TELKOMNIKA Telecommunication Computing Electronics and Control
Vol. 23, No. 2, April 2025, pp. 455~465
ISSN: 1693-6930, DOI: 10.12928/TELKOMNIKA.v23i2.26529

Prototype of alternate wetting and drying rice cultivation using internet of things for precision agriculture

Akkachai Phuphanin, Metha Tasakorn
Department of Electrical Engineering, Faculty of Industry and Technology, Rajamangala University of Technology Isan, Sakon Nakhon, Thailand

Article Info

Article history:

Received Aug 5, 2024
Revised Dec 6, 2024
Accepted Dec 26, 2024

Keywords:

Alternate wetting and drying
Encrypted secure protocol-network over wireless protocol
Internet of things
Irrigation
Precision agriculture
Sensor networks

ABSTRACT

This study introduces a semi-automatic system for alternating wet and dry rice cultivation using internet of things (IoT) technology to enhance precision agriculture and address critical challenges in water resource management. The prototype consists of node and master devices powered by ESP32 microcontrollers integrated with sensors to monitor air temperature, humidity, and water levels. Communication between the devices is achieved through the low-latency, low-power encrypted secure protocol-network over wireless (ESP-NOW) protocol, enabling real-time monitoring and remote control of water pumps. Data collected by the system is displayed on ThinkSpeak servers and Nextion touch screens, aiding efficient irrigation and environmental management for farmers. Performance testing demonstrates that the system achieves reliable communication up to 115 meters with efficient energy consumption, operating for approximately two hours with a 3,000 mAh battery. By optimizing irrigation practices, the system reduces water waste while ensuring adequate crop hydration, promoting sustainable farming practices. This scalable IoT solution not only enhances productivity and resource efficiency but also contributes to broader efforts in agricultural sustainability by supporting precise environmental control and minimizing dependency on manual labor.

Corresponding Author:

Metha Tasakorn
Department of Electrical Engineering, Faculty of Industry and Technology
Rajamangala University of Technology Isan
Sakon Nakhon Campus, 47160, Thailand
Email: metha.ta@rmuti.ac.th

1. INTRODUCTION

Climate change is increasingly unpredictable, directly affecting water storage and management worldwide. This uncertainty impacts water systems both directly and indirectly, posing challenges for efficient water use, especially as water resources are expected to become critically limited. Enhancing irrigation efficiency and cultivating crops that minimize water loss are key strategies. In ASEAN countries, where rice is a primary economic crop, popular methods like alternating wet and dry farming, also known as “teasing rice,” help conserve water and are gaining popularity. Given rice’s water-intensive nature and its economic importance, finding sustainable irrigation solutions is essential for agricultural resilience and food security amid escalating water scarcity concerns.

Alternating wetting and drying (AWD) is a water-saving technique that periodically allows rice fields to dry out between irrigation cycles, instead of remaining continuously flooded [1]. While similar intermittent flooding practices have existed for decades, the International Rice Research Institute (IRRI) established official AWD guidelines in 2002. Research in the Philippines has shown that AWD can reduce irrigation hours by about

38% without significantly affecting yield or profits, leading to substantial savings in water and energy [2]. Additionally, combining AWD with rice straw and manure increases grain yield by 64%, even with reduced fertilizer and straw inputs, achieving a 51% yield boost compared to conventional flooding [3]. Although AWD is highly effective for water conservation, challenges in monitoring and control hinder its widespread adoption.

Technology is increasingly used to enhance agricultural production processes, particularly through the internet of things (IoT), which can improve efficiency and yield rates. Government initiatives encourage large rice farmers to adopt IoT to boost export potential, promoting innovations like precision irrigation, environmental monitoring, and crop health management to increase resource efficiency in rice farming [4], [5]. For widespread adoption, IoT systems should be scalable and cost-effective, with carefully chosen sensors, actuators, and communication technologies [6], [7]. Advanced data processing methods, such as machine learning (ML) and artificial intelligence (AI), are crucial for precision agriculture, alongside fog/edge computing and software-defined networking (SDN), which support decision-making [8]-[10]. Integrating IoT with AWD offers real-time monitoring and control, addressing the limitations of traditional irrigation methods and improving agricultural productivity and sustainability.

In IoT technology, effective communication is essential for devices to interact with systems and users. The choice of communication method depends on factors like device type, distance, data speed, and power limitations. Wi-Fi, for instance, is widely used for connecting IoT devices to the Internet, offering compatibility with many devices and high data rates [11]-[13]. Bluetooth, with low data rates but low power consumption, is ideal for short-range communication, often linking sensors to mobile devices for local data collection, commonly used in industrial field equipment [14]. Zigbee is frequently chosen for home smart systems, such as lighting or humidity sensors, as it supports up to 64,000 devices with low power usage and short-range communication [15]. For long-distance communication, long range (LoRa) connects IoT devices over wide areas and is particularly suitable for applications needing minimal data transmission, like environmental sensors measuring weather conditions [16]. Another option, encrypted secure protocol-network over wireless (ESP-NOW), developed by espressif for ESP32 and ESP8266 devices, is efficient for specific IoT applications due to its reliable performance. In agriculture, however, IoT implementation faces challenges. High costs, network complexity, and the difficulty of maintaining connectivity across large, often remote fields can hinder adoption. Agricultural IoT systems must balance power efficiency with the need for real-time data transmission, especially in rural areas with limited power and network infrastructure. Therefore, developing cost-effective, scalable solutions that conserve resources while ensuring reliable communication is crucial for IoT in agriculture.

