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Design And Development of an IoT-Based Drone System For Optimizing Rice Spraying Processes In Sumbawa Regency

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ABSTRACT

The manual spraying of liquid fertilizer on rice crops still faces challenges in terms of relatively long processing time, high labor requirements, and suboptimal liquid distribution. This study aims to design and develop an Internet of Things (IoT)-based drone system to support the optimization of rice-crop spraying processes for the farmer in Sumbawa Regency. The system uses a Pixhawk autopilot flight controller as the main controller and an ESP32 as a data concentrator, which is integrated with a water flow sensor, ultrasonic sensor, Solid State Relay (SSR), buzzer, 16×2 LCD, and a Flutter application for real-time monitoring and control. The drone carries a hose with four spray nozzles, while the tank and pump are positioned on the ground. A mixed-methods approach was applied through observation, interviews, literature review, and system performance testing in Batu Alang Hamlet, Pernek Village, Sumbawa Regency. At an altitude of 2 meters, the system produced a flow rate of 1.18 L/min with a spray width of 1.8 meters, while at 5 meters it produced 1.20 L/min with a spray width of 2.8 meters. The multi-nozzle configuration provided wider coverage and more uniform distribution, supporting time efficiency and optimization of the spraying process. The Flutter-based monitoring system displayed sensor and system conditions in real time.

INTRODUCTION

The agricultural sector plays a crucial role in Indonesia's economy; however, it continues to face challenges, including low crop productivity, suboptimal resource utilization, and less-than-optimal crop yields. Law No. 7 of 1996 concerning Food states that food security is reflected in the availability of sufficient, safe, evenly distributed, and accessible food for every household. Therefore, the appropriate application of fertilizer is one of the determining factors in crop productivity (Friha et al., 2021; Yang et al., 2021). Liquid fertilizer is widely used by farmers because it is considered more practical and effective than solid fertilizer. However, improper application may have negative impacts on soil and the environment. The application of liquid organic fertilizer in rice farming systems has been reported to increase dry grain yield by 4.4–17.4% (Ahadiyat et al., 2021).

Based on interviews with farmers in Batu Alang Hamlet, Pernek Village, it was found that liquid fertilizer spraying on approximately 3 hectares of rice fields is still carried out manually using spraying machines. This method requires considerable time and labor (Agustina et al., 2024; Ahadiyat et al., 2021). Drone technology integrated with IoT has developed rapidly as a solution for modern agriculture because it can support automated and more uniform spraying over large areas in a shorter period than conventional manual methods (Teoretis et al., 2025). It has also been reported to reduce agricultural operational costs by up to 85% (Farid Bdr et al., 2021).

A previous study by (Widiasari et al., 2020) developed an quadcopter liquid fertilizer spraying prototype using a drone equipped. However, the study primarily focused on the basic spraying function and did not optimize fertilizer distribution uniformity over larger areas (Chen et al., 2021; Meiyanti et al., 2025; Subramanian et al., 2021). Therefore, this study develops the previous system by implementing a multi-nozzle configuration in an IoT-based liquid fertilizer spraying system using a drone. The development is intended to improve fertilization efficiency and liquid fertilizer distribution uniformity over rice fields while comparing its efficiency with the manual spraying method (De Padua et al., 2021; Seo & Umeda, 2021).

LITERATURE REVIEW

The Internet of Things (IoT) is a technology that enables physical devices, sensors, and actuators to be interconnected for real-time data exchange and control. In agriculture, IoT can be applied to monitor system conditions and support decision-making based on data obtained from sensors. The integration of IoT with agricultural equipment also enables remote monitoring, allowing farming activities to be performed in a more controlled and efficient manner (Dwiningtias & Fatoni, n.d.). The use of the ESP32 microcontroller in IoT-based systems is particularly relevant

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because it provides wireless communication capabilities and can integrate various sensors and actuators into a single system(Wibowo et al., 2024).

