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IoT Fertigation Dashboard for Precision Agriculture Monitoring and Control

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Keywords

Raspberry Pi, ESP32 Microcontroller, Real-Time data monitoring, Node-Red, InfluxDB.

Abstract

This research involves the development of an IoT-based fertigation dashboard for precision agriculture. A single RS-485 soil sensor was used to measure temperature, moisture, pH, and electrical conductivity. The ESP32 sent this data over Wi-Fi using the MQTT protocol to a Raspberry Pi 5, which acted as the MQTT broker and hosted a real-time dashboard using Node-RED. The system provided live monitoring and remote access. Sensor readings were accurate after calibration, with values like moisture around 10–12%, pH 5.7–6.8, and temperature around 28°C. InfluxDB Cloud was used to store the data online, and it could be downloaded as a CSV file for analysis in Excel. The system was tested successfully, proving to be low-cost, reliable, and suitable for smart farming.

1. Introduction

The agriculture sector faces growing challenges in meeting global food demands while managing limited resources and promoting sustainability. Fertigation, the technique of applying fertilizers through irrigation, offers an efficient way to improve nutrient uptake and water use [1]. However, conventional systems often lack automation and precision [2][3]. This project introduces a custom IoT-based fertigation dashboard that integrates a low-cost RS485 soil sensor to measure temperature, pH, moisture, and conductivity [4]. The ESP32 microcontroller collects the data and transmits it via WiFi using the MQTT protocol to a Raspberry Pi 5, which runs a real-time monitoring dashboard through Node RED [5]. The system provides live data visualization, remote access, and greater flexibility compared to generic platforms like Blynk or ThingSpeak. Both hardware and software components, including sensor calibration, PCB design, MQTT setup, and InfluxDB Cloud integration for data storage, were successfully implemented [6]. This solution supports precision agriculture by reducing manual work, improving decision-making, and enabling cost-effective and sustainable farm management [7].

2. Methodology

This research project was developed in two main phases: hardware design and software implementation. The process began with information gathering from online resources and industry reports to support the project's objectives, which were refined through ongoing discussions with the project supervisor. To stay within a moderate budget of approximately RM500, a selection of cost-effective and suitable components was made. Circuit designs, datasheets, and relevant documentation were reviewed to support the development of the system's mechanical and electrical structure. The hardware integration involved an ESP32 microcontroller and a Raspberry Pi 5, communicating through the MQTT protocol for real-time data exchange. The software development included programming the ESP32 using the Arduino IDE, setting up the MQTT broker on the

Raspberry Pi, creating a dashboard using Node-RED, and integrating InfluxDB Cloud for online data storage. Troubleshooting was performed throughout the process to identify and solve technical issues. The final system was evaluated through both quantitative and qualitative testing to ensure it met the intended project goals.

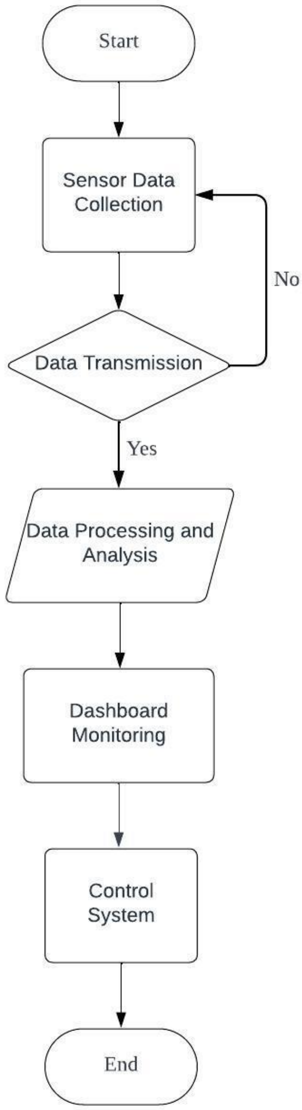

Fig. 1 *Flowchart of the project*

The flowchart illustrated in Fig. 1 shows how the IoT fertigation system operates, starting with the collection of soil data using sensors. This data is transmitted to the IoT platform, where it is processed and analyzed. The system then displays the results on a real-time dashboard that allows users to monitor and supervise the fertigation process. The main objective of the system is to enhance the efficiency of agricultural activities by automating nutrient control, minimizing human errors, and conserving resources such as water and fertilizer.

