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Research article

IoT-Enabled Solar-Powered Pest Control for Rice Agriculture: Monitoring and Efficiency of Light-Based Traps

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Abstract: Rice is a staple food in Indonesia and globally, but its production is threatened by pests such as the brown planthopper. Conventional pest control methods, including pesticides and traditional techniques, often prove ineffective and have negative environmental impacts. Light traps have been explored as an alternative due to the brown planthopper's phototactic behavior, yet existing designs lack efficiency in capturing pests. This study presents an IoT-based solar-powered pest control system that integrates light as an attractant and an electric trap for effective pest elimination. The system features real-time monitoring of voltage, current, and light intensity using an LCD display, powered by a 35 Wp solar panel and managed through an Arduino Uno microcontroller. Experimental results show that brown planthoppers are most attracted to an LED light with an intensity of 780 lux, operating at 11.5 V and 0.97 A. The system consumes 112.52 Wh, with a full battery charge requiring approximately 6 hours and 7 minutes. These findings highlight the potential of a sustainable, energy-efficient solution for pest control in rice agriculture.

Keywords: Internet-of-things, pest control, solar energy, agriculture

1. Introduction

Indonesia is a developing country with a predominantly agricultural economy, where most of the population works as farmers. One of its key agricultural products is rice, which serves as a staple food not only for Indonesians but also for many around the world [1]. According to data from the Central Statistics Agency (BPS) in 2021, rice production in Indonesia reached 54.42 million tons, reflecting a decrease of 233.91 thousand tons or 0.43 percent compared to 2020, when production was 54.65 million tons [2]. This decline is attributed to several factors, including pest infestations that damage rice crops. One of the primary pests affecting rice farmers is the brown planthopper[3].

Planthoppers are small-bodied, plant-sucking insects, with green and brown species being the most recognized. These insects damage crops directly and also act as vectors for plant diseases, particularly viruses. Planthoppers adapt well to various environmental conditions, with some species developing resistance to specific threats [4]. Farmers have attempted various pest control strategies, including physical, mechanical, and biological methods. However, these approaches often prove ineffective. Chemical pesticides, while more efficient, pose significant health and environmental risks when misused [5]. Another control method involves light traps, taking advantage of planthoppers' sensitivity to light, but this method lacks efficiency due to inadequate trap design. A proposed solution is to use a combination of light as an attractant and a weak electric current as a trapping mechanism. This system comprises water traps, electric traps, and light traps [6].

In recent years, the integration of Internet of Things (IoT) technology with sustainable agricultural practices has garnered significant attention as a means to enhance both productivity and environmental stewardship [7], [8], [9]. Among the many challenges faced by farmers, pest management remains one of the most critical, particularly in rice cultivation [10], [11]. Traditional methods of pest control, such as chemical pesticides, not only pose risks to human health and the environment but also often fail to provide long-term solutions [12], [13]. As the demand for more eco-friendly and efficient agricultural practices rises, the potential for IoT-enabled systems to optimize pest control strategies has become increasingly apparent [14], [15].

One promising approach is the use of solar-powered, light-based traps, which exploit the natural behavior of pests attracted to specific wavelengths of light [16], [17]. When coupled with IoT technology, these traps can offer real-time monitoring and data-driven insights, enabling farmers to make timely and informed decisions regarding pest management [18], [19]. The energy-efficient and autonomous nature of solar-powered systems, combined with the connectivity offered by IoT, provides a sustainable alternative to traditional pest control methods, reducing the reliance on chemical inputs while minimizing costs and labor [20].

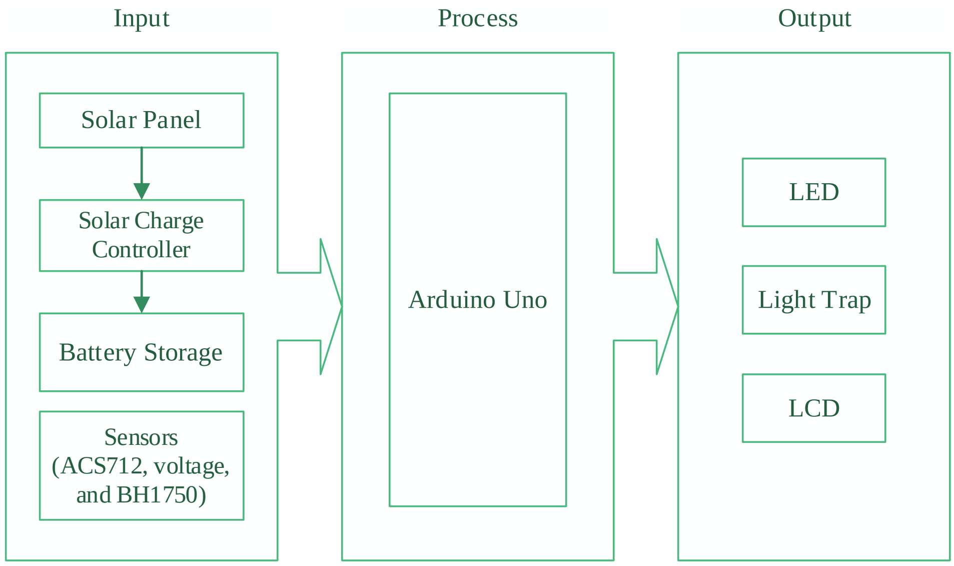
This paper explores the development and implementation of IoT-enabled solar-powered light traps for pest control in rice agriculture. By focusing on the efficiency and monitoring capabilities of these systems, we aim to assess their potential to revolutionize pest management practices in rice farming, providing an innovative solution that aligns with the growing demand for sustainable agriculture. To improve this approach, a monitoring system is required to measure voltage, current, and light intensity on the brown planthopper trap. This system aims to provide farmers with real-time data, enabling easier and quicker analysis via an LCD display. Voltage and current are measured using the ACS712 and voltage sensor modules, while light intensity is monitored using the BH1750 sensor module. The system is powered by solar panels.