The ESP-NOW protocol operates on the 802.11 wireless standard at 2.4 GHz, transmitting data up to 250 bytes at a rate of 1 Mbps over distances of up to 220 meters [17]. This low-latency, direct communication protocol does not require a Wi-Fi network, supporting both broadcast and unicast communication with encryption for secure data exchange. Ideal for IoT applications, sensor networks, and home automation, ESP-NOW enables efficient peer-to-peer communication with minimal setup, making it a practical choice for situations that demand fast, reliable data transfer. Studies highlight its use in smart home systems for device control via an ESP-NOW mesh network [18] and in residential monitoring for alerts on intrusions, gas leaks, or fires [19]. However, factors like system design, algorithms, and environmental conditions—such as reflections and obstacles—can affect transmission efficiency [20]. To overcome these challenges, this research proposes a semi-automated AWD system that integrates IoT. Using ESP32 microcontrollers, the system monitors temperature, humidity, and water levels in rice fields. Node and master devices communicate through the ESP-NOW protocol, chosen for its low latency and energy efficiency, supporting prolonged field deployment. Data from the system is visualized on ThinkSpeak servers, enabling farmers to remotely manage irrigation with precision, which could enhance AWD adoption rates.

The reviewed literature emphasizes the growing role of IoT technology in precision agriculture, particularly in selecting suitable communication protocols and evaluating system performance across environments. This article introduces a semi-automated wet and dry rice cultivation prototype using IoT, with a focus on evaluating the ESP-NOW wireless communication protocol's efficiency within this system. The article is organized as follows: system overview and algorithm, prototype performance experiments, structure connection design, result and discussion and finally conclusion. This study enhances precision agriculture by offering a practical, scalable IoT solution tailored for rice farming. By addressing the limitations of traditional AWD methods and high-cost IoT implementations, it aims to promote water conservation and improve rice production sustainability.

2. SYSTEM OVERVIEW AND ALGORITHM

An overview of the prototype semi-automatic wet and dry rice cultivation system using IoT technology is shown in Figure 1. The system consists of two parts. The first part is a node device with an ESP32 (node) connected to sensors that measure air temperature and humidity, an ultrasonic water level sensor, and a relay module for water pump control. It is powered by a 7.4-volt Li-Po battery, with the voltage reduced to 5V using a step-down DC-DC converter and connected to the micro-USB port of the ESP32. The second part is the master device, which includes an ESP32 (master) connected to real time clock and touch display module. Communication between the ESP32 (master) and the ESP32 (gateway) is achieved via the inter-integrated circuit (I^2C) Protocol to send data to the ThinkSpeak server, where it is displayed on a dashboard for monitoring. The node device and the master device communicate via the ESP-NOW protocol, designed for ESP microcontroller devices. This protocol is low-cost, low-latency, and low-power, but powerful enough for sending and receiving sensor data, making it suitable for a wide range of applications [21]-[23].

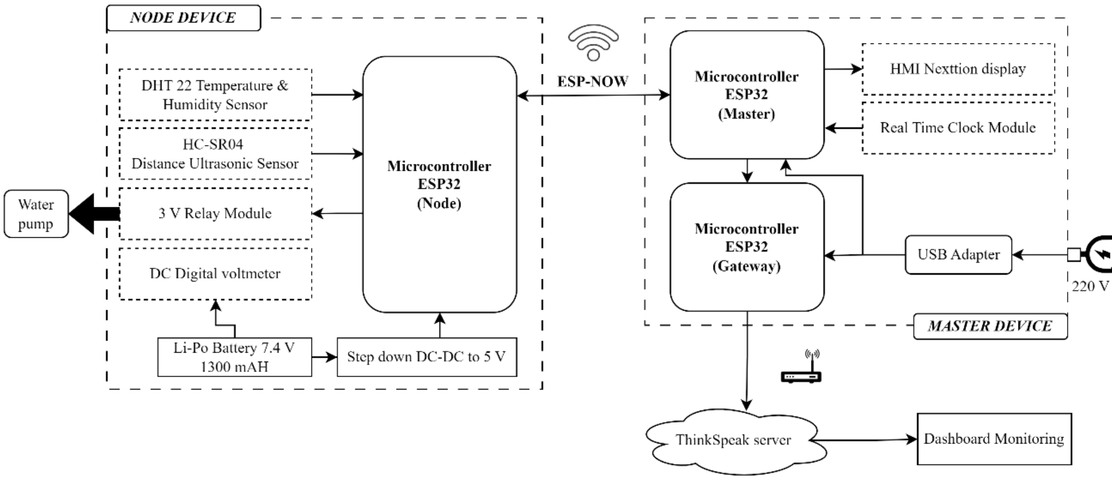
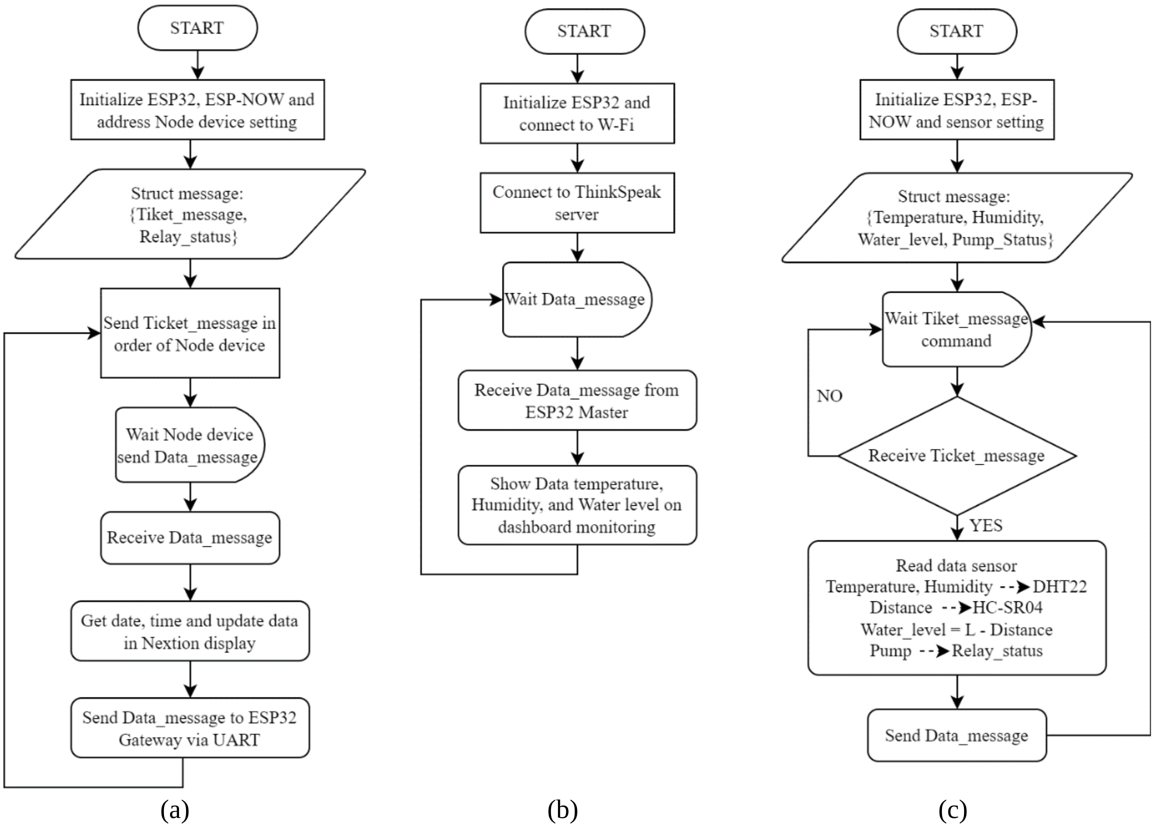