The software flowchart in Fig. 2 outlines the logical sequence used to develop and operate the fertigation dashboard system. It begins with initializing the sensor and microcontroller setup, followed by data acquisition from the soil sensor. The ESP32 then processes and transmits this data using the MQTT protocol to the Raspberry Pi. Upon receiving the data, the Raspberry Pi stores it in InfluxDB and displays it on a real-time Node-RED dashboard. This flow ensures continuous and automated monitoring of soil parameters, enabling precise and efficient agricultural decision-making.

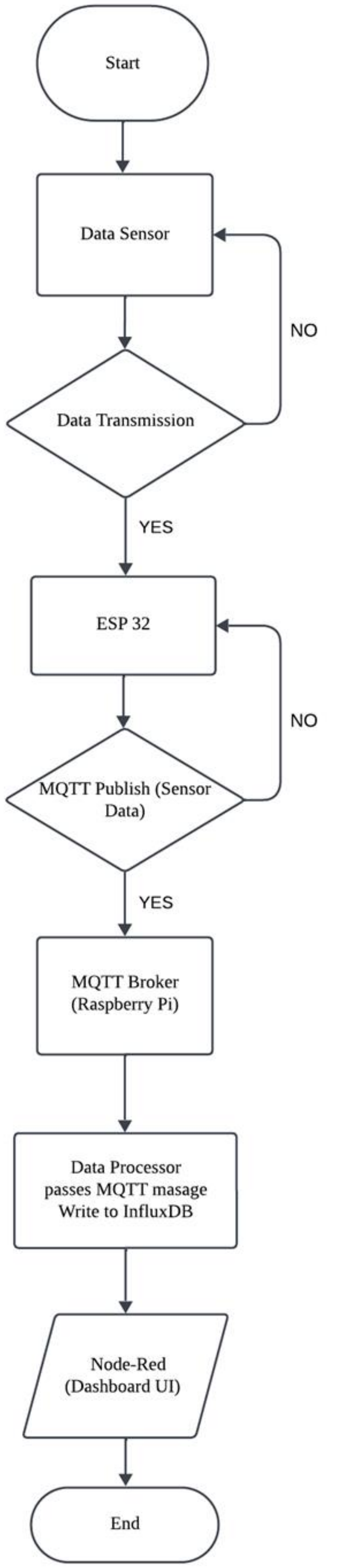

Fig. 2 *Software flowchart*

2.1 Block Diagram

The block diagram in Fig. 3 shows how the smart monitoring system works using sensors, an ESP32 microcontroller, and a Raspberry Pi. The system uses sensors to measure soil moisture, nutrients, temperature, and pH levels. Each sensor is connected to the ESP32, which collects and processes the data before sending it to the Raspberry Pi. The Raspberry Pi acts as the main controller and displays the data in a simple web dashboard for monitoring. This system is designed for smart farming, helping users manage irrigation, fertilization, and plant health more easily and accurately.

Fig. 3 *Block diagram of the project*

2.2 Hardware Part Setup

This section explains the hardware components used in the development of the IoT-Fertigation Dashboard for Precision Agriculture Monitoring. Each component plays a critical role in ensuring the system functions effectively, from sensing soil parameters to transmitting data for real-time monitoring. The subtopics in this chapter provide detailed descriptions of each hardware element, including their specifications, functions, and integration within the overall system. This includes the microcontroller (ESP32), the RS485 multi-parameter soil sensor, the Raspberry Pi 5, OLED display, power supply modules, and connection interfaces. Understanding the purpose and functionality of each component is essential to demonstrate how the system was designed to achieve the project objectives in terms of automation, monitoring, and data management in precision farming.