2. Methods

2.1. Block Diagram

The block diagram of the system as seen in Figure 1 consists of several interconnected components. Solar panels serve as the primary energy source by converting sunlight into electrical energy. A Solar Charge Controller regulates the current that charges the battery and prevents overcharging and excessive voltage from the solar panels. The battery stores electricity and stabilizes voltage and current. Planthopper pests are the targets for trapping. The ACS712 and voltage sensors detect voltage and current values, while the BH1750 sensor detects light intensity.

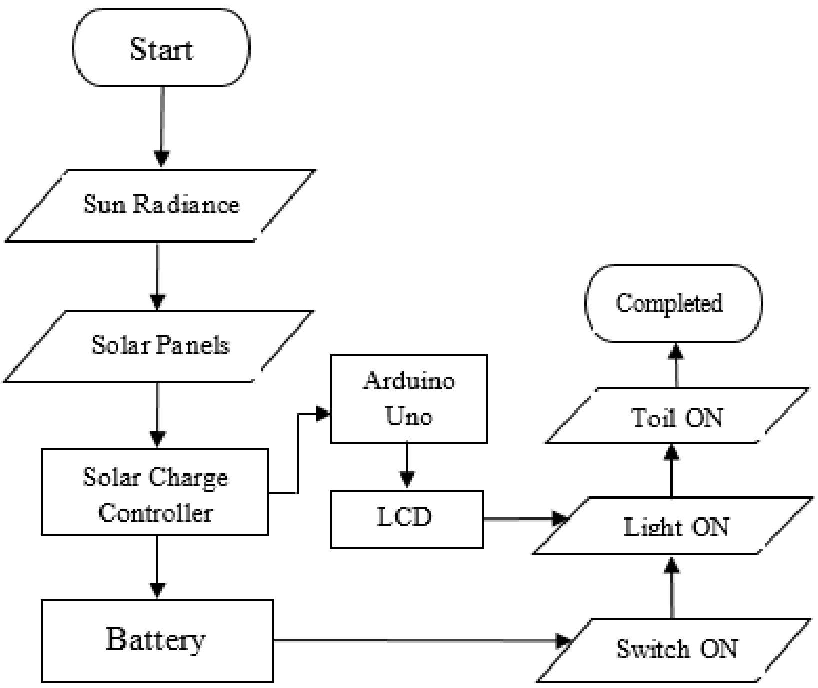
Figure 1. System's block diagram.



2.2. Flowchart

The flowchart in Figure 2 illustrates the operational process of the planthopper pest control system. It begins with the convertion of sun radiance into electrical energy by the solar panels. This energy is regulated by the solar charge controller to prevent overcharging and ensure a stable power supply. The regulated energy is then stored in a battery. The Arduino Uno microcontroller manages the system by receiving inputs from the solar charge controller and displaying voltage, current, and light intensity values on an LCD. When the switch is turned on, the light trap activates, illuminating the lamp. Once the lamp is on, the trap system is activated, and the process continues until completion.

Figure 2. System's flowchart.



3. Results and Discussion

3.1. Sensor Testing

Sensor tests were conducted to verify the accuracy of voltage, current, and light intensity readings compared to standard measuring instruments. These tests were done under different lamp loads to determine sensor performance.

3.1.1. Voltage and Current Sensor

This sensor test aims to determine the performance of the voltage and current sensors in a closed circuit and to compare their readings with those of a standard multimeter. The voltage sensors tested included a voltage sensor module and the ACS712 sensor, with the electrical load provided by lamps of varying power ratings: 6 watts, 9 watts, and 12 watts. The testing was conducted by measuring values every 15 minutes and observing how accurately the sensors tracked voltage and current values in real-time conditions. This test was essential to assess the reliability of the sensors when integrated into the planthopper trapping system.

