IoT implementation in systems spraying pheromones pineapple skin for control integrated bee horn coconut palm oil

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Abstract: This study presents the design and evaluation of an Internet of Things (IoT)-based automated pheromone spraying system for the control of *Oryctes rhinoceros* in oil palm plantations. The proposed system integrates a microcontroller with an infrared sensor, a load cell, a real-time clock (RTC), a GSM communication module, and an ultrasonic mist generator to support real-time monitoring and automated pheromone release. Experimental procedures included component validation and field testing conducted over a seven-day period. The results demonstrate that the infrared sensor achieved a detection accuracy of 100% under low-light conditions, while the load cell showed a coefficient of variation of approximately 2%, indicating high measurement precision. The GSM module was capable of transmitting data with delays ranging from 0 to 51 seconds over a communication range of up to 5 km. Field evaluation further revealed that the trap positioned at a height of 2.5 meters yielded the highest capture rate of rhinoceros beetles compared to other configurations. Overall, the findings indicate that the developed system is reliable, energy-efficient, and applicable for sustainable pest management in oil palm plantations.

Keyword: IoT Based Pest Control, Oryctes Rhinoceros, Traps Pheromones, Infrared Sensors, Load Cells, Agriculture Sustainable

1. Introduction

Oil palm (Elaeis guineensis Jacq.) is one of the most vital plantation commodities in Indonesia, contributing significantly to the national economy. In 2023, the total area of oil palm plantations in Indonesia will reach approximately 15.93 million hectares, with crude palm oil (CPO) production exceeding 48 million tons (Badan Pusat Statistik, 2024). The productivity of palm oil is highly influenced by plant health conditions; therefore, pest control is a key factor in maintaining crop yields. It has been reported that pest infestations, such as those caused by the rhinoceros beetle (Oryctes rhinoceros), can reduce yields by up to 25% if not properly managed (Azhar, 2021). Therefore, an integrated, environmentally friendly, and sustainable control strategy is required to reduce the population of these pests (Azhar, 2021). The rhinoceros beetle typically attacks the growing point of the plant, causing severe physical damage that can even lead to plant death. This pest is nocturnal (active at night) and is highly attracted to decaying organic matter as well as attractant compounds such as pheromones (Parinduri et al., 2020) Various control methods have been developed, including mechanical, biological, and chemical approaches. One technique considered both effective and environmentally friendly is the use of pheromone traps (Widodo & Sembiring, 2024).

Pheromones function as natural attractants that can lure adult male beetles without causing adverse effects on the environment (Munawaroh et al., 2023)It has been shown that pineapple peel extract contains volatile compounds that are effective in attracting rhinoceros beetles and can be used as an alternative to pheromones (Lestari et al, 2020) It has also been reported that modifications in trap design, height, and strategic placement can increase capture rates by up to 40%.

Technological advancements have enabled the integration of trapping systems with automated sensors and data communication modules. GSM modules such as the SIM800L allow information on capture results to be transmitted in real time, while load cells and infrared sensors can automatically monitor pheromone weight and the number of captures (Ar-Razy & Wagyana, 2024). This method is considered more efficient compared to traditional approaches, which still rely on manual inspection and periodic recording. With the implementation of an automated system, data accuracy can be improved, labor requirements can be reduced, and monitoring can be carried out continuously without the need to be physically present at the trap location (Putri et al, 2023).

However, most previous studies have primarily focused on the use of single sensors or simple data transmission systems, without comprehensive integration between sensors, communication modules, and automated control systems (Candra et al., 2019)This provides an opportunity for further research to develop a more intelligent and efficient rhinoceros beetle trapping system capable of monitoring environmental conditions and capturing results in real time with a high level of precision (Syaputra & Martha, 2024).

Study This aim For design and evaluate system trap automatic based microcontroller that is capable of do spraying pheromones in a way scheduled (Lima et al., 2020), The system is also designed to monitor pheromone availability in real time and to transmit capture reports accurately via SMS. It is expected that the developed system will enhance the effectiveness of rhinoceros beetle control in an autonomous and efficient manner, while also supporting sustainable energy use through the utilization of solar panels as the primary power source (Pertiwi et al, 2025).

2. Methods

2.1. Time and Place

This study employed an experimental approach involving the design, development, and testing of a microcontroller-based automated pheromone trapping system to address the problem of rhinoceros beetle (*Oryctes rhinoceros*) infestation (Ahmed, 2024). The trapping system was designed to operate automatically at night, between 18:00 and 06:00 WIB, using an ultrasonic mist maker as a medium for dispersing pheromones derived from pineapple peel extract as a natural attractant (Kadek et al, 2025)

The system design adopts an integrated approach combining automation technology and Internet of Things (IoT)-based monitoring systems, which are increasingly applied in pest control due to their ability to enhance efficiency, effectiveness, and accuracy compared to conventional methods (Kartono et al, 2025). In addition, the developed trap design combines the working principles of traditional pheromone-based traps with modern technology, enabling the system to operate in a more adaptive and responsive manner to field conditions (Lika et al, 2025).

The implementation of an automated system for regulating operational timing and pheromone distribution is expected to reduce the need for direct manual monitoring, thereby lowering operational costs and minimizing the risk of capture failure due to delays in trap management (Lima et al., 2020). The main equipment and materials used in this study are presented in the following section. Table 1.