2.3 Major Component

Fig. 4 shows the role of the Raspberry Pi in the IoT-based fertigation system, where it acts as the central hub for data processing, visualization, and communication. The Raspberry Pi was selected for this project due to its versatility, compact size, and ability to handle multiple tasks simultaneously. It serves as the main controller that receives real-time sensor data from the ESP32 via the MQTT protocol. Acting as an MQTT broker using the Mosquitto service, the Raspberry Pi ensures efficient communication between devices in the IoT network. Additionally, it hosts the Node-RED dashboard, which provides a user-friendly interface for real-time data visualization, system monitoring, and remote access via VNC. Its ability to run a lightweight operating system and support various programming environments makes it ideal for integrating hardware and software components in a smart agriculture system. The use of Raspberry Pi in this project enables reliable processing, flexibility for future upgrades, and a cost-effective solution for managing and supervising fertigation activities.

Fig. 4 *Raspberry Pi 5*

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2.4 Software Part Setup

Fig. 5 illustrates the use of Raspberry Pi Imager during the initial setup process. Raspberry Pi Imager made it easy to set up the Raspberry Pi by allowing me to choose and install the operating system directly onto the SD card. It also let me enable SSH and set up Wi-Fi in advance, which was useful for this IoT project since no monitor was needed. The setup process was fast and smooth, making it ideal for preparing the Raspberry Pi to monitor the fertilizer and irrigation system.

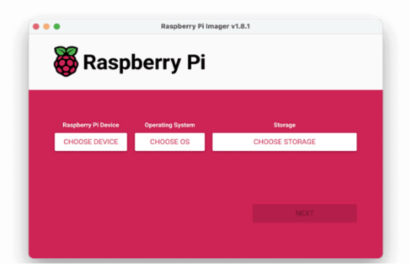

Fig. 5 *Raspberry Pi Imager*

2.5 MQTT Protocol

MQTT (Message Queuing Telemetry Transport) is a lightweight publish-subscribe protocol that is ideal for IoT applications, especially in environments with limited bandwidth or unstable connections. In smart agriculture, MQTT enables efficient communication between sensors, controllers, and dashboards. Devices send data to an MQTT broker using specific topics, and other devices or applications can subscribe to those topics to receive real-time updates. In this project, the Mosquitto broker is used to manage that communication. Mosquitto is an open-source MQTT broker that is easy to set up, supports secure connections, and works well on devices with limited resources like the Raspberry Pi. Using MQTT with Mosquitto allows the system to transfer sensor data quickly and reliably, making it suitable for real-time monitoring and automation in precision farming.

2.6 PCB Testing

Fig. 6 shows the initial testing of the ESP32 microcontroller using a Mini-Blink program. System testing was also severe by testing each component to ensure that it was functional. The ESP32 microcontroller of the PCB was easily programmed with the simplest Mini-Blink program and then with an advanced program that tests its GPIO pins and Wi-Fi capability.

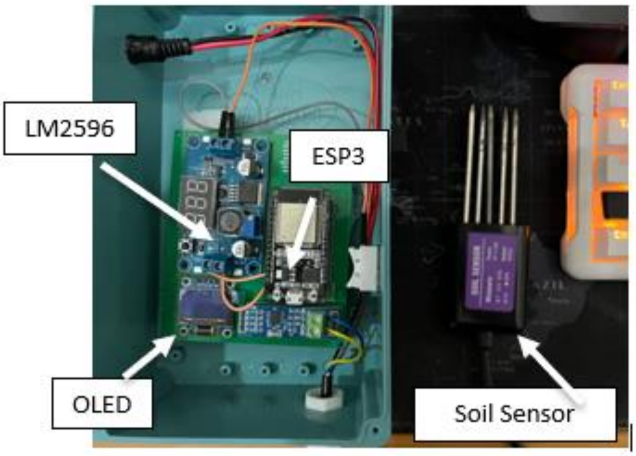

Fig. 6 *Soldered PCB with components*

3. Result and Discussion

The results of testing the IoT-Fertigation Dashboard, which was created with Node-RED to gather, store, and display real-time sensor data, are shown in this chapter. The system was created to help farmers automate fertilizer and irrigation applications and monitor soil conditions. The system successfully enhanