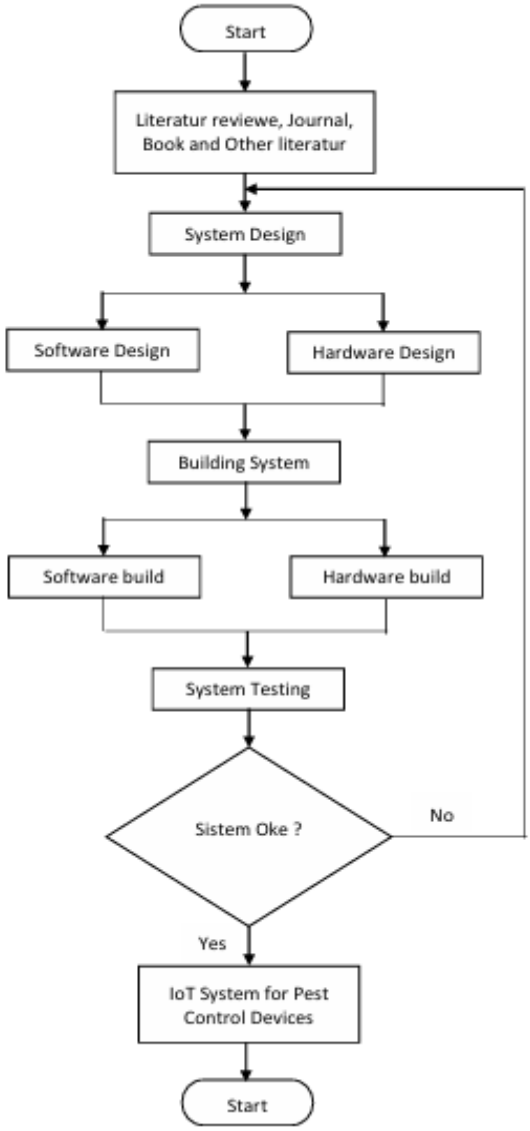


Figure-3. Conceptual research flow diagram.

The next stage carried out is the design of both hardware and software components, with the overall system illustrated as shown in the Figure-4.

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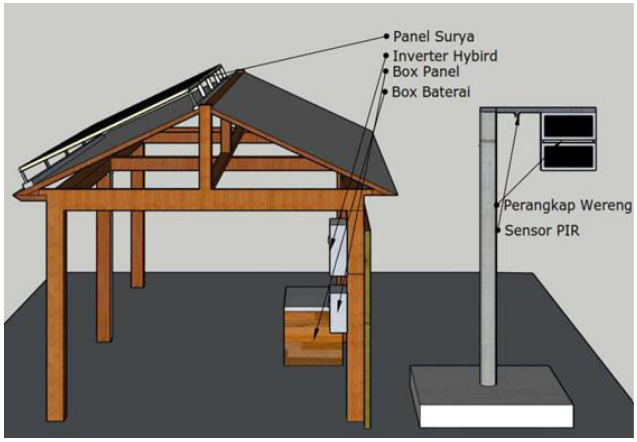


Figure-4. Design of the IoT-based rice pest control system integrated with a solar power plant (PV System).

The system designed in this study consists of a control unit and a solar power system (PLTS) installed in a location protected from water and positioned at a certain distance from the rice fields to prevent pesticide sprayed by the pump from coming into contact with the crops. Another aspect of the hardware design involves the wiring diagram of the solar power system, which serves as the electrical energy source to supply the IoT control system, pump, and pest-trapping lamp, as illustrated in Figure-5.

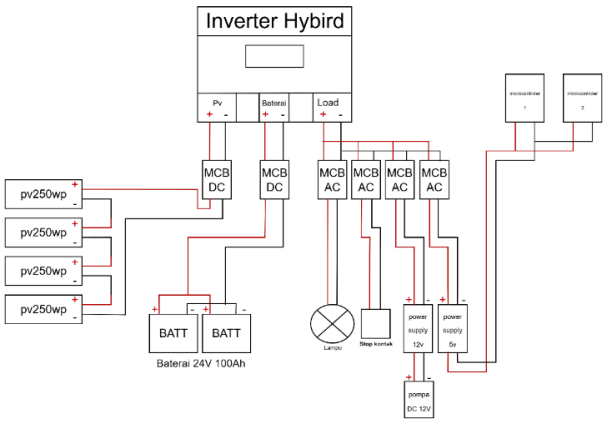


Figure-5. Solar power system (PLTS) wiring diagram.

The solar panel system was designed using four panels, each with a capacity of 250 Wp, connected to a 1500 VA inverter. Energy storage is provided by two LiFePO4 batteries, each with a voltage of 24 volts and a capacity of 100 Ah. The energy system was designed based on a detailed calculation of the required load. The energy utilized in this system is as follows:

Table-1. Electrical power requirements.

Device Name	Quantity	Total Power Consumption (Watt)	Operating Time (Hours)	Total Power Consumption (Watt-hours)
Mercury Lamp	1	250	10	2.500
Microcontroller	2	6	24	144
Sprayer Pump	1	3	10/30mnt	60
Total Power		259		2.704

The ESP32 is connected to the PIR sensor, RTC, and PZEM-004T on the input side, while on the output side, the controller is connected to the pump, relay, and LCD as the display unit. The figure illustrates the wiring diagram of the ESP32.

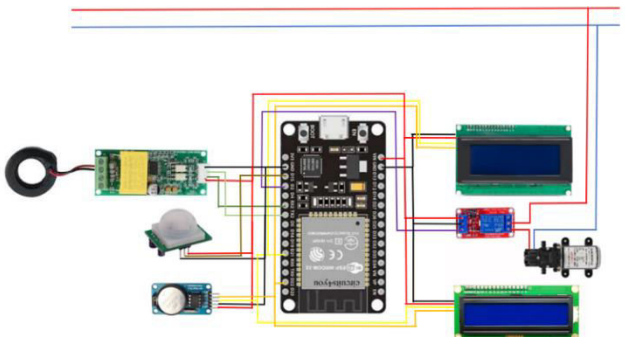


Figure-6. ESP32 wiring diagram.

The web server display on Blynk is designed to be very simple so that farmers can easily operate it without difficulty in understanding modern agricultural technology. The web server interface is shown in Figure-7.

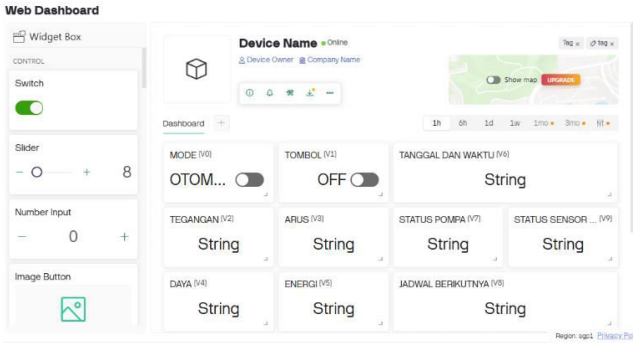


Figure-7. IoT Web dashboard.

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In the program structure design, it is divided into two main parts: setup ( ) and loop ( ). In the setup ( ) function, the system performs initialization of serial communication, sensor setup, WiFi connection, and time synchronization. Meanwhile, in the loop( ) function, the system executes the main logic, which includes reading the PIR sensor, monitoring electrical parameters, and controlling the pump according to the automatic RTC schedule or manual commands from the Blynk application.

RESULT AND DISCUSSIONS

Device Implementation

The device was successfully installed in the rice field, powered entirely by four solar panels, each with a capacity of 250 Wp. Two 24V/100Ah batteries were used to supply 2,704 Wh of energy, allowing operation at night for up to 8 hours.



Figure-8. Rice pest control device.

The automatic rice pest spraying control system was successfully implemented by integrating hardware and software based on the ESP32 microcontroller. The system is equipped with a DS3231 RTC for scheduling spray times, a PIR sensor to detect pest movement, and a PZEM-004T sensor to monitor electrical parameters such as voltage, current, power, and energy. The results are displayed on the web server, as shown in Figure-9.



Figure-9. Web server display at night.

From the testing results of the RTC, PZEM-004T, and PIR sensor, the following data were obtained:

Table-2. AC Electrical parameter testing data.

Waktu	Tegangan Panel (V)	Arus Pompa (A)	Daya (W)	Energi (Wh)	Status Pompa
18.00	226,7	0,7	152,1	0,1	OFF
18.30	226,7	0,8	161,5	0,2	Aktif
19.00	226,8	0,6	172,6	0,3	Aktif
19.30	226,7	0,7	140,5	0,4	Aktif
20.00	226,7	0,6	126,9	0,5	Aktif
20.30	226,7	0,7	152,8	0,6	Aktif
21.00	226,6	0,7	172,5	0,7	Aktif
21.30	226,6	0,7	161,7	0,8	Aktif
22.00	225,7	0,6	158,4	0,8	Aktif
22.30	226,6	0,9	178, 6	0,9	Aktif
23.00	226,6	0,7	195,7	1,0	Aktif
23.30	226,6	0,7	150,9	1,1	Aktif
00.00	226,6	0,8	166,9	1,1	Aktif
00.30	226,7	0,7	158,7	1,3	Aktif
01.00	226,4	0,6	149,5	1,3	Aktif
01.30	226,5	0,8	163,1	1,4	Aktif
02.00	226,5	0,7	163,4	1,4	Aktif
02.30	226,5	0,7	152,3	1,5	Aktif
03.00	226,5	0,7	146,4	1,6	Aktif
03.30	226,5	0,7	141,9	1,6	Aktif
04.00	226,5	0,7	141,6	1,7	Aktif
04.30	226,4	0,6	149,5	1,7	Aktif
05.00	226,5	0,8	163,1	1,8	OFF

The testing results are presented in Table-2, which shows that the system voltage remained relatively stable in the range of 225-227 V throughout the testing period. The pump current during operation ranged between 0.6-0.9 A, while the measured electrical power was between 126–195 W. The cumulative energy consumed was recorded at 1.8 Wh, increasing gradually with each spraying cycle and then remaining constant after 05:00 as the pump stopped operating.