Table 1. Table and Materials

No	Tools/Materials	Function
1	Arduino Uno R3	Microcontroller system control center
2	*Infrared* (IR) Sensor	Detecting the presence of beetles
3	*Load cell* + HX711	Measuring the remaining pheromone weight
4	RTC DS3231	Set the pheromone spraying time automatically
5	Mist maker	Turning the pheromone solution into mist
6	GSM Module SIM800L	Sending data on the number of catches and pheromone weight via SMS
7	6V 3W solar panel	The main resource for charging the battery
8	20,000 mAh Power Bank	Storing energy for system supply
9	4 inch diameter PVC tube	Component containers to protect from the weather
10	Pheromones from pineapple skin	Natural attractants to attract rhinoceros beetles
11	Relay	Controlling the on/off of the ultrasonic mist maker
12	System Box	Place the entire electronic circuit to be protected
13	Pheromone Tube	Pheromone liquid container to attract beetles

2.2. Design and Construction Trap

The physical structure of the trap was constructed using a 4-inch diameter PVC pipe equipped with drainage holes at the bottom to prevent water accumulation. A funnel was installed at the top of the pipe to direct beetles into the trap (Paudel et al., 2023). An infrared sensor was installed on the side of the pipe to detect the presence of beetles entering the trap (Sejati et al., 2022). A mini solar panel connected to a power bank was used as the power source, ensuring a continuous energy supply even during nighttime. The overall design of the rhinoceros beetle trapping system is presented in Figure 1.

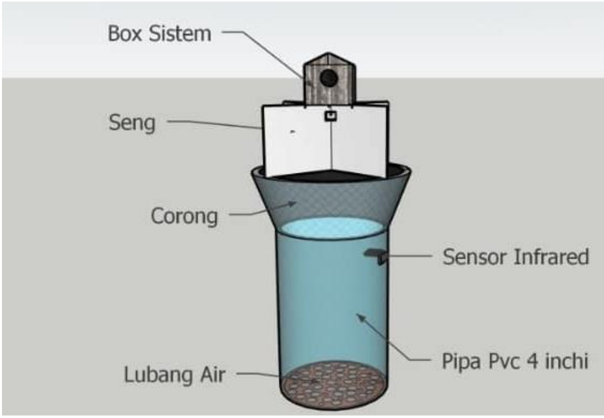

Figure 1. System Design Block Diagram

The electronic components were placed inside an enclosure designed to protect the circuitry from rain and environmental exposure. This enclosure houses an Arduino Uno R3 microcontroller as the main controller, a DS3231 RTC module for timekeeping, a SIM800L module for transmitting reports via SMS, a load cell with an HX711 module for measuring the remaining pheromone, and a relay to control the operation of the ultrasonic mist maker.

The mist maker converts liquid pheromone into a fine mist, enabling more efficient dispersion of the pheromone scent. The enclosure is also equipped with a pheromone container and an outlet chimney to release the mist into the air, as illustrated in Figure 2.

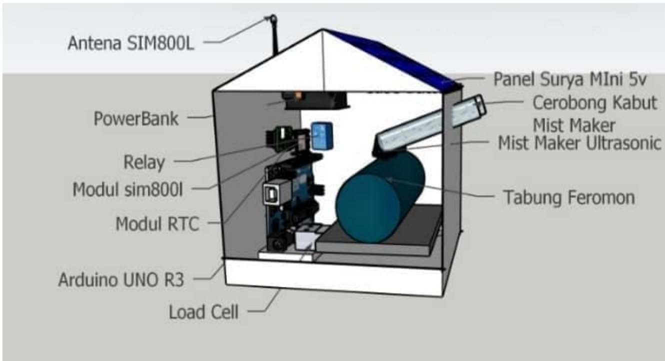

Figure 2. System Box Design

2.3. Integration and Evaluation Component

After the design and assembly processes were completed, the next stage involved the integration and testing of the main components before field deployment. This stage aims to ensure that each sensor and module functions properly according to the expected performance.

The testing was carried out in stages, beginning with the verification of sensor accuracy, followed by the evaluation of data communication stability, and concluding with the assessment of the solar panel's energy supply performance as the system's primary power source. (Sukarman et al., 2025). This testing phase is essential to ensure that the system can operate optimally when implemented under actual field conditions. Several related studies have also emphasized the importance of initial validation of energy components and sensors to ensure the sustainability of IoT-based systems in real-world applications. (Sukarman et al., 2025).

The components tested consist of four main parts. First, the load cell was evaluated to verify the accuracy of weight measurements by comparing sensor readings with standard weights. Measurement precision was analyzed using the Coefficient of Variation (CV), as expressed in Equation. (1)

$$CV = \frac{SD}{\bar{x}} \times 100\% \quad (1)$$

Information :
SD: Standard deviation
$\bar{x}$: Average

Second, the SIM800L module was tested with a focus on the stability of GSM data communication. (Fahyurisandi & Neforawati, 2020), including transmission delay and data delivery success rate. Third, the infrared (IR) sensor was tested to evaluate object detection sensitivity, effective detection range, and potential detection errors under varying lighting conditions. Finally, the solar panel was tested to measure battery charging capacity and the stability of the power supply under different light intensity levels. (Ar-Razy & Wagyana, 2024). Through these stages, an initial assessment of the system's reliability was obtained before conducting field testing under real conditions.

2.4. *Ways of working System*

The system operation begins with the provision of an energy source through a solar panel connected to a power bank, which serves as the main energy storage and supply unit. The generated energy is then used to power all system components. Once the system is activated, an initialization and component recognition process is carried out, including the Arduino Uno microcontroller, the DS3231 RTC module for timekeeping, an infrared sensor for object detection, a load cell integrated with the HX711 module for measuring pheromone weight, and the SIM800L module for data communication.

After the initialization process is completed, the system enters a continuous daily operation mode (looping) that runs for 24 hours, starting from 06:00 WIB to 06:00 WIB the following day. During this phase, the system performs two main functions: detecting the presence of beetles and automatically regulating the timing of pheromone spraying.

The detection process is carried out using an infrared sensor placed at the entrance of the trap. When the sensor detects an incoming object, the system identifies the event as an indication of the presence of a rhinoceros beetle, then records and automatically increments the capture count. The detection data is stored within the system and subsequently used as the basis for reporting to the user via the communication module.

In addition to the detection function, the system also regulates the pheromone spraying mechanism on a scheduled basis. Between 18:00 and 06:00 WIB, the system activates the ultrasonic mist maker via a relay to generate pheromone mist from the storage container. This nighttime operation is aligned with the nocturnal behavior of the rhinoceros beetle, thereby enhancing trapping effectiveness (Parinduri et al., 2020). The mist maker is activated periodically every 30 minutes, with a spraying duration of 3 minutes per cycle, ensuring consistent and uniform distribution of pheromones in the area surrounding the trap.

At the same time, the load cell periodically measures the pheromone weight to monitor the remaining solution in the container. This information is essential for maintenance purposes, particularly in determining the appropriate time for pheromone refilling. Thus, the integration of detection, automated spraying, and pheromone availability monitoring enables the system to operate autonomously, efficiently, and sustainably under field conditions.

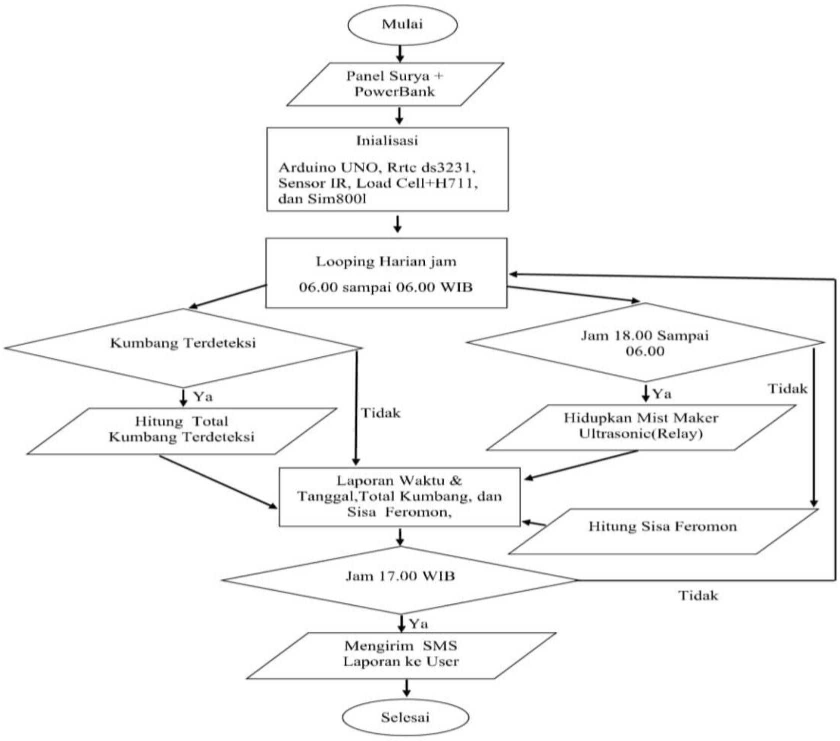

Figure 2. *Flowchart System*

This study was conducted in a community-owned oil palm plantation located on Pekanbaru – Bangkinang Road, Riau, over a period of seven consecutive days. The observed parameters included the number of captures per day, the reduction in pheromone weight, and the effectiveness of SMS transmission. Data were collected automatically and analyzed using a quantitative descriptive method to evaluate the performance of the trapping system under field conditions.

3. Results and Discussion

3.1. Result

In this study, a series of experiments were conducted on the main components of an automated trap system based on a microcontroller. The testing included the use of a load cell to measure the decrease in pheromone weight, an infrared sensor to detect the presence of pests, and a SIM800L communication module to transmit device status notifications in real time. In addition, the performance of the solar panel was evaluated as an energy source, along with the overall effectiveness of system integration under field conditions.

1) Load Cell Testing

The purpose of the load cell testing was to evaluate the device's ability to measure the reduction in pheromone weight during the automatic spraying process. Two testing sessions were conducted, each consisting of ten repetitions, where the amount of pheromone dispensed was determined based on the difference in mass measured every 5 minutes.

Table 1. Digital Scale Test

Test to -	Initial Mass (g)	Final Mass (g)	Difference (g)	Volume (ml)	Time (minutes)
1	356.93	354.09	2.84	0.00284	5
2	354.09	352.28	1.81	0.00181	5
3	352.28	350.33	1.95	0.00195	5
4	350.33	348.43	1.9	0.0019	5
5	348.43	346.66	1.77	0.00177	5
6	346.66	344.86	1.8	0.0018	5
7	344.86	342.96	1.9	0.0019	5
8	342.96	341.19	1.77	0.00177	5
9	341.19	339.22	1.97	0.00197	5
10	339.22	337.35	1.87	0.00187	5

Table 2. Load Cell Test

Test to -	Initial mass (g)	Final Mass (g)	Difference (g)	Volume (mL)	Time (minutes)
1	356.64	354.08	2.56	0.00256	5
2	354.08	352.28	1.8	0.0018	5
3	352.28	350.22	2.06	0.00206	5
4	350.22	348.25	1.97	0.00197	5
5	348.25	346.44	1.81	0.00181	5
6	346.44	344.86	1.58	0.00158	5
7	344.86	342.89	1.97	0.00197	5
8	342.89	341.18	1.71	0.00171	5
9	341.18	339.22	1.96	0.00196	5
10	339.22	337.27	1.95	0.00195	

Tables 1 and 2 present the measurement results of pheromone weight reduction from two consecutive testing sessions. The average decrease in pheromone solution weight for each spraying cycle was approximately 1.9 grams, with a fixed time interval of 5 minutes for each cycle.

A value of approximately 2% was obtained, which is considered reasonably precise. This indicates that the load cell sensor used in the system is reliable for accurately monitoring pheromone consumption over repeated durations. These results support the system's ability to consistently detect mass changes and serve as an essential component in maintaining the effectiveness of automatic spraying. Accurate weight measurement is also crucial for automated decision-making processes, such as determining the appropriate time to refill the pheromone solution.

2) Infrared Sensor Testing

The infrared sensor was tested under four different lighting conditions to evaluate its accuracy in detecting the presence of objects (simulating beetles). The results showed that under dusk and nighttime conditions, the sensor successfully detected all objects with 100% accuracy. However, during bright daylight, the sensor was unable to detect any objects.

Table 3. IR Sensor Test

Test to -	Condition Light	Intensity Light (lx)	Amount Entry Object	Detected By IR	Accuracy (100%)
1	Bright Daylight	9154	0	0	0%
2	Late afternoon	531	10	10	100%
3	Dark Night	5	10	10	100%
4	Morning Light	9052	0	0	0%

Table 4 presents the test results, indicating that the infrared sensor performs best under low-light conditions, which aligns with the nocturnal behavior of the rhinoceros beetle.

3) SIM800L Module Testing

The SIM800L module was tested to evaluate the system's ability to transmit data or status notifications directly to users via the GSM network. This experiment involved sending signals from the automated trap installed various at distances and under different conditions (outdoor and indoor) to assess signal strength, message transmission speed (delay), and location accuracy.

Table 4SIM800L Outdoor Test

Delivery Time	Receive Time	Status	Delay (s)	Signal	Road Distance (m)	Coordinate System	Coordinate Monitor	Radius (m)
01/21/03	01/21/06	Sent	3	Strong	500	0°30'4.1"N	0°30'20.3"N	500
10.21.00	10.22.00	Sent	0	Strong	1000	0°29'47.8"N	0°30'16.8"N	1000
21.14.05	22.14.10	Sent	5	Strong	1500	0°29'31.4"N	0°30'13.0"N	1500
21.17.17	22.17.34	Sent	17	Strong	2000	0°29'15.2"N	0°30'9.0"N	2000
21.22.54	22.23.00	Sent	6	Strong	2500	0°28'58.9"N	0°30'4.8"N	2500
21.26.15	22.26.30	Sent	15	Strong	3000	0°28'42.5"N	0°30'0.5"N	3000
21.29.21	22.29.42	Sent	21	Strong	3500	0°28'26.2"N	0°29'56.0"N	3500
21.32.32	22.33.02	Sent	32	Strong	4000	0°28'9.9"N	0°29'51.4"N	4000
21.45.01	22.45.02	Sent	1	Strong	4500	0°27'53.5"N	0°29'46.6"N	4500
21.49.17	22.49.34	Sent	17	Strong	5000	0°27'37.2"N	0°29'41.7"N	5000

Table 5. SIM800L Indoor Test

Delivery Time	Receive Time	Status	Delay (s)	Signal	Road Distance (m)	Coordinate System	Coordinate Monitor	Radius (m)
22.00.23	23.00.24	Sent	1	Strong	5000	0°27'37.2"N	0°29'46.6"N	5000
04.22.06	04.23.12	Sent	6	Strong	4500	0°27'53.5"N	0°29'46.6"N	4500
06.22.51	23.07.42	Sent	51	Strong	4000	0°28'9.9"N	0°29'51.4"N	4000
10/22/01	10/23/02	Sent	1	Strong	3500	0°28'26.2"N	0°29'56.0"N	3500
12/22/18	12/23/36	Sent	18	Strong	3000	0°28'42.5"N	0°30'0.5"N	3000
22.14.18	23.14.36	Sent	18	Strong	2500	0°28'58.9"N	0°30'4.8"N	2500
22.16.36	23.17.12	Sent	36	Strong	2000	0°29'15.2"N	0°30'9.0"N	2000
22.19.43	23.20.26	Sent	43	Strong	1500	0°29'31.4"N	0°30'13.0"N	1500
22.22.51	23.22.42	Sent	51	Strong	1000	0°29'47.8"N	0°30'16.8"N	1000
22.25.19	23.25.38	Sent	19	Strong	500	0°30'4.1"N	0°30'20.3"N	500

Based on the results presented in Tables 5 and 6, all messages were successfully transmitted with a "sent" status, both in outdoor and indoor conditions. The transmission delay ranges from 0 to 51 seconds, depending on distance and location conditions. The experiment demonstrated that the GSM signal remained strong up to a distance of 5 kilometers, in both open and enclosed environments. This confirms that the SIM800L module is reliable for transmitting data from the device to users, even across wide and remote areas.