Figure 1. Overview of a semi-automatic alternating wet and dry rice planting system using IoT

The prototype system for semi-automatic alternating wet and dry rice cultivation using IoT technology comprises three ESP32 microcontroller boards, each with distinct functions. The ESP32 (master) device is responsible for communication using the ESP-NOW two-way communication protocol to receive data and display results. The process begins with setting up the ESP32 and ESP-NOW communication, including specifying the addresses of the node devices on the network. The message structure to be sent is then defined. This structure includes the Tiket_message, which acts as a command ticket for the receiving node device to send data back to the master device. The Tiket_message is sent in a loop to each node device in sequence. Another command sent to the node devices is the Relay status command, allowing the user to control the water pump remotely. After the ticket message is sent, the master device enters a waiting state, anticipating data from a node device. Upon receiving the data, the master device reads the time value, updates the display, and sends the data to the ESP32 (gateway). This process repeats for the number of node devices, as illustrated in Figure 2(a).

Figure 2(b) illustrates the flowchart of the ESP32 (gateway). Once the ESP32 is set up and connected to Wi-Fi. In our system, Wi-Fi connectivity is facilitated by a 4G LTE router acting as a hotspot to distribute the signal. A separate ESP32 microcontroller serves as a dedicated gateway, enabling efficient management and minimizing errors that could arise if a single microcontroller were tasked with simultaneously handling both ESP-NOW and Wi-Fi connections. The network name and password are pre-configured in the program for seamless integration. The system connects to the ThinkSpeak server and waits to receive data from the master device via wired I^2C communication. Upon receiving a Data_message, it displays temperature, humidity, and water level. The node device, equipped with an ESP32 (node), waits to receive commands, specifically the Ticket_message, from the master device. Upon receipt, it reads the temperature and humidity data from the DHT22 sensor and the distance value from the ultrasonic sensor. The water level is calculated by subtracting the distance read from the sensor from the length of the pipe. Additionally, the water pump’s operating status is determined from the Relay status. Once all information is obtained, it is formatted into strings and sent via the ESP-NOW protocol, as depicted in the flowchart in Figure 2(c).

The separation of functions between the ESP32 (master), which uses the ESP-NOW protocol for two-way communication, and the ESP32 (gateway), which uses Wi-Fi communication, is intended to enhance system stability and simplify algorithm development. Communication between the master device and node devices is designed such that data transmission from each node device occurs only upon request from the master device. This approach minimizes the risk of simultaneous data transmission from multiple node devices, which could lead to data loss and prevent the master device from receiving data. Additionally, this system can support the integration of additional node devices in the future.



(a) (b) (c)

Figure 2. Flowchart of the prototype of a semi-automatic alternating wet and dry rice planting system using IoT; (a) ESP32 master device, (b) ESP32 gateway, and (c) ESP32 node device

3. PROTOTYPE PERFORCEMANCE EXPERIMENTS

To study and test the performance of the wireless communication system using the ESP-NOW protocol, we created a preliminary test kit consisting of a node device equipped with all necessary sensors and devices to measure power consumption and range. Data is transmitted via the ESP-NOW protocol from the node device. The principle for testing energy use involves measuring the voltage across a 1-ohm resistor (actually measured at 0.9 ohms) connected in series between the power supply and the system [17]. The receiver is equipped with an organic light-emitting diode (OLED) screen to display the temperature, humidity, and received signal strength indicator (RSSI) values received from the node device. Additionally, the relay status and data transmission are indicated using light-emitting diodes (LEDs), as shown in Figure 3. The receiver does not require energy use testing because it utilizes a 220-volt home power supply.

The performance testing of the prototype system for semi-automatic alternating wet and dry rice cultivation using IoT technology was conducted in terms of energy consumption in transmitting data over a wireless network. The node device data consists of temperature (4 bytes), humidity (4 bytes), water level (4 byte) and water pump operating status (4 bytes), totaling 16 bytes. The power consumption test considered two cases: one where all devices and sensors were connected but no data was transmitted, and the second where 16 bytes of data were sent. In each case, a total of 30 data points were collected to find the average. The average power consumption was calculated by multiplying the current (According to Ohm’s law, once the voltage measurement is obtained and the resistor value is known, the current can be calculated) by the voltage from the battery (7.44 volts). The test results showed that the power consumption during no data transmission was 1442.54 mW, while the power consumption during data transmission by the node device was 1489.98 mW. Since our system uses additional sensor modules, it has a higher power consumption compared to the study [17] that considered the transmission of 200 bytes (the maximum) of data and did not account for power consumption from other sensor modules.