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have been increasingly developed to support agricultural activities, particularly crop monitoring and spraying. The use of drones enables spraying operations to be performed over relatively large areas without requiring operators to directly access the field. Previous studies on UAV applications in agriculture indicate that this technology has the potential to improve time efficiency and reduce labor requirements compared with conventional methods (Farid Bdr et al., 2021). The development of drone-based spraying systems also indicates that spraying configurations, including the number and arrangement of nozzles, influence the coverage and uniformity of liquid distribution. Therefore, integrating drone technology with IoT and a multi-nozzle configuration represents a promising approach for achieving a more controlled agricultural spraying process.

METHOD

Research Methodology

Figure 1 consists of three main phases: the deductive phase, the design phase, and the evaluation phase. The deductive phase involves data collection, problem formulation, and identification of research needs. The design phase focuses on system design, component development, prototyping, and testing. Finally, the evaluation phase assesses the test results against the established criteria to determine system performance and provide the basis for the final report.

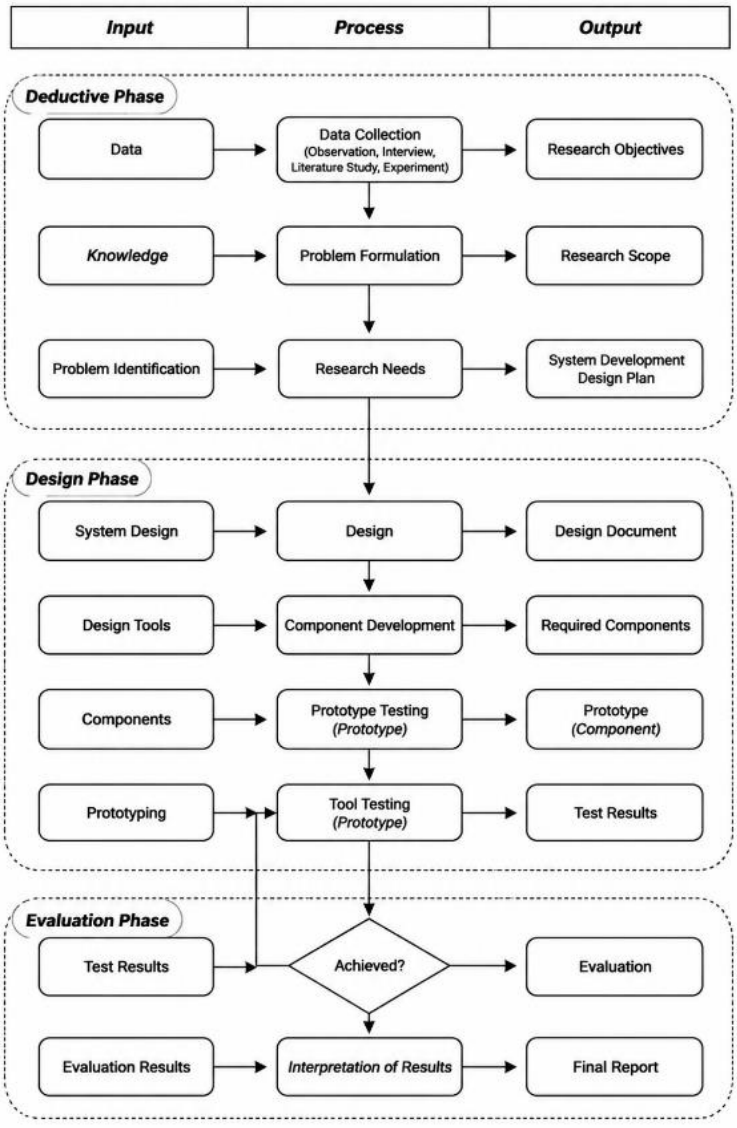


Figure 1. Flowchart of the research

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Data Collection Techniques

Data were collected using four techniques: field observations of agricultural conditions in rice fields, interviews with local farmers regarding fertilizer application requirements and challenges, a literature review of references related to IoT, agricultural drones, and the ESP32 microcontroller, and direct experiments involving the design, development, and testing of the prototype (Erawati et al., 2025; Ula et al., 2025).