A graph of panel voltage, pump current, power, and energy over time illustrates the patterns of power and energy changes throughout the operation and their correlation with the pump status (OFF/Active).



Figure-10. IoT system web server graph.

The DC electrical parameter testing data are presented in Table-3.

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Table-3. DC electrical parameter testing data.

Waktu	Arus Pompa (A)	Daya Aktual (W)	Energi (Wh)	Keterangan
18.00	3,2	38,4	0,1	OFF
18.30	3,5	42,0	0,2	Aktif
19.00	3,8	45,6	0,3	Aktif
19.30	4.0	48,0	0,4	Aktif
20.00	4,2	50,4	0,5	Aktif
20.30	3,9	46,8	0,6	Aktif
21.00	4,5	54,0	0,7	Aktif
21.30	4,8	57,6	0,8	Aktif
22.00	4,6	55,2	0,8	Aktif
22.30	4,9	58,8	0,9	Aktif
23.00	3,7	44,4	1,0	Aktif
23.30	3,5	42,0	1,1	Aktif
00.00	3,6	43,2	1,1	Aktif
00.30	4,0	45,6	1,3	Aktif
01.00	3,8	48,0	1,3	Aktif
01.30	3,9	49,2	1,4	Aktif
02.00	4,0	46,8	1,4	Aktif
02.30	3,9	43,2	1,5	Aktif
03.00	4,1	44,7	1,6	Aktif
03.30	4,0	48,0	1,6	Aktif
04.00	3,9	49,2	1,7	Aktif
04.30	3,7	46,8	1,7	Aktif
05.00	3,6	43,2	1,8	OFF

This graph illustrates the measurement system on the web server, as shown in Figure-10:

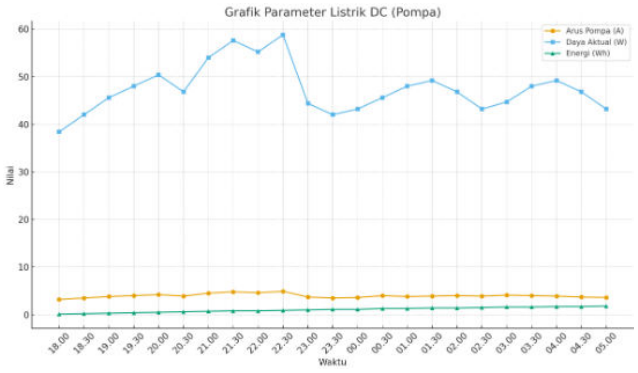


Figure-11. DC electrical parameter graph.

The current remained relatively stable in the range of 3.2 to 4.9 A, with a peak of 4.9 A occurring at 22:30. This indicates that the pump load was higher at that time. The current gradually decreased toward the morning, reaching approximately 3.6-3.7 A between 04:30 and 05:00. The actual electrical power varied between 38.4 and 58.8 W, with the highest power of 58.8 W recorded at 22:30. Power tended to increase during the night from 21:00 to 22:30 and then gradually declined.

Energy consumption was cumulative, increasing over time from 0.1 Wh at 18:00 to 1.8 Wh by 05:00, with consistent energy spikes occurring whenever the pump was active.

Overall, the system demonstrated stable pump operation, with increased load during the night until 22:30, followed by a gradual decrease toward the morning.

From the analysis and discussion, it can be concluded that the system can operate automatically without continuous supervision, supporting modern, environmentally friendly agricultural practices.

CONCLUSIONS

The conclusions of this study are:

a) The implementation of IoT in the rice pest control system integrated with solar power (PLTS) has been proven to control pests automatically, operate independently in terms of energy, and remain environmentally friendly. This system allows farmers to monitor real-time conditions via a smartphone, reduces dependence on pesticides, operates automatically without continuous supervision, and supports modern, eco-friendly agricultural practices.

b) The testing results indicate that the system operates as designed. The inverter output voltage remained relatively stable at 225-227 V, the pump current was recorded between 0.6–0.9 A, electrical power ranged from 126-176 W, and the energy consumed in one day was 2.3 Wh. The low energy consumption demonstrates that the system can operate effectively using only power supplied by the solar panels (PLTS).

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