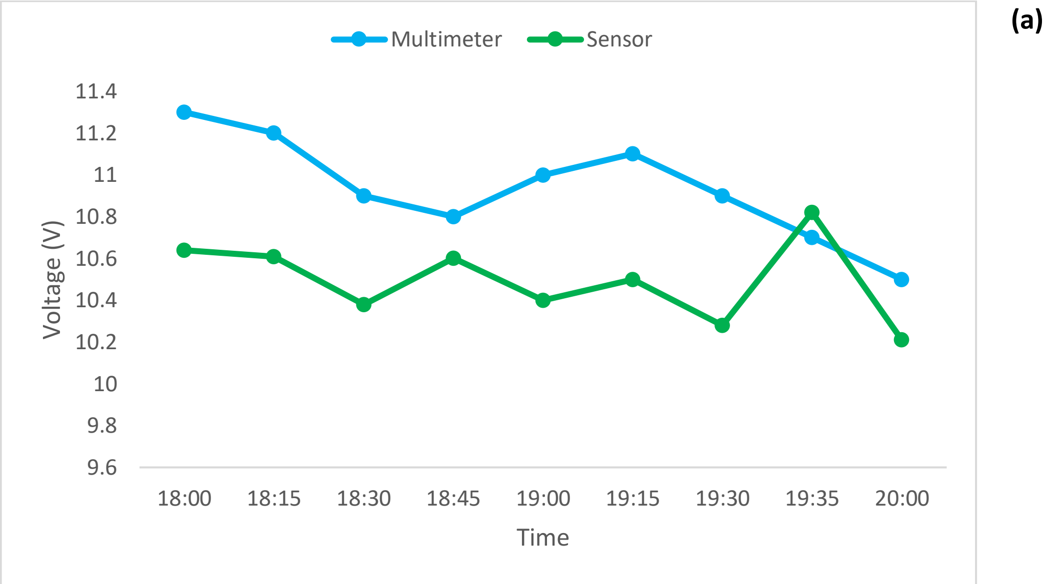
The results for the 6-watt lamp testing are presented in Table 1. The testing began at 18:00 and lasted until 20:00 when the battery was depleted. During this two-hour duration, voltage and current values were recorded using both a multimeter and the sensors. The results demonstrate that the sensors closely matched the multimeter readings, with minor variations. The average error between the sensor and multimeter readings was small, indicating that the sensors are reasonably accurate for monitoring electrical values in the system. These results also show the consistency of the sensor data throughout the two-hour testing period.

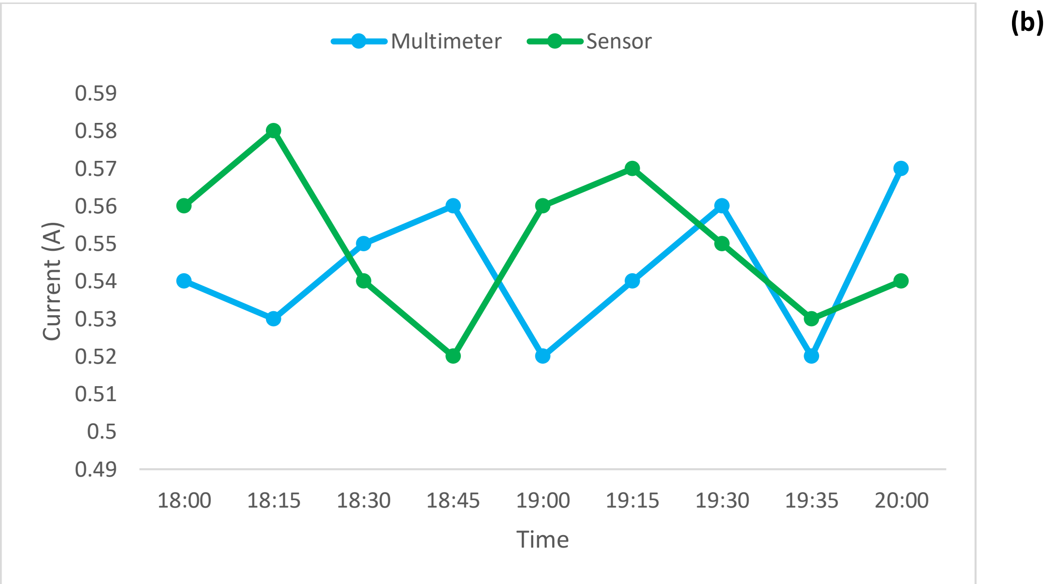
Table 1. Results of voltage and current testing on 6-Watt lamp.

Time	Multimeter		Sensor		Error (%)	
	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Voltage	Current
18:00	11.3	0.54	10.64	0.56	0.05	0.03
18:15	11.2	0.53	10.61	0.58	0.05	0.09
18:30	10.9	0.55	10.38	0.54	0.04	0.01
18:45	10.8	0.56	10.60	0.52	0.01	0.07
19:00	11.0	0.52	10.40	0.56	0.05	0.07
19:15	11.1	0.54	10.50	0.57	0.05	0.03
19:30	10.9	0.56	10.28	0.55	0.05	0.01
19:35	10.7	0.52	10.82	0.53	0.01	0.01
20:00	10.5	0.57	10.21	0.54	0.02	0.05

To enhance the understanding of sensor performance over time, Figures 3 is included to provide a visual representation of the trends in voltage and current during the early phase of the test. Figure 3 shows the correlation between both voltage and current with time, comparing readings from the clamp meter and sensors. These graphs allow for a clear view of how both instruments performed as the battery power gradually declined. While Table 1 offers a comprehensive numerical analysis, the graphs help illustrate the overall trends and highlight the minor discrepancies observed between the instruments.