Research Equipment and Materials

The prototype was developed using several tools and materials as depicted below

Table 1. Basic Equipment

No	Equipment	Quantity
1	Laptop	1 unit
2	Scissors	1 unit
3	Soldering iron	3 units
4	Screwdriver (+/−)	3 units
5	Arduino IDE	1 application
6	ESP32	1 unit
7	16×2 LCD	1 unit
8	Water Flow Sensor	1 unit
9	Water Pump	1 unit
10	Battery	1 unit
11	Drone	1 unit
12	Ultrasonic Sensor	1 unit
13	Buzzer	1 unit

Table 1 presents the equipment used in the development of the prototype, consisting of hardware components, software, and supporting tools. A laptop and Arduino IDE were used for programming and system configuration, while the ESP32 served as an electronic component in the prototype development. The main supporting components included a 16×2 LCD for displaying system information, a water flow sensor for detecting water flow, a water pump for pumping operations, a battery as the power source, an ultrasonic sensor for distance measurement, and a buzzer for providing warning signals. In addition, tools such as a soldering iron, screwdrivers, and scissors were used during the assembly and installation processes. These equipment items supported the overall development process, including system design, component assembly, programming, and prototype testing.

Table 2. Basic Materials

No.	Material	Quantity
1	Nails	1 kg
2	Hose	15 m
3	Tank	1 unit
4	Screws	1 kg
5	Solder wire	1 roll
6	Black electrical tape	1 roll
7	Double-sided tape	1 roll

Table 2 lists the basic materials required for the prototype assembly and construction. These materials consist of mechanical, plumbing, and electrical supporting materials. Nails and screws were used to support the installation and fastening of structural components, while the hose served as a channel for water flow and the tank was used as a water storage container. Solder wire was utilized to support electrical connections between components. Meanwhile, black electrical tape and double-sided tape were used for electrical insulation and component mounting purposes. These materials supported the physical construction, installation, and integration of the prototype components.

System Design

The system was designed to control the liquid fertilizer spraying process on rice crops using an IoT-based drone. The drone functions only as a carrier for the hose and spray nozzles, while the liquid fertilizer tank and pump are positioned on the ground. The battery serves as the primary power source and supplies electrical power to the Solid State Relay (SSR), which controls the water pump, as well as to the ESP32 as the main control unit.

The ESP32 processes data obtained from the water flow sensor to determine the fertilizer flow rate and from the ultrasonic sensor to monitor the fertilizer level inside the tank. When an empty-tank or low-flow condition is detected, the buzzer is activated as a warning. Meanwhile, the 16×2 LCD displays the system status directly, and the Flutter application displays the same information in real time through a Wi-Fi connection (Friha et al., 2021; Pratama et al., 2021).

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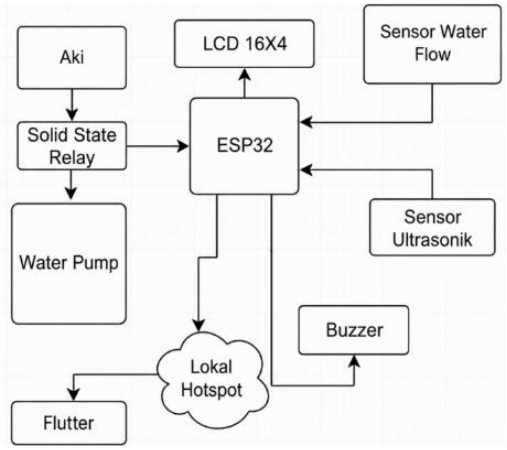


Figure 2. The system diagram

RESULT

Prototype Design Results

The IoT-based multi-nozzle liquid fertilizer spraying drone prototype was successfully developed as an integrated system consisting of mechanical components, electronic components, and software. The mechanical system includes the frame, tank, and nozzles, while the electronic system consists of the ESP32, sensors, and actuators. The software system consists of the ESP32 program and Flutter monitoring application.

The ESP32 functions as the central controller responsible for processing sensor data, controlling the water pump, activating the buzzer when necessary, displaying system status on the LCD, and transmitting monitoring data to the application through a Wi-Fi connection.

Based on the implementation results, the drone was able to carry a hose equipped with four nozzles while maintaining stable flight. The water pump was also able to produce a continuous and stable fertilizer flow without a noticeable decrease in performance during testing.