4) Solar Panel Testing

The solar panel was tested to evaluate how effectively the system could automatically charge the battery based on light intensity and weather conditions. Data collection was conducted over six consecutive days, with measurements taken hourly between 09:00 and 15:00 WIB. The parameters measured included the solar panel voltage, current supplied to the power bank, the initial battery level indicated by four blinking LED indicators on the power bank, and light intensity in lux, as presented in Table 7.

Table 6. Solar Panel Test

Day	Weather	Charging Hours	Panel Voltage (V)	Current (A)	Battery Level Beginning(%)	Intensity Light (lx)
Friday, 18/07-2025	Bright	09.00	5.7	1.46	0	9154
	Bright	10.00	4.8	1.44	1	9268
	Bright	11.00	4.98	1.41	2	9723
	Bright	12.00	5.6	1.47	3	9778

Day	Weather	Charging Hours	Panel Voltage (V)	Current (A)	Battery Level Beginning(%)	Intensity Light (lx)
	Bright	13.00	4.5	1.73	3	9698
	Bright	14.00	5.17	1.60	3	9560
	Bright	15.00	5.2	1.43	4	9222
Saturday, July 19, 2025	Overcast	09.00	3.6	0.87	0	7786
	Overcast	10.00	5.4	1.01	0	7970
	Overcast	11.00	4.8	0.95	0	8072
	Bright	12.00	5.0	1.2	0	9560
	Bright	13.00	5.3	1.46	1	9556
	Overcast	14.00	5.3	0.75	1	7151
	Overcast	15.00	5.1	0.98	2	7042
Sunday, July 20, 2025	Bright	09.00	4.4	1.41	1	9377
	Bright	10.00	5.2	1.39	1	9655
	Bright	11.00	4.8	1.57	2	9492
	Bright	12.00	5.5	1.67	2	9725
	Bright	13.00	4.7	1.48	3	9727
	Bright	14.00	5.6	1.52	3	9768
	Overcast	15.00	4.1	1.26	3	9150
Monday, 21/07-2025	Bright	09.00	5.2	1.60	0	8934
	Bright	10.00	4.9	1.54	1	9158
	Overcast	11.00	4.6	1.02	1	8681
	Bright	12.00	5.1	1.38	1	9042
	Bright	13.00	5.4	1.57	2	9268
	Bright	14.00	5.6	1.65	2	9437
	Bright	15.00	4.9	1.32	3	9654
Tuesday, 22/07-2025	Overcast	09.00	4.8	1.02	2	7786
	Bright	10.00	5.3	1.31	2	8380
	Bright	11.00	5.1	1.25	2	8599
	Overcast	12.00	5.1	0.98	2	8202
	Overcast	13.00	4.6	1.01	3	8059
	Overcast	14.00	4.8	1.06	3	7920
	Overcast	15.00	4.4	0.84	3	7299
Wednesday, July 23, 2025	Bright	09.00	5.0	1.30	0	8949
	Bright	10.00	4.9	1.41	0	9247
	Bright	11.00	5.6	0.90	1	9288
	Bright	12.00	5.3	1.81	2	9422
	Bright	13.00	5.1	1.71	2	9512
	Bright	14.00	5.2	1.07	2	9562
	Bright	15.00	5.7	1.20	3	9598
Thursday, 24/07-2025	Overcast	09.00	4.6	1.21	1	7361
	Overcast	10.00	5.1	1.35	1	7466
	Overcast	11.00	4.9	1.07	2	7680
	Overcast	12.00	5.3	1.48	2	7833
	Bright	13.00	5.7	1.26	3	8086
	Bright	14.00	5.2	1.70	3	8272
	Overcast	15.00	4.6	0.87	3	8008

The test results showed that the solar panel performed best under sunny conditions, with voltages exceeding 5 V and currents above 1.8 A. Conversely, during cloudy weather, both voltage and current decreased, resulting in longer charging times. The battery level showed a gradual increase, particularly during hours with high light intensity. These findings indicate that the solar panel can provide a consistent and reliable power supply for autonomous system operation in the field.

5) Testing System

Field testing was conducted in an approximately 2-hectare oil palm plantation, with four trap points installed in the central area of the plantation at intervals of about 15 meters. Three of the traps were microcontroller-based automated devices installed at varying heights of 0.5 m, 1.5 m, and 2.5 m above the ground. For comparison, one traditional trap consisting of an open container filled with ripe pineapple was placed 1.5 m above the ground without any automation system. Details of the locations and installation coordinates are presented in Table 8.