Figure 3. Testing results of 6-Watt lamp: **(a)** voltage; **(b)** current.





The test for the 9-watt lamp aimed to evaluate sensor accuracy under a higher power load. This test began at 18:00 and continued for 1 hour and 45 minutes, ending at 19:45 when the battery was depleted. Measurements were recorded at 15-minute intervals to monitor changes in voltage and current over time. As in the previous test, the system employed both a multimeter and voltage and current sensors, and the results were compared to assess the reliability and performance of the sensor system.

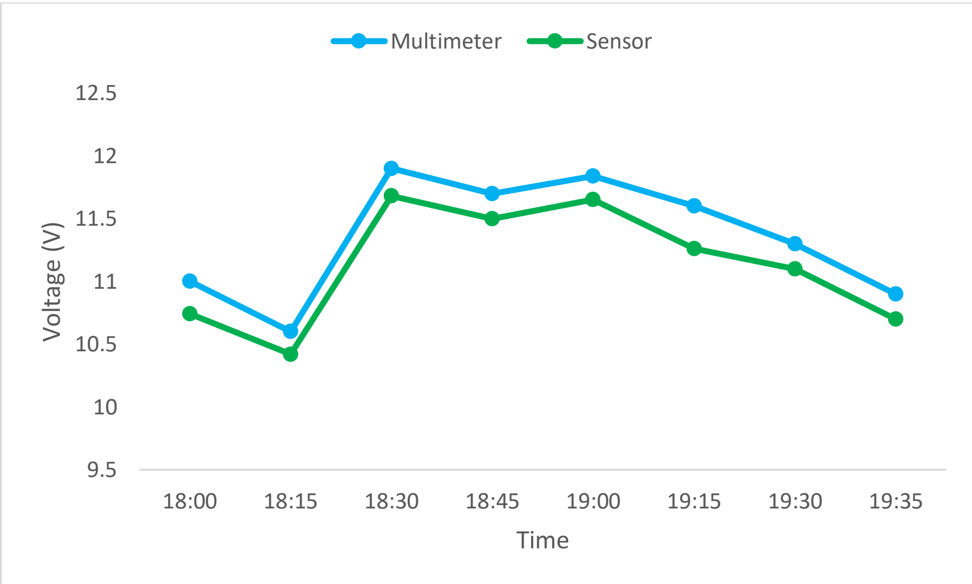
The recorded data is presented in Table 2. It shows the measured voltage and current values from both the multimeter and sensors, along with the corresponding percentage error. The highest voltage observed during the test was 11.9 V, and the highest current was 0.84 A. These peak values were recorded by the multimeter, providing a reference for evaluating the sensor readings. Throughout the test, the sensor readings remained close to the multimeter values, with relatively small error percentages, indicating reliable sensor performance. However, in the latter part of the test, particularly after 19:00, larger deviations were observed in current readings, with sensor values underestimating the current.

Table 2. Results of voltage and current testing on 9-Watt lamp.

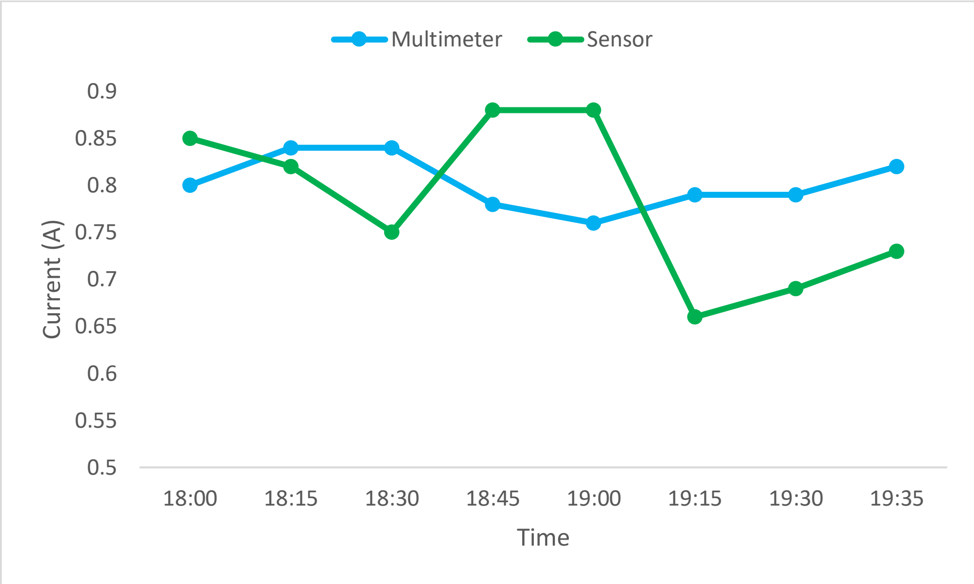
Time	Multimeter		Sensor		Error (%)	
	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Voltage	Current
18:00	11.0	0.80	10.74	0.85	0.02	0.06
18:15	10.6	0.84	10.42	0.82	0.01	0.02
18:30	11.9	0.84	11.68	0.75	0.01	0.10
18:45	11.7	0.78	11.5	0.88	0.01	0.12
19:00	11.8	0.76	11.65	0.88	0.01	0.15
19:15	11.6	0.79	11.26	0.66	0.02	0.16
19:30	11.3	0.79	11.10	0.69	0.01	0.16
19:45	10.9	0.82	10.70	0.73	0.01	0.10

Figures 4 complements Table 2 by illustrating the progression of voltage and current measurements over time. Charts in Figure 4 show the correlation between voltage and time, as well as current and time, comparing the data from the clamp meter and sensors. These visual representations focus on the same period covered in Table 2, allowing for a side-by-side understanding of data behavior and the accuracy of the sensor readings. The figures reveal that while voltage readings from both devices closely align, current measurements show a growing divergence toward the end of the test, reflecting the discrepancies noted in the table.

Figure 4. Testing results of 9-Watt lamp: **(a)** voltage; **(b)** current.



(a)



(b)

The 12-watt lamp test was conducted to examine sensor performance under the highest power load used in the study. The test started at 18:00 and concluded at 19:16 when the battery was fully depleted, with measurements taken at 15-minute intervals. Both multimeter and sensor readings were recorded to assess accuracy and consistency in voltage and current monitoring.

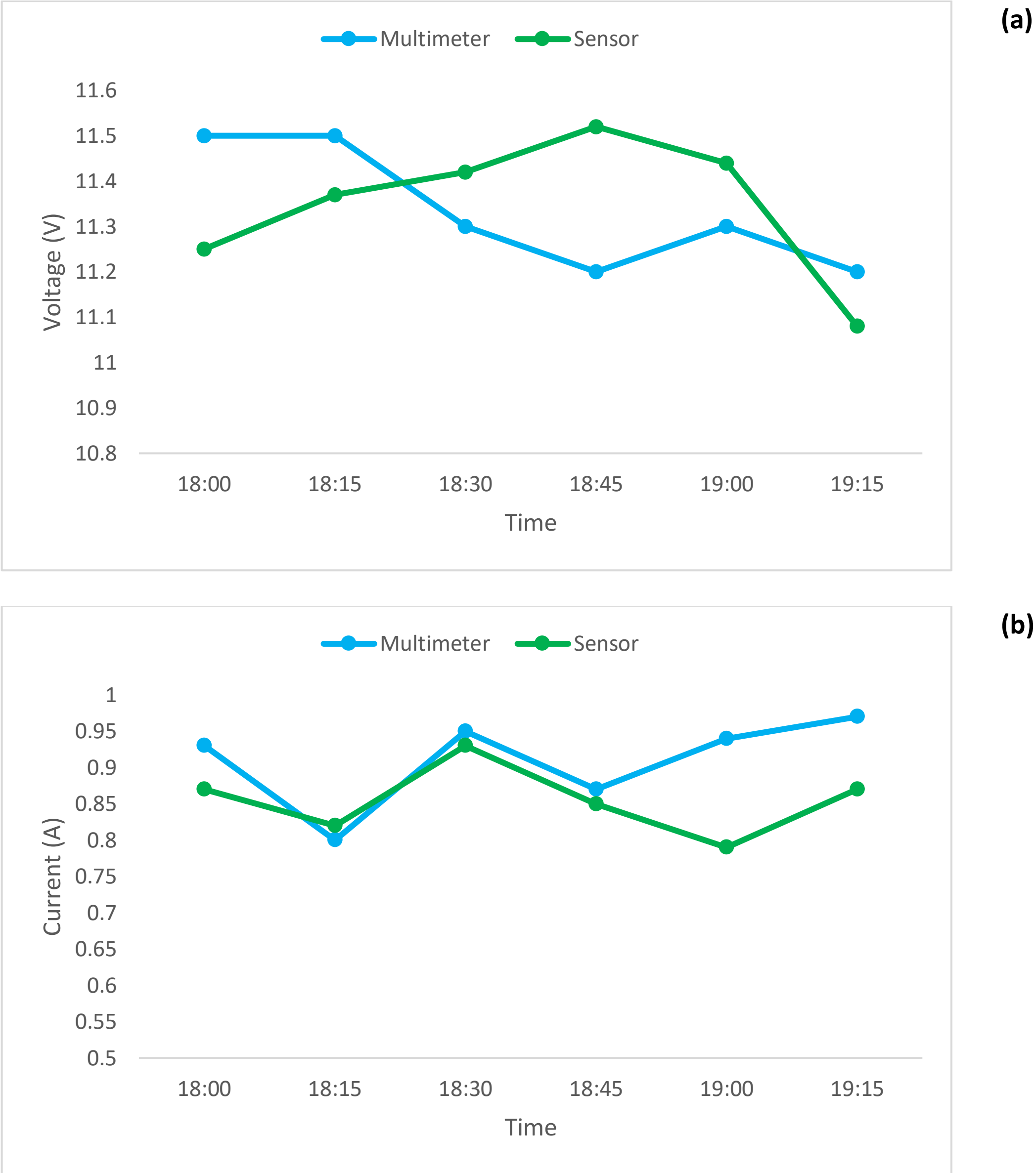
The detailed results are presented in Table 3. The highest recorded voltage using the multimeter was 11.5 V, and the peak current reached 0.97 A. The sensor values remained close to the multimeter readings throughout the testing period. The differences between the two sets of readings were minimal, with voltage errors generally staying within 0.01–0.02% and current errors showing slightly higher variations in the final stages of the test, reaching up to 0.15%. Despite the increase in deviation toward the end, the sensor continued to follow the overall trend, confirming its operational reliability.