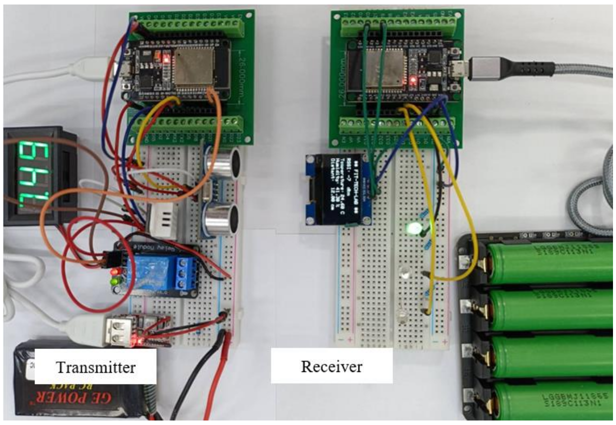


Figure 3. System performance testing kit

From the test data, the difference in power consumption between the two cases was found to be 47.44 mW, which is smaller than the difference observed in the study [17]. This indicates that the amount of data sent affects energy consumption, but the relationship is not linear. Factors such as transmission time, packet size, transmission frequency, and environment also influence this relationship. Performance mechanisms of the protocol, such as packet size management and acknowledgment, play a role in determining overall energy use. If data is sent every hour, we calculate the average power consumption over this period.

$$P_{avg} = \frac{P_{tx}+P_{idle}}{2} \tag{1}$$

When P_{tx} is the power consumption during data transmission and P_{idle} is the power consumption during idle state. From the test results, it can be calculated P_{avg} as 1,466.26 mW. Now, to find the battery life (L) in hours:

$$L = \frac{Battery\ capacity}{P_{avg}} \tag{2}$$

Therefore, with a 3,000 mAh. battery capacity and considering the average power consumption, the battery can last approximately 2.04 hours (approximately 2 hours and 2 minutes) under the described operating conditions, where data is sent every hour.

Figure 4 shows the relationship between distance and the acceptable RSSI value. The test is divided into two cases. The first case involves data transmission between the receiver and transmitter without any packaging (no obstacles). The second case involves data transmission with the device installed in a PVC plastic box (as used in actual conditions) for both the receiving and transmitting parts. Both test cases were conducted on an open walkway, with RSSI values measured at each location 10 times and averaged. The results indicate that RSSI values decrease as distance increases, characterized by an exponential decline. At the starting point of 5 meters, the RSSI values in both cases were -50.7 and -51.8 dBm, respectively, showing a slight difference. However, as the distance increases, the rate of decline for the case with the box is noticeably greater than that for the case without the box. Tests showed that when the RSSI value is lower than -90 dBm, data transmission in both cases sometimes fails. This conclusion is based on 10 transmission attempts, where not all attempts succeeded, which is consistent with previous research [17], [24] that identified -90 dBm RSSI as a critical threshold for reliable data transmission. When considering the maximum distance for both cases, it was found that without the box, data can be transmitted up to 135 meters. With the box, data can be transmitted via the ESP-NOW protocol up to 115 meters. However, the maximum distance for data transmission depends on various factors, such as grassy areas, walkways, balconies, or playgrounds [25]. Even testing in the same open area may yield different maximum distances. We can model the relationship between distance and RSSI value, which can accurately characterize the actual condition of RSSI in position estimation space. RSSI is inversely proportional to the distance d between the transmitter and receiver in two-dimensional space. In this model, the equation accounts for the effect of obstructions, known as the log-normal shadowing model [26]. The received power $RSSI(d)$ is related to the distance d through the following model [27].

$$RSSI(d) = RSSI(d_0) - 10\lambda \log\left(\frac{d}{d_0}\right) + \zeta_\sigma \tag{3}$$

Where $RSSI(d_0)$ is the transmitted power in dBm received at the reference position d_0 in meters. λ is the path loss exponent, which depends on the surrounding environment and varies between 1.4 and 5.1 for outdoor settings. ζ_σ represents a Gaussian distribution of random variables with a standard deviation σ. For outdoor environments, ζ_σ ranges from 1.73 to 3.32, as indicated in Table 1 [25]. To study the efficiency of the prototype system for semi-automatic alternating wet and dry rice cultivation using IoT technology, this research simulates a mathematical model to calculate the RSSI value corresponding to the system, shown by the green line. The $RSSI(d_0)$ measured at a reference distance (d_0) of 5 meters is -51.8 dBm (with case), with λ=1.9 and ζ_σ=3.32 (playground). It can be observed that when the RSSI value is greater than -80 dBm, the simulation results from the mathematical model closely match the actual measurement results. This mathematical model can be used as a reference for determining the installation distance between the master device and the node device.