Table 7. Coordinates and specifications of field test traps

Trap	Types of Traps	Installation Height (m)	Coordinate
Trap 1	Automatic	0.5	0°25'44.0"N 101°19'27.2"E
Trap 2	Automatic	1.5	0°25'43.7"N 101°19'26.0"E
Trap 3	Automatic	2.5	0°25'42.9"N 101°19'26.2"E
Trap 4	Traditional	1.5	0°25'42.6"N 101°19'25.4"E

The testing was conducted over seven consecutive days using an automated system designed to enhance pest control effectiveness. The system periodically sprays pheromones derived from fermented pineapple peel using a fogging device, allowing the pheromone scent to disperse more evenly and attract rhinoceros beetles from a wider area. In addition, the system was integrated with an SMS gateway that sends real-time notifications to the user whenever a capture occurs, facilitating monitoring without the need for direct field inspection.

During the testing period, data on the number of rhinoceros beetle captures were systematically collected and recorded daily. The data were then visualized in graphical form to provide a clearer representation of capture trends, including increases or decreases in the number of beetles caught. Through these graphs, the effectiveness of the system in attracting and capturing rhinoceros beetles can be analyzed, as well as the identification of pest activity patterns based on testing times. These results serve as an important indicator for evaluating the performance of the device and its potential application as an efficient, technology-based pest control solution.

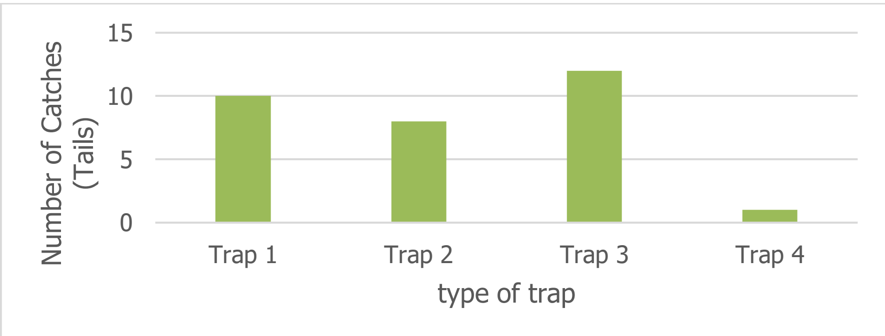

Figure 1. Number of Catches

The results of rhinoceros beetle (O. rhinoceros) captures showed variations in practical effectiveness among different types of traps. The automated trap placed at a height of 2.5 meters (Trap 3) tended to catch more beetles compared to traps at 0.5 meters and 1.5 meters. This indicates that trap height influences the rate of pest arrival, consistent with the findings of W. Lestari (Lestari, 2020b), who reported that O. rhinoceros is more active at a height of 2.5 meters above the ground.

For comparison, the control trap (Trap 4), using ripe pineapple placed at ground level, also captured rhinoceros beetles, but the number caught was much lower than that of the automated traps. This supports the notion that the pheromone derived from pineapple extract itself is attractive, but the addition of an automated system and a mist maker enhances pheromone dispersion, thereby increasing capture effectiveness.

In addition to analyzing capture results, daily measurements of the remaining pheromone were also investigated.

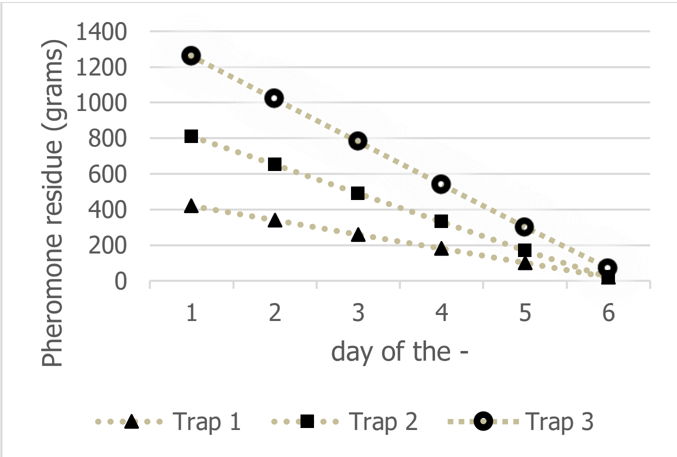

Figure 2 Pheromone Residue

The graph shows that pheromone levels gradually decrease each day. This indicates that continuously sprayed pheromones diminish over time, making periodic refilling necessary to maintain trap effectiveness. The mist maker was able to distribute the pheromone consistently, although slight variations were observed between traps, likely due to environmental factors such as humidity, wind direction and speed, and microclimatic conditions at the testing site

During the experiment, the SMS-based notification system integrated with the communication module functioned effectively in delivering timely information to the user. This success demonstrates that the system is capable of providing efficient remote monitoring. Evidence of SMS message reception by the user is shown in Figure 6, indicating that the communication system operated as designed and proven reliable under field conditions.

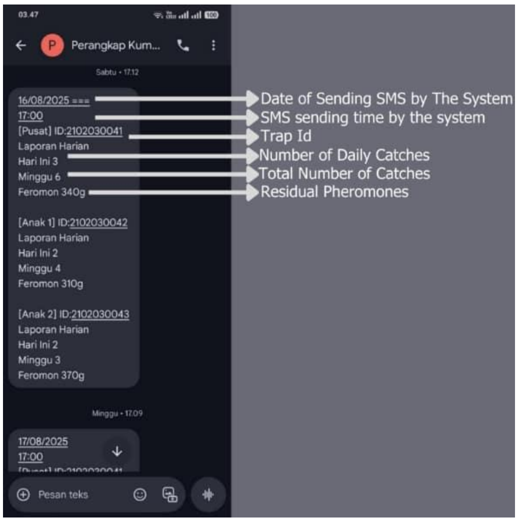

Figure 3. Screenshot of SMS notification of beetle detection results

However, during the observation period, some delays in SMS message delivery were noted, with intervals ranging from 5 to 15 minutes. These delays were attributed to fluctuations in cellular network signal quality within the plantation area. The results of this study are consistent with previous research indicating that trap height has a significant impact on the success of capturing rhinoceros beetles. Previous studies have shown that the most effective height range is between 2 and 3 meters, confirming that the 2.5-meter position in this study is the most efficient.