Table 3. Results of voltage and current testing on 12-Watt lamp.

Time	Multimeter		Sensor		Error (%)	
	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Voltage	Current
18:00	11.5	0.93	11.25	0.87	0.02	0.06
18:15	11.5	0.80	11.37	0.82	0.01	0.02
18:30	11.3	0.95	11.42	0.93	0.01	0.02
18:45	11.2	0.87	11.52	0.85	0.01	0.02
19:00	11.3	0.94	11.44	0.79	0.01	0.15
19:15	11.2	0.97	11.08	0.87	0.01	0.10

To provide a clearer view of the trends, Figures 5 presents comparison graphs for both voltage and current readings. These visual aids support the numerical data from Table 3 by showing that while voltage tracking remained consistent, current readings experienced minor discrepancies toward the end of the test. The consistency across all lamp tests indicates that the voltage and current sensors are sufficiently accurate for real-time monitoring in this application.

Figure 5. Testing results of 12-Watt lamp: **(a)** voltage; **(b)** current.



3.1.2. Light Intensity Sensor

The light intensity sensor testing was conducted to evaluate the performance of the BH1750 sensor in measuring the illumination produced by different lamp loads. The sensor readings were compared to those from a standard lux meter to assess accuracy. The test involved three lamp power levels: 6 watts, 9 watts, and 12 watts, with measurements taken at 15-minute intervals. The error percentage was calculated based on the difference between the sensor and lux meter readings.

The results for the 6-watt lamp are shown in Table 4. The test recorded the highest light intensity at 240 lux. The sensor readings slightly overestimated the values throughout the test period, resulting in error percentages ranging from 0.05% to 0.13%. Despite these variations, the sensor tracked the changes in light intensity consistently, indicating acceptable accuracy for practical use. Figure 6 provides a graphical comparison of lux meter and sensor readings over time, showing that the sensor's trend closely follows that of the lux meter, with minimal deviation.

Table 4. Results of light intensity testing on 6-Watt lamp.

Time	Luxmeter	Sensor	Error (%)
18:00	240	273	0.13
18:15	240	269	0.12
18:30	230	251	0.09
18:45	230	246	0.06
19:00	230	242	0.05
19:15	220	231	0.05
19:30	220	234	0.06
19:45	210	227	0.07
20:00	180	168	0.06

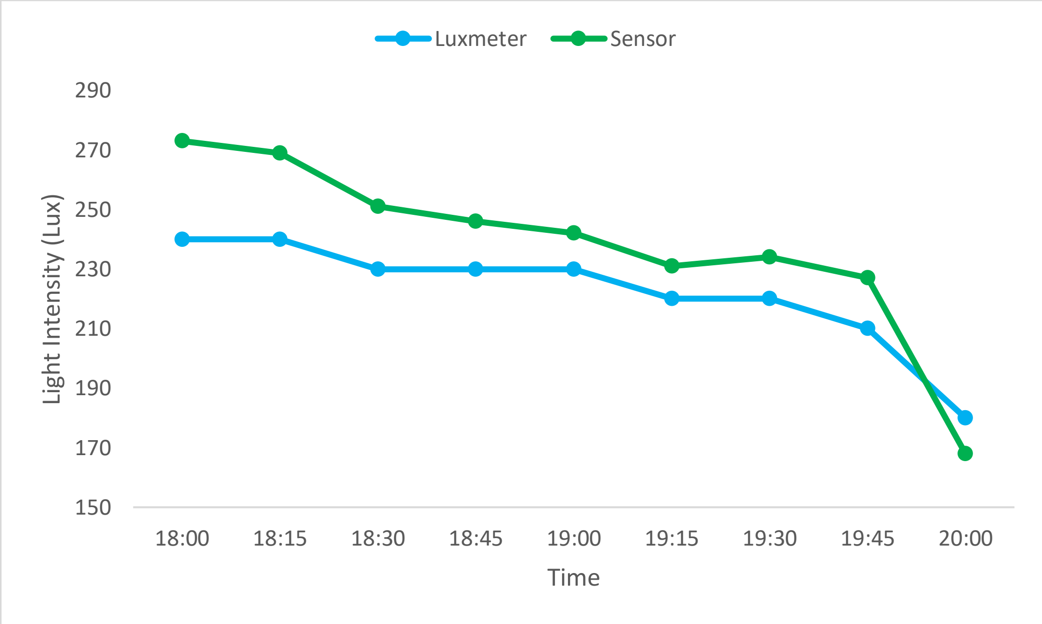


Figure 6. Light intensity testing results of 6-Watt lamp.