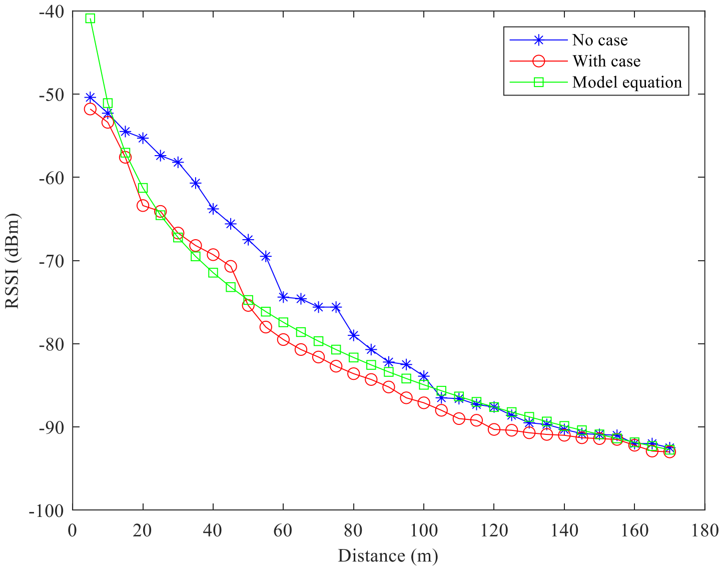


Figure 4. RSSI measurement of testing kit

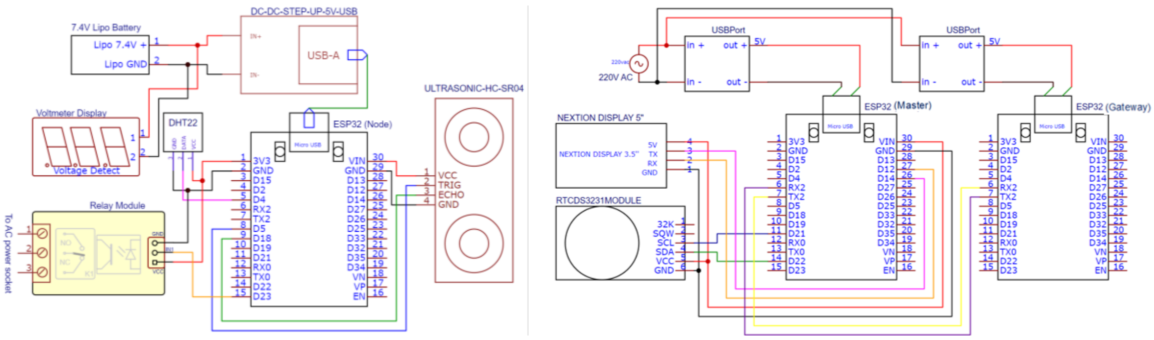
Table 1. λ and ζ_σ value for different condition

Condition	λ	ζ_σ
Lawn	4.6~5.1	1.67~2.23
Balcony	1.4~2.4	2.00~4.00
Laboratory	1.4~2.2	2.39~3.46
Playground	1.9~2.2	1.73~3.32

4. STRUCTURE AND CONNECTION DESIGN

This section discusses the design process involved in connecting the hardware and structure of a prototype semi-automatic wet and dry rice cultivation system using IoT technology. Figure 5 shows the circuit connections: Figure 5(a) node device circuit connections: The node device uses a 7.4-volt battery power supply. A voltmeter is connected to the battery to display the voltage status of the system. The ultrasonic sensor and DHT22 sensor are connected to the digital pins of the ESP32 board, which serve as inputs, and use the 5V and 3.3V outputs from the ESP32 as their power supply. The relay, which controls the operation of the water pump, is connected to a digital pin as an output and uses a 3.3 V supply. Figure 5(b) master device circuit connections: The master device is powered by a 220-volt house power supply, using a voltage converter to step down to 5 volts for connection to the ESP32 boards. A real-time clock module, driven by a 5-volt supply, uses I^2C serial communication through two digital pins, which serve as input pins. The Nextion touch-screen display communicates data via two digital pins using the RS232 standard, which supports full-duplex data transmission, allowing simultaneous sending and receiving of data. The display also uses a 5-volt supply from the ESP32.

Figure 6 shows the structure and placement of the node device. The main structure is a 4-inch PVC pipe with holes drilled at the end to allow water to flow into the pipe. At the top is a cone-shaped tube that holds the circuit board. A hole is drilled in the side to install a male power plug for connecting the water pump and DHT22 sensor. The top threaded cap is equipped with a voltmeter and an on-off switch. The length of the pipe is measured from the tip of the ultrasonic sensor to the end of the pipe, totaling 50 centimeters. The water level can be determined by subtracting the distance measured by the sensor from the length of the pipe. However, the length tube will change as the pipe is inserted into the ground.



(a) (b)

Figure 5. Schematic circuit diagram of; (a) node device and (b) master device

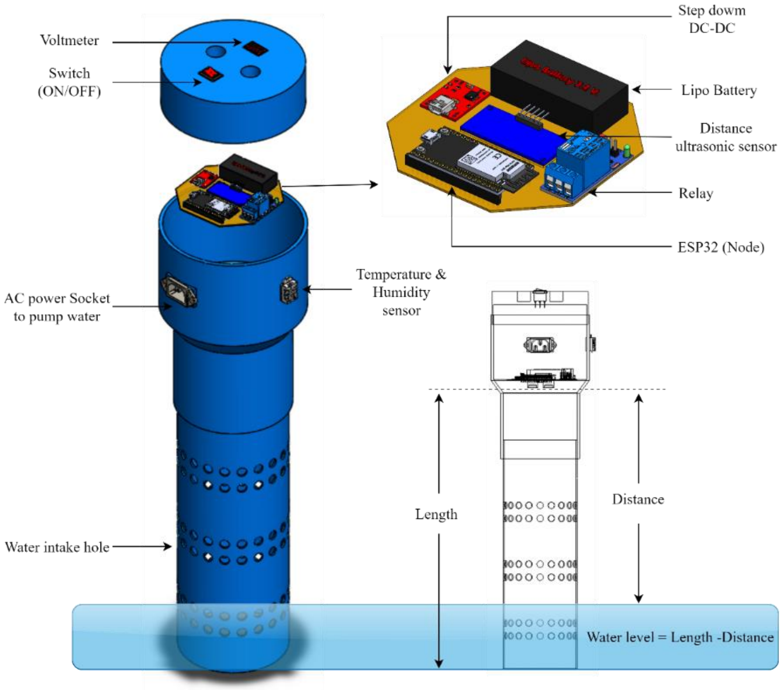


Figure 6. Structure of node device prototype alternate wetting and drying rice cultivation using IoT

5. OPERATION AND DISPLAY

For the NEXTION touch-screen display, we designed a total of four display screens, as shown in Figure 7. The first screen shows the time and date retrieved from the real time clock, along with a login button. When the login button is pressed, the second page appears, where a 4-digit password must be entered. After entering the password, pressing the enter button (bottom left) will take you to the third page if the code is correct. The third page displays all the node sensors in the network installed in the rice fields. You can press the check-in button (red) to go to the fourth page, which shows the temperature, humidity, and current water levels in the fields. Additionally, there is a water pump control button to manage water levels in the rice fields according to the desired settings. Pressing the number 1 button on the display will pump water into the rice fields until the set level is reached, while pressing the number 2 button will pump water out of the rice fields. As shown in Figure 8, all four screens were designed using the Nextion editor program, a tool for designing human-machine interfaces (HMI). Various parameter data are displayed and received through the programming screen using the Arduino IDE, allowing the ESP32 (master) and the Nextion display to communicate via the universal asynchronous receiver-transmitter (UART) communication protocol.