Table 3. Specification of the Control System Components

No.	Component	Specification	Function/Description
1	Solid State Relay	3–32 V DC	Electronic switch for controlling the DC pump based on ESP32 commands
2	Component Box	Dust- and water-resistant plastic	Housing for the electronic components, including ESP32, SSR, cables, and modules
3	Ultrasonic Sensor	5 V DC; detection range 2–400 cm	Measures the distance between the fertilizer surface and the upper part of the tank
4	Water Flow Sensor	5–18 V DC; 1–30 L/min	Measures the liquid fertilizer flow rate through the pipe
5	Buzzer	3.3–5 V	Audible indicator when the fertilizer volume falls below the minimum threshold
6	16×2 LCD	5 V	Displays pump status, flow rate, and fertilizer volume in real time
7	ESP32	3.3 V; Wi-Fi & Bluetooth	Main system controller and data transmitter to the Flutter application
8	Battery	12 V DC	Main power source for the DC pump, ESP32, and sensors
9	Water Pump	12 V DC; 18 W	Pumps liquid fertilizer from the tank to the nozzles
10	Tank	20 L; empty weight approximately 0.8–1.2 kg	Stores liquid fertilizer during spraying

Table 3 presents the specifications and functions of the main components used in the prototype's control system. Each component plays a specific role in supporting the operation, monitoring, and control of the liquid fertilizer distribution process. The ESP32 acts as the main controller and transmits system data to the Flutter application through Wi-Fi and Bluetooth connectivity. The solid-state relay (SSR) functions as an electronic switching device to control the DC water pump based on commands from the ESP32. An ultrasonic sensor is used to measure the distance between the fertilizer surface and the upper part of the tank, enabling the system to monitor the remaining fertilizer volume. Meanwhile, the water flow sensor measures the flow rate of liquid fertilizer passing through the pipe. The measured parameters are displayed in real time on the 16×2 LCD, while the buzzer provides an audible warning when the

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fertilizer volume falls below the minimum threshold. The battery supplies electrical power to the pump, ESP32, and sensors, while the component box protects the electronic components from dust and water exposure. The water pump delivers liquid fertilizer from the storage tank to the distribution nozzles. These components are integrated to establish an automated control and monitoring system for liquid fertilizer distribution.

Results of Ultrasonic Sensor, Water Flow Sensor, and Buzzer Testing

Testing was conducted to evaluate the ability of the ultrasonic sensor, water flow sensor, and buzzer to detect and respond to tank conditions in real time.

Table 4. Sensor Testing Time

Test Time	Ultrasonic Sensor Distance	Flow Rate	Total Volume	Buzzer Condition	Description
13:00	29 cm	–	–	Off	Water at threshold level; refilling required
13:01	28 cm	–	–	Off	Water at threshold level; refilling required
13:03	–	0.21 L/min	31.37 L	–	Flow measurement operating normally
13:04	20 cm	–	–	Off	Water at threshold level; refilling required
13:06	–	0.00 L/min	31.37 L	–	Flow stopped; volume remained constant
13:07	3 cm	–	–	On	Tank full; normal condition
13:09	18 cm	–	–	On	Sufficient volume; normal condition

Table 4 presents the results of testing the ultrasonic sensor, water flow sensor, and buzzer at different time intervals. The ultrasonic sensor recorded distance measurements of 29 cm, 28 cm, 20 cm, 3 cm, and 18 cm, indicating variations in the fertilizer level inside the tank. The water flow sensor recorded a flow rate of 0.21 L/min at 13:03, while at 13:06 the flow rate decreased to 0.00 L/min, indicating that the liquid flow had stopped. During this period, the recorded total volume remained at 31.37 L. The buzzer condition and descriptions in the table also indicate the system's response to different tank conditions. At 13:07, the ultrasonic sensor recorded a distance of 3 cm, corresponding to the tank-full condition, while at 13:09, a distance of 18 cm was recorded and the system indicated sufficient fertilizer volume. Overall, these measurements demonstrate the operation of the sensors in monitoring fertilizer levels and flow conditions during the testing process. All components functioned properly without significant problems, indicating that the integration among the components was successfully implemented and enabled the system to operate as intended.