Furthermore, the findings reinforce the hypothesis that microcontroller-based automated traps using natural pheromones are more effective than control traps relying solely on pineapple extract. Variation in trap height proved to have a significant effect, with the trap placed at 2.5 meters achieving the highest number of captures. Thus, the research hypothesis is supported, demonstrating that the automated system enhances capture efficiency while confirming that trap height plays a crucial role in attracting *Oryctes rhinoceros* .

6) Discussion

The results of the study indicate that the system operates optimally under conditions that align with the biological behavior of *Oryctes rhinoceros,* which is active at night. The infrared sensor demonstrated a detection accuracy of 100% under low-light conditions, due to minimal interference from ambient light. Conversely, detection failure under high-light conditions was likely caused by infrared signal disruption resulting from strong light intensity

The load cell sensor demonstrated consistent performance with a coefficient of variation of approximately 2%, indicating a high level of precision and reliability in monitoring pheromone usage. This level of accuracy is crucial for maintaining optimal pheromone availability, thus ensuring the sustained effectiveness of the traps.

The GSM module exhibited data transmission delays ranging from 0 to 51 seconds, influenced by signal quality and environmental conditions. Despite these variations, all data were successfully transmitted, demonstrating that the communication system is sufficiently reliable for remote monitoring.

Furthermore, field test results showed that traps installed at a height of 2.5 meters captured the highest number of beetles compared to other configurations. This supports previous studies indicating that rhinoceros beetle flight activity is more pronounced at certain heights. The use of an ultrasonic mist maker was also shown to enhance pheromone dispersion, thus increasing the attractant efficiency compared to conventional trapping methods.

The results of the study indicate that the developed microcontroller-based pest trap system operates optimally when accounting for the nocturnal behavior of *Oryctes rhinoceros* . The infrared sensor demonstrated a detection accuracy of 100% under low-light conditions, due to minimal interference from ambient light, allowing the infrared signal to be received more stably. Conversely, under high-light conditions, sensor performance declined because the infrared signal was disrupted by strong environmental light intensity.

From a measurement perspective, the load cell demonstrated consistent performance with a coefficient of variation of approximately 2%, indicating a high level of precision and reliability in monitoring pheromone usage. This level of accuracy is crucial for maintaining optimal pheromone availability, thus ensuring the sustained effectiveness of the traps.

Meanwhile, the GSM module exhibited data transmission delays ranging from 0 to 51 seconds, influenced by network signal quality and environmental conditions. Despite these variations, all data were successfully transmitted, indicating that the communication system is reliable for supporting remote monitoring.

Field test results showed that traps placed at a height of 2.5 meters achieved the highest capture rates. This finding aligns with the behavior of *Oryctes rhinoceros,* which tends to be more active at certain heights, particularly in the canopy area. In addition, the integration of an ultrasonic mist generator was shown to enhance pheromone dispersion. Pheromones released in the form of a micro-mist allow volatile compounds to be distributed more widely and evenly in the air, thus increasing the likelihood of pests detecting the attractant compared to conventional methods.

Conceptually, the increased effectiveness of this system results from the synergy between electronic technology and a biological approach. The use of natural pheromones derived from pineapple peel extract demonstrates potential as a more environmentally friendly alternative to synthetic pheromones. Volatile compounds produced through the fermentation of organic materials can attract insects even with a more complex composition. The advantages of this approach lie in its lower production costs and minimal chemical residues, making it safer for the environment and surrounding ecosystems.

Furthermore, the use of solar panels as the primary energy source adds value from a sustainability perspective. The system can operate independently without relying on external electricity, making it highly suitable for deployment in plantation areas, which are often located in remote locations. This integration not only enhances operational efficiency but also supports the implementation of sustainable agriculture practices.

Overall, the developed system demonstrates strong potential as an automated, efficient, and environmentally friendly pest control solution. This study also reinforces the application of Internet of Things (IoT) technology in crop protection, particularly in automated pest monitoring and management systems.

However, several aspects still require further investigation, such as optimizing pheromone dosage to achieve maximum effectiveness, improving sensor sensitivity and range, and enhancing device durability under long-term field conditions. Future development in these areas is expected to improve overall system performance and expand its potential for broader implementation in the agricultural sector.