Figure 7. Nextion display screen of master node

Figure 8. Prototype of alternate wetting and drying rice cultivation using IoT for precision agriculture

Figure 9 illustrates data transmission from a prototype of a semi-automatic wet and dry rice planting system using IoT technology, utilizing ThinkSpeak as a server to display results through the dashboard. The figure comprises graphs displaying temperature, humidity, and water level data measured from two node sensors (field 1, 3, 5 for node sensor 1 and field 2, 4, 6 for node sensor 2) over a period of 3 days, with data sent every hour. All six charts demonstrate the water level measurements: node sensor 1 pumped water in until it reached a level of 15 centimeters and pumped water out until it reached levels of 10 and 5 centimeters, respectively. Node sensor 2 alternated pumping water in and out at levels of 5 and 10 centimeters. These tests aimed to evaluate the accuracy and precision of water level measurement. The charts provide insights into variations in temperature, humidity, and water levels over the specified time period. Consistency in data formatting across both fields for each parameter indicates the reliability and validity of the data. Such detailed analysis of time-varying data can significantly aid in environmental monitoring, resource management, and understanding daily climate changes in rice fields.

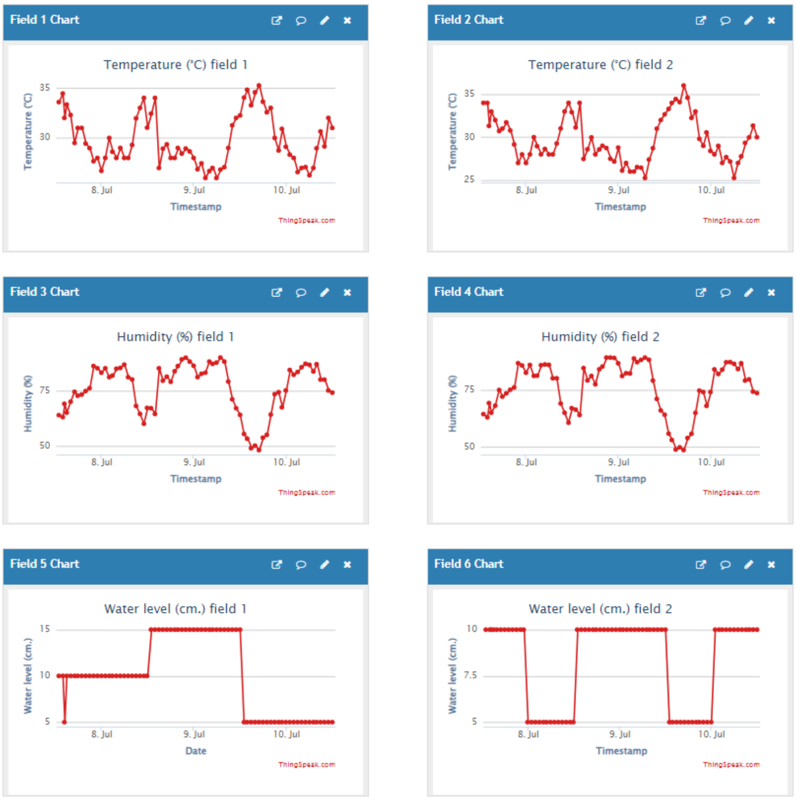


Figure 9. ThingSpeak dashboard

6. RESULT AND DISCUSSION

The prototype system demonstrate its effectiveness in supporting semi-automatic alternate wetting and drying rice cultivation through reliable and efficient data communication and control mechanisms. Using ESP32 microcontrollers and the ESP-NOW protocol, the system maintained low energy consumption and stable data transmission over a range of up to 115 meters, even in outdoor conditions, making it suitable for field applications. The clear separation of functions between the master and gateway ESP32 devices improved system stability and reduced data loss by ensuring that data transmission from node devices only occurred upon request from the master, minimizing interference. The relay module effectively controlled the water pump based on real-time sensor data, allowing responsive water level adjustments according to the predefined settings. The ThinkSpeak server’s integration enabled remote monitoring and visualization of key parameters, such as temperature, humidity, and water levels, which could assist farmers in managing irrigation needs more precisely. This system’s successful implementation and performance in managing water resources align with the objectives of precision agriculture, providing a scalable and sustainable solution that can be expanded by adding more nodes or integrating advanced data analysis for further optimization.

Additionally, we have presented a communication protocol between the master device and node devices. This protocol addresses potential data collision issues, which can occur if multiple node devices are deployed across a large field and need to send data to a single master device. If all node devices attempt to transmit data simultaneously, data collisions may arise. To manage the order of communication, our protocol designates the master device as the controller of data transmission. The master device sends a ticket to the first node device in the network, prompting it to transmit its data, followed sequentially by each node device until all devices have successfully communicated. With this transmission protocol, node devices are prevented from sending data to the master device at the same time. However, it is essential to ensure that all node devices within the network are continuously operational.

The testing prototype focused on evaluating the energy consumption and transmission range of the node device using the ESP-NOW protocol. Performance was assessed under two conditions: one with all sensors connected but idle, and another during active data transmission, where temperature, humidity, and water pump status data were sent. By measuring voltage across a known resistor, current consumption was calculated to determine power usage, revealing a slight increase in energy consumption during transmission. The results also explored how factors like data packet size and transmission frequency impact power consumption, indicating that while data size affects energy use, the relationship is non-linear. Additionally, experiments on transmission range highlighted that RSSI values declined with distance, with reliable data transmission achievable up to 115 meters in field conditions, aligning with a critical threshold RSSI value of -90 dBm. These results were complemented by an RSSI-distance model to guide practical node placement, supporting efficient energy and data management in the field.

The design of the node and master devices is presented in detail, emphasizing how each component and connection serves the study's objectives of achieving energy-efficient and reliable communication for rice field irrigation. The node device is housed in a durable PVC structure, supporting both weather resistance and ease of maintenance, with sensors carefully positioned for optimal data collection on water levels, temperature, and humidity. The connection of each sensor to the ESP32 microcontroller and its power regulation system is illustrated, and the inclusion of a relay for water pump control is outlined. A master device, powered by a stable 220 V supply, is configured to aggregate data from multiple nodes and transmit it via ESP-NOW to ThinkSpeak for monitoring.