Battery Test Results

Battery testing was conducted to determine the ability of the power source to supply the water pump during the spraying process.

Table 5. Battery Testing

No.	Operating Time Range	Operating Duration	Battery Status	Tank Condition
1	13:00–13:09	9 minutes	Normal	Functional
2	10:23–10:28	6 minutes	Normal	Functional
3	11:24–11:27	4 minutes	Normal	Functional

Table 5 presents the results of battery testing conducted to evaluate the battery's ability to supply power during continuous pump operation. The testing was performed over three different operating periods, with durations of 9, 6, and 4 minutes, respectively. Throughout these tests, the battery status remained normal, while the tank maintained its functional condition. These findings indicate that the power supply was able to support the pump operation during the observed testing periods without causing system interruptions. The results also demonstrate that the battery and tank operated reliably under the tested conditions. However, further testing with continuous voltage and current measurements is necessary to determine the actual battery discharge characteristics and estimate its maximum operating duration.

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ESP32 Test Results

Testing of the ESP32 focused on data communication stability, power consumption, and its ability to execute all programmed functions simultaneously.

Table 6. ESP32 Testing

No.	Test Parameter	Status	Description
1	ESP32 power-on	Successful	The system can be powered on normally
2	Wi-Fi connection	Successful	ESP32 successfully connects to the network
3	Sensor readings	Successful	Water flow and ultrasonic sensors are detected properly
4	Actuator control	Successful	Pump and buzzer are controlled according to ESP32 commands

Table 6 shows the ESP32 testing results, which were conducted to evaluate its functionality as the main controller of the developed system. Four parameters were examined, including power-on operation, Wi-Fi connectivity, sensor data acquisition, and actuator control. All parameters achieved successful results. The ESP32 was able to power on normally, establish a connection to the Wi-Fi network, receive readings from the water flow and ultrasonic sensors, and control the pump and buzzer according to the programmed commands. These results confirm that the ESP32 can perform its intended functions as the central control unit and facilitate communication between the sensors, actuators, and the application. Therefore, the ESP32 provides the necessary control and communication capabilities for the overall system operation.

Drone Test Results

Drone testing was conducted to evaluate the performance of the drone as a liquid fertilizer spraying platform using a hose-spraying system. In this configuration, the drone only carries the hose, which is connected to an electric tank positioned on the ground.

Table 7. Drone Testing

Drone Altitude	Drone Speed	Flow Rate	Spraying Status	Result
2 m	1.0 m/s	1.18 L/min	Smooth	Successful
5 m	1.5 m/s	1.20 L/min	Stable	Successful

Table 7 presents the drone testing results, which were conducted to evaluate its flight performance while carrying the spraying hose connected to a ground-based electric pump. The tests were performed at two different flight altitudes, namely 2 m and 5 m. At an altitude of 2 m, the drone operated at a speed of 1.0 m/s, producing a flow rate of 1.18 L/min with smooth spraying performance. Meanwhile, at an altitude of 5 m, the drone operated at a speed of 1.5 m/s, with a flow rate of 1.20 L/min and stable spraying performance. Both tests achieved successful results, indicating that the drone was able to maintain flight stability while carrying the spraying hose at different altitudes and speeds. The relatively consistent flow rates also suggest that changes in flight altitude and speed did not substantially affect the liquid delivery during the tested conditions. These findings demonstrate the feasibility of using the drone as a mobile spraying platform in the developed system.

Multi-Nozzle Spraying Test Results

The spraying tests were conducted to evaluate liquid flow performance and spray consistency produced by the multi-nozzle configuration.

Table 8. spraying testing

Trial	Drone Altitude	Spray Width	Condition
1	2 m	1.8 m	Even
2	5 m	2.8 m	Very even

Table 8 presents the results of multi-nozzle spraying tests conducted to evaluate the spray distribution and coverage area at different drone altitudes. Two testing trials were performed at altitudes of 2 m and 5 m. At an altitude of 2 m, the spraying system produced a spray width of 1.8 m with an even distribution. When the altitude was increased to 5 m, the spray width expanded to 2.8 m, while the spraying condition remained very even. These results indicate that increasing the drone altitude resulted in a wider spray coverage area under the tested conditions, without noticeably compromising spray distribution uniformity. The findings demonstrate that the multi-nozzle configuration can provide relatively consistent spraying performance while expanding the coverage area at greater flight altitudes. This characteristic is beneficial for improving the efficiency of liquid fertilizer application over wider agricultural areas.