Table 5 presents the results for the 9-watt lamp, where the highest light intensity recorded was 570 lux. As with the previous test, the sensor values showed minor deviations, with error percentages ranging from 0.02% to 0.07%. The readings indicate that the BH1750 sensor maintained good consistency and followed the actual light intensity trend as captured by the lux meter. Figure 7 visually compares the sensor and lux meter readings for the 9-watt lamp, further supporting the sensor's reliability.

Table 5. Results of light intensity testing on 9-Watt lamp.

Time	Luxmeter	Sensor	Error (%)
18:00	570	588	0.03
18:15	570	586	0.02
18:30	530	512	0.03
18:45	420	442	0.05
19:00	400	423	0.05
19:15	390	418	0.07
19:30	370	357	0.03
19:45	360	348	0.03

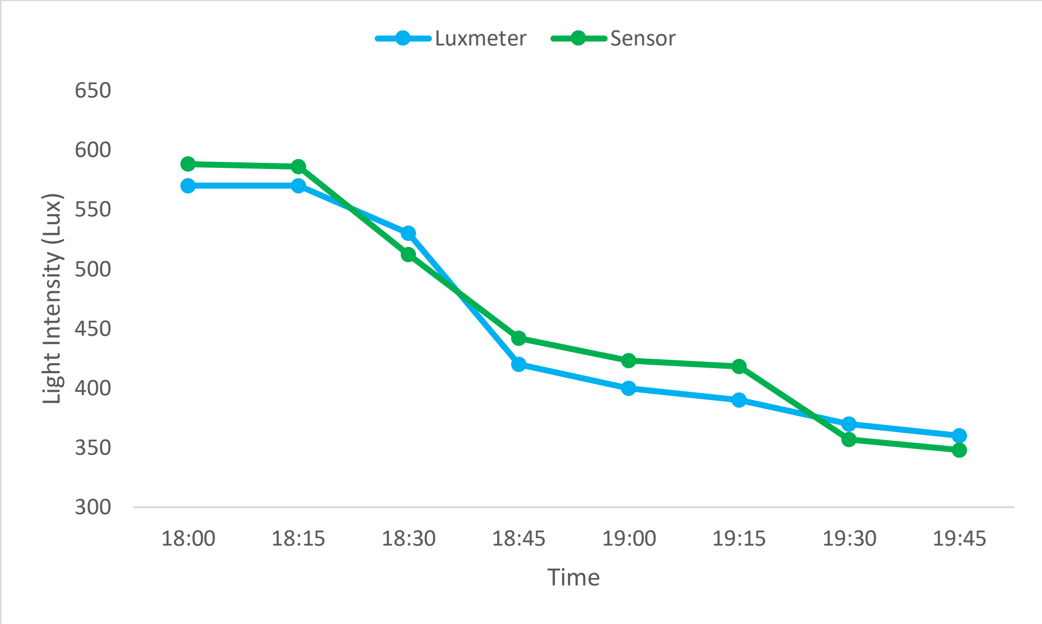


Figure 7. Light intensity testing results of 9-Watt lamp.

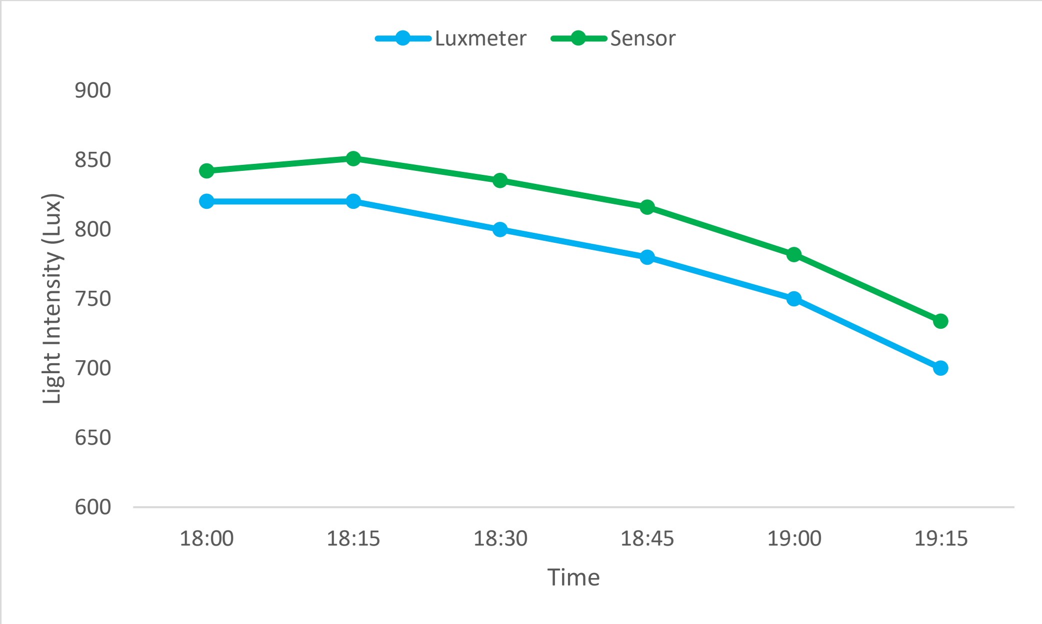
The results for the 12-watt lamp are shown in Table 6. The highest intensity recorded by the lux meter was 820 lux. Sensor readings were slightly higher but maintained a steady margin of error between 0.02% and 0.04%. This suggests the BH1750 sensor is capable of accurately capturing higher-intensity light levels with minimal deviation. Figure 8 presents the visual comparison for the 12-watt test, showing that the sensor readings remained closely aligned with the lux meter values throughout the test duration.