7. CONCLUSION

This study presents a scalable, IoT-based prototype for alternating wet and dry rice cultivation, with findings that underscore the system's potential to enhance precision agriculture through efficient water management and real-time environmental monitoring. The system's use of ESP32 microcontrollers and the ESP-NOW protocol demonstrated low energy consumption, reliable data transmission, and a practical communication range suitable for field deployment, addressing critical objectives related to energy efficiency and resource conservation. Performance evaluations confirmed that the system could reliably transmit data up to 115 meters, with the designed hardware configuration proving resilient in outdoor agricultural environments. These results align with previous research on IoT applications in agriculture, while the addition of user-friendly interfaces and robust real-time control contributes significantly to practical applications, making this system accessible and manageable for farmers aiming to improve resource use and crop yield.

For the research field and agricultural community, these findings represent a substantial step forward in developing sustainable, cost-effective technology for crop management, especially in water-scarce regions. The adaptability of this system allows for further extensions, such as incorporating solar power to extend battery life, adding more nodes to cover larger areas, or integrating ML algorithms to refine irrigation schedules based on predictive data models. Future research could explore optimizing sensor networks for varied environmental conditions or integrating this system with other IoT-based solutions in agriculture, creating a comprehensive approach to resource management. Ultimately, this research contributes a valuable tool for the agricultural community, advancing the adoption of precision agriculture technologies to address both current and future challenges in food production and sustainability.

REFERENCES

[1] R. M. Lampayan, R. M. Rejesus, G. R. Singleton, and B. A. M. Bouman, "Adoption and economics of alternate wetting and drying water management for irrigated lowland rice," *Field Crops Research*, vol. 170, pp. 95–108, 2015, doi: 10.1016/j.fcr.2014.10.013.

[2] R. M. Rejesus, F. G. Palis, D. G. P. Rodriguez, R. M. Lampayan, and B. A. M. Bouman "Impact of the alternate wetting and drying (AWD) water-saving irrigation technique: Evidence from rice producers in the Philippines," *Food Policy*, vol. 36, no. 2, pp.280–288, 2011, doi: 10.1016/j.foodpol.2010.11.026.

[3] Y. Suzuki, S. Kamma, C. Chutteang, N. Chaichana, and T. Pakoktom, "Effects of alternate wetting and drying water management and rice straw incorporation on sustainable rice production under rainy season conditions in central Thailand," *Agriculture and Natural Resources*, vol. 57, no. 5, pp. 777–786, 2023, doi: 10.34044/j.anres.2023.57.5.04.

[4] Ray and P. Pratim, "Internet of Things for Smart Agriculture: Technologies, Practices and Future Direction," *Journal of Ambient Intelligence and Smart Environments*, vol. 9, no. 4, pp. 395–420, 2017, doi: 10.3233/AIS-170440.

[5] L. Kumar, P. Ahlawat, P. Rajput, R. I. Navsare, and P. Singh, "Internet Of Things (Iot) For Smart Precision Farming And Agricultural Systems Productivity: A Review," *International Journal of Engineering Applied Sciences and Technology*, vol. 5, no. 9, pp. 141-146, doi: 10.33564/IJEAST.2021.V05I09.022.

[6] N. Sales, O. Remedios, and A. Arsénio, "Wireless sensor and actuator system for smart irrigation on the cloud," in *World Forum on Internet of Things*, in *IEEE 2nd World Forum on Internet of Things (WF-IoT)*, Milan, Italy, 2015, pp. 693-698, doi: 10.1109/WF-IoT.2015.7389138.

[7] M. N. Mowla, N. Mowla, A. F. M. S. Shah, K. M. Rabie, and T. Shongwe, "Internet of Things and Wireless Sensor Networks for Smart Agriculture Applications: A Survey," *IEEE Access*, vol. 11, pp. 145813-145852, 2023, doi: 10.1109/ACCESS.2023.3346299.

[8] R. K. Singh, R. Berkvens, and M. Weyn, "AgriFusion: An Architecture for IoT and Emerging Technologies Based on a Precision Agriculture Survey," *IEEE Access*, vol. 9, pp. 136253-136283, 2021, doi: 10.1109/ACCESS.2021.3116814.

[9] W. K. Alazzai, Sh. Z. Abood, M. Al-Jawahry, and M. K. Obaid, "Precision Farming: The Power of AI and IoT Technologies," in *International Conference on Environmental Development Using Computer Science (ICECS '24)*, Tamil Nadu, India, Jan. 2024, pp. 1–6, doi: 10.1051/e3sconf/202449104006.

[10] Nitin and S. B. Gupta, "Artificial Intelligence in Smart Agriculture: Applications and Challenges," *Current Applied Science and Technology*, vol. 24, no. 2, 2023, doi: 10.55003/cast.2023.254427.

[11] B. Sarma, R. Baruah, and A. Borah, "Internet of Things based Smart Farming," in *2020 Fourth International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC)*, 2020, pp. 30-34, doi: 10.1109/I-SMAC49090.2020.9243364.

[12] R. Karthiga, C. L. B. Devi, R. Janaki, C. Gayathri, V. S. Pandim, and D. Shobana, "IoT Farm: A Robust Methodology Design to Support Smart Agricultural System Using Internet of Things with Intelligent Sensors Association," in *2023 7th International Conference on Electronics, Communication and Aerospace Technology (ICECA)*, Coimbatore, India, 2023, pp. 1332-1337, doi: 10.1109/ICECA58529.2023.10395635.

[13] M. Rahman, M. S. R. Kohinoor, and A. A. Sami, "Enhancing Poultry Farm Productivity Using IoT-Based Smart Farming Automation System," in *2023 26th International Conference on Computer and Information Technology (ICCIT)*, Cox's Bazar, Bangladesh, 2023, pp. 1-6, doi: 10.1109/ICCIT60459.2023.10441525.