Overall System Test Results

The overall system test was performed by operating the entire system simultaneously, starting from liquid fertilizer filling, ESP32 connection to the Flutter application, drone takeoff, and the spraying process. Sensor data were

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displayed in real time through the application.

Table 9. Overall System

Component	Status
Drone	Successful
Spraying Hose	Successful
Tank	Successful
Pump	Successful
SSR-40 DD	Successful
Ultrasonic Sensor	Successful
ESP32	Successful
Water Flow Sensor	Successful
Flutter Application	Successful

Table 9 summarizes the overall system testing results by evaluating the functionality of all major hardware and software components integrated into the developed liquid fertilizer spraying system. The evaluated components include the drone, spraying hose, tank, pump, SSR-40 DD, ultrasonic sensor, ESP32 microcontroller, water flow sensor, and Flutter application. All components achieved successful test results, indicating that each subsystem was able to perform its intended function during system operation. The successful performance of the drone and spraying hose demonstrates the feasibility of the aerial spraying mechanism, while the tank and pump support the liquid storage and distribution processes. Furthermore, the sensors and ESP32 facilitate data acquisition and system control, whereas the Flutter application provides the user interface for system monitoring and operation. Overall, these results confirm that the hardware and software components can operate together as an integrated system, demonstrating the functionality of the developed prototype under the tested conditions.

DISCUSSION

Based on the design, development, and testing stages, the IoT-based liquid fertilizer spraying prototype using a multi-nozzle drone was successfully developed according to the research objectives. All major components, including the ESP32, water flow sensor, ultrasonic sensor, SSR, water pump, LCD, buzzer, Flutter application, and multi-nozzle system, functioned and interacted according to the initial design.

The ESP32 successfully performed its role as the central control unit by processing sensor data, controlling the water pump through the SSR, and transmitting sensor readings to the monitoring application in real time via Wi-Fi. The ultrasonic sensor provided consistent measurements of changes in fertilizer volume inside the tank. As the fertilizer volume decreased, the measured distance increased. When the fertilizer volume fell below the minimum threshold, the system automatically activated the buzzer to provide a warning and help prevent the pump from operating without sufficient liquid.

The implementation of the multi-nozzle system also demonstrated an improvement in spraying effectiveness. Compared with a single-nozzle configuration, multiple nozzles operating simultaneously expanded the spraying coverage during a single drone flight path. Consequently, the spraying time could be reduced while achieving a more even fertilizer distribution across the crop surface.

CONCLUSION

Based on the design, implementation, and testing of the IoT-based liquid fertilizer spraying prototype for rice crops using a drone with a multi-nozzle system, several conclusions can be drawn. First, the prototype was successfully designed and implemented by integrating an ESP32, water flow sensor, ultrasonic sensor, SSR, water pump, 16×2 LCD, buzzer, and Flutter-based monitoring application into a unified system. Second,

the ESP32 successfully functioned as the central control unit by reading sensor data, controlling the water pump through the SSR, displaying system information on the LCD, and transmitting data to the monitoring application in real time. Third, the water flow sensor was able to measure the liquid fertilizer flow rate delivered to the multi-nozzle system, while the ultrasonic sensor was able to monitor the volume of liquid fertilizer inside the tank, allowing the fertilization process to be monitored and controlled more effectively. Fourth, the implementation of the multi-nozzle system on the drone produced more uniform liquid fertilizer spraying compared with the single-nozzle configuration, while also improving spraying time efficiency and reducing labor requirements during the rice fertilization process.

For future development, a camera can be added to the drone to enable real-time monitoring of crop conditions. The fertilizer tank may also be mounted directly on the drone to improve system mobility. In addition, altitude or wind-speed sensors can be incorporated so that the spraying process can be adjusted more effectively according to environmental conditions.

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