Table 5. Results of light intensity testing on 9-Watt lamp.

Time	Luxmeter	Sensor	Error (%)
18:00	820	842	0.02
18:15	820	851	0.03
18:30	800	835	0.04
18:45	780	816	0.04
19:00	750	782	0.04
19:15	700	734	0.04

Overall, Figures 6 through 8 demonstrate that the BH1750 light intensity sensor performs reliably across varying lamp powers. The trends in the sensor readings align well with the lux meter, and the small percentage errors confirm that the sensor can be confidently used for real-time light intensity monitoring in the planthopper trap system.

Figure 8. Light intensity testing results of 12-Watt lamp.



3.2. Pest Mortality Results

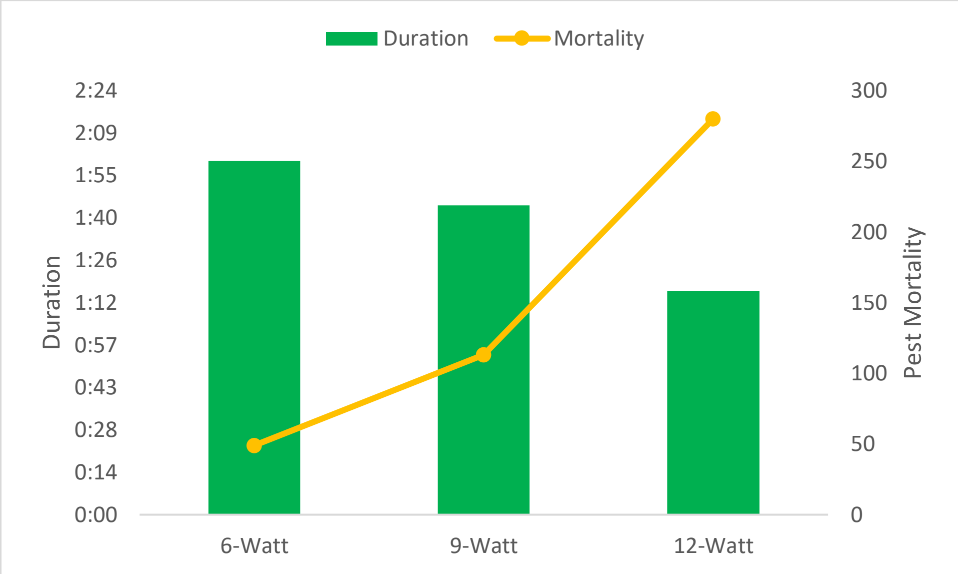
Pest mortality was tested using three different lamp powers: 6 watts, 9 watts, and 12 watts. Each lamp operated for a different duration based on battery capacity. Table 7 shows that the 6-watt lamp operated for 2 hours and killed 49 pests. The 9-watt lamp ran for 1 hour and 45 minutes, resulting in 113 pest deaths. The 12-watt lamp ran for 1 hour and 16 minutes and killed 280 pests.

Table 6. Pest mortality results.

Lamp	Duration	Mortality
6-Watt	2 hours	49 pests
9-Watt	1 hour 45 minutes	113 pests
12-Watt	1 hour 16 minutes	280 pests

This result also shows that illumination time decreases due to faster battery drainage. However, higher lamp power significantly increases the number of pests captured. This suggests that stronger light intensity improves the trap's effectiveness but requires careful energy management. Balancing energy consumption with trap efficiency is essential for developing a sustainable IoT-based pest control system. The correlation between power and pest capture indicates that higher light intensity increases the likelihood of attracting more pests into the trap. Therefore, optimizing the lighting system design by considering both energy efficiency and trapping effectiveness is crucial to improving the sustainability of IoT-based pest control systems. The correlation is illustrated in Figure 9.

Figure 8. Light intensity testing results of 12-Watt lamp.



4. Conclusions

The testing results indicate that the 12-watt lamp load produced an average voltage of 11.34 V from the sensor and 11.3 V from the measuring instrument. The current output averaged 0.85 A from the sensor and 0.91 A from the measuring instrument. The average light intensity from the 12-watt lamp was 810 lux as measured by the sensor and 778 lux by the measuring instrument. Tests using 6-watt, 9-watt, and 12-watt lamps showed that planthoppers were most attracted to the 12-watt lamp, with a corresponding light intensity of 780 lux.

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Conflicts of Interest: The authors declare no conflicts of interest.

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