[14] R. N. Gore, H. Kour, M. Gandhi, D. Tandur, and A. Varghese, "Bluetooth based Sensor Monitoring in Industrial IoT Plants," in *2019 International Conference on Data Science and Communication (IconDSC)*, 2019, pp. 1-6, doi: 10.1109/IconDSC.2019.8816906.

[15] X. -R. Huang, C. -H. Chen, and L. -B. Chen, "An Intelligent Lighting Monitoring and Controlling System Based on ZigBee Low-Power Wireless Technology for Smart Homes," in *2023 IEEE International Conference on Consumer Electronics (ICCE)*, Las Vegas, NV, USA, 2023, pp. 1-2, doi: 10.1109/ICCE56470.2023.10043566.

[16] A. J. Lakshmi, G. Kishore, V. Koushik, and T. D. Kumar, "Deploying LoRa Technology to Enhance Weather Monitoring system," in *2023 2nd International Conference on Automation, Computing and Renewable Systems (ICACRS)*, Pudukkottai, India, 2023, pp. 329-333, doi: 10.1109/ICACRS58579.2023.10405135.

[17] D. Eridani, A. F. Rochim, and F. N. Cesara, "Comparative Performance Study of ESP-NOW, Wi-Fi, Bluetooth Protocols based on Range, Transmission Speed, Latency, Energy Usage and Barrier Resistance," in *2021 International Seminar on Application for Technology of Information and Communication (iSemantic)*, 2021, pp. 322-328, doi: 10.1109/iSemantic52711.2021.9573246.

[18] J. A. C. Paguay, G. A. H. Brito, D. L. H. Rojas, and J. J. C. Calva, "Secure home automation system based on ESP-NOW mesh network, MQTT and Home Assistant platform," *IEEE Latin America Transactions*, vol. 21, no. 7, pp. 829-838, Jul. 2023, doi: 10.1109/TLA.2023.10244182.

[19] M. F. Wicaksono and M. D. Rahmatya, "IoT for Residential Monitoring Using ESP8266 and ESP-NOW Protocol," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, Vol. 8, no.1, pp. 93-106, 2022, doi: 10.26555/jiteki.v8i1.23616.

[20] D. Urazayev, A. Eduard, M. Ahsan, and D. Zorbas, "Indoor Performance Evaluation of ESP-NOW," in *2023 IEEE International Conference on Smart Information Systems and Technologies (SIST)*, 2023, pp. 1-6, doi: 10.1109/SIST58284.2023.10223585.

[21] A. Kviesis, V. Komasilovs, N. Ozols, and A. Zacepins, "Bee colony remote monitoring based on IoT using ESP-NOW protocol," *PeerJ Computer Science*, 2023, doi: 10.7717/peerj-cs.1363.

[22] A. Sharma, A. Karmakar, and S. Sharma, "IPWC: Integrative Peer to Peer Wireless Communication of MEMS based Remote Temperature Sensor using ESP NOW and IoT Networking," in *2022 URSI Regional Conference on Radio Science (USRI-RCRS)*, Indore, India, 2022, pp. 1-4, doi: 10.23919/URSI-RCRS56822.2022.10118574.

[23] R. R. Isnanto, Y. E. Windarto, J. I. D. Gloriawan, and F. N. Cesara, "Design of a Robot to Control Agricultural Soil Conditions using ESP-NOW Protocol," in *2020 Fifth International Conference on Informatics and Computing (ICIC)*, Gorontalo, Indonesia, 2020, pp. 1-6, doi: 10.1109/ICIC50835.2020.9288575.

[24] Yoppy, R. H. Arjadi, H. Candra, H. D. Prananto, and T. A. W. Wijanarko, "RSSI Comparison of ESP8266 Modules," in *2018 Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS)*, Batu, Indonesia, 2018, pp. 150-153, doi: 10.1109/EECCIS.2018.8692892.

[25] R. Jin, H. Xu, Z. Che, Q. He, and L. Wang, "Experimental evaluation of reducing ranging-error based on receive signal strength indication in wireless sensor networks," *IET Wireless Sensor Systems*, vol. 5, no. 5, pp. 228–234, 2015, doi: 10.1049/iet-wss.2013.0139.

[26] A. Swain, M. Bepari, N. Patnaik, H. B. Sahu, and S. K. Das, "On the Significance of RSSI Modeling Studies for Wireless Sensor Networks in Mines," in *2018 2nd International Conference on Imaging, Signal Processing and Communication (ICISPC)*, Kuala Lumpur, Malaysia, 2018, pp. 97-101, doi: 10.1109/ICISPC44900.2018.9006680.

[27] S. R. Theodore, "Wireless communication: principles and practice," *Prentice-Hall*, 2nd ed., l, 2002.

BIOGRAPHIES OF AUTHORS

Akkachai Phuphanin received the B.Eng., M.Eng. and Ph.D. degree in Telecommunication Engineering from Suranaree University of Technology, Thailand, in 2019, 2011 and 2017, respectively. Currently, he is lecturer at the Department of Electrical Engineering, Rajamangala University of Technology Isan Sakonnakhon Campus. His research interests include wireless sensor networks and applications, reinforcement learning, learning (artificial intelligence), smart farm and home technology, coverage control, internet of thing, and signal processing. He can be contacted at email: akkachai.ph@rmuti.ac.th.

Metha Tasakorn received the B.Eng. degree in Industrial Electrical Technology from King Mongkut's Institute of Technology North Bangkok (KMITNB), Bangkok, Thailand, in 1993, M.Sc. degree in Electronics Electrotechnics and Automatics from Université Paris-Est Créteil Val-de-Marne, Créteil, France, in 2002. He is a lecturer with the Department of Electrical Engineering, Faculty of Industry and Technology, Rajamangala University of Technology Isan Sakon Nakhon Campus, Sakon Nakhon, 47160 Thailand. His research interests include biosensor, optical tweezer, robotics, power electronics, learning (artificial intelligence), smart farm, home technology, and internet of thing. He can be contacted at email: metha.ta@rmuti.ac.th.