4. Conclusion

This study successfully developed and validated an IoT-based automated pheromone spraying system for controlling Oryctes rhinoceros in oil palm plantations. The developed system demonstrated highly reliable performance, with the infrared sensor achieving 100% detection accuracy under low-light conditions and the load cell sensor exhibiting high precision with a coefficient of variation of approximately 2%. The GSM module also consistently transmitted data with delays ranging from 0 to 51 seconds over a coverage area of up to 5 km, demonstrating its suitability for real-time remote monitoring

Field test results indicated that traps installed at a height of 2.5 meters achieved the highest beetle capture rates, suggesting an optimal placement strategy aligned with pest behavior . Furthermore, the integration of an ultrasonic mist generator was shown to improve pheromone dispersion efficiency compared to conventional methods

These results strongly confirm that the proposed system is not only effective but also energy-efficient and environmentally friendly, making it a viable solution for modern pest control. This study contributes practically to the field of precision agriculture and demonstrates clear improvements over conventional, non-integrated pest control systems

As a follow-up to this research, several recommendations can be made for future development. First, the system could be further enhanced by integrating cloud-based monitoring, allowing capture data and device status to be accessed in real time via applications or web platforms. Second, long-term field trials with a larger number of traps and varying environmental conditions are needed to obtain more representative and generalizable results.

Third, optimizing the pheromone spraying dosage should be undertaken to improve efficiency without compromising capture effectiveness. Fourth, future research should focus on enhancing device durability under field conditions such as rain, extreme temperatures, and high humidity. Fifth, conducting an economic feasibility analysis (cost-benefit analysis) is essential to assess the potential for widespread adoption by farmers. With these developments, the system is expected to provide not only academic value but also practical, real-world application as an innovative and sustainable pest control solution.

References

Ahmed, S., et al. (2024). *IoT-based intelligent pest management system for precision agriculture . Scientific Reports, 14* (1), 1–15. https://doi.org/10.1038/s41598-024-83012-3

Ar-Razy, H., & Wagyana, A. (2024). Design and development of a solar-powered IoT-based monitoring system for solar panels and hydroponic plants. *Tesla: Journal of Electrical Engineering, 26* (2), 118–127.

Azhar, N., et al. (2021). Review on development of integrated pest management for basal stem rot and rhinoceros beetle in palm oil. [Journal name not fully specified], 11, 151–155.

Central Statistics Agency . (2024). *Coconut Plantation Company Directory Indonesian Palm Oil 2023* .

Candra, R., Meganningrum, P., Prayudha, M., & Susanti, R. (2019). Innovation new pineapple fruit as alternative replacement pheromones chemical For trap pest borer stem . Agrium, 22(2), 81–85. https://doi.org/10.30596/agrium.v21i3.2456

Fahyurisandi, R., & Neforawati, I. (2020). Design get up door monitoring system PT XYZ warehouse is based on Android using SIM800L device and microcontroller ATmega 328P. Multinetics, 5(1), 37–45. https://doi.org/10.32722/multinetics.v5i1.2793

Kartono, Rusdiyanto, & Utari, W. (2025). The Influence burden work and stress Work to performance nurse through quality service nursing . Journal Student Management and Accounting (JUMMA'45), 4(1), 465–492.

Lestari, W. (2020). The Influence Height Trap Pheromones In Control Bee Rhinoceros (Oryctes Rhinoceros L.) in PT Herfinta Plantation . *Journal Agroplasma, 7* (2), 80–84. https://doi.org/10.36987/agroplasma.v7i2.1846

Lika, NP, Wasiyem, W., & Suraya, R (2025). The Influence Stres Work and Workload on Nurse Performance House Sick General Wulan Windy Medan . Journal of Law, Administration, and Social Science, 5 *(4), 429–439.*

Lima, MCF, Leandro, MEDA, Valero, C., Coronel, LCP, & Bazzo, COG (2020). Automatic detection and monitoring of insect pests—A review. Agriculture, 10(5), 161. https://doi.org/10.3390/agriculture10050161

Parinduri, S., Yosephine, IO, Dai, M., & Nasution, R. (2020). Comparison effectiveness ferotrap, lighttrap and ferolight trap against Oryctes rhinoceros on plants Not yet produce coconut palm oil . *Agrohita Journal, 5* (1), 12–24.

Paudel, S., Jackson, T.A., Mansfield, S., Ero, M., Moore, A., & Marshall, SDG (2023). Use of pheromones for monitoring and control strategies of coconut rhinoceros beetle (Oryctes rhinoceros): A review. Crop Protection, 174. https://doi.org/10.1016/j.cropro.2023.106400

Pertiwi, AS, Suharsono, TN, Syahidin, R., Malik, R., & Paramata, V. (2025). *The Influence burden work and stress Work to performance nurse care stay at home*

Sick General Mutiasari Duri Riau . Journal Nurses, 9 (4), 6878–6886.

Putri, A., Sari, NM, & Yuliana, R. (2023). Relationship burden Work with performance nurse in care nursing . Journal Nursing, 15(2), 123–130.

Sejati, H., Parinduri, S., Ningsih, T., & Margolang, RH (2022). Effectiveness use of fruit traps made from pineapple and various color light as trap bee horns . Journal Agro Estate, 6(1), 27–35. https://doi.org/10.47199/jae.v6i1.99

Sukarman, RJ, Nugraha, AL, & Ramadhan, S. (2025). Utilization solar panel energy for smart gardens based on the Internet of Things using Blynk application . Transmission : Journal Electrical Engineering Science, 27(2), 122–129. https://doi.org/10.14710/transmisi.27.2.122-129

Syaputra, AN, & Martha, L. (2024). The Influence stress work and load Work to performance nurse Bunda Medical Center (BMC) Padang. Journal Research Management, 2(1), 379–398.

Widodo, A., & Sembiring, E. (2024). The Influence burden Work to performance nurse at home Sick Regional General Journal Health Science, 13(1), 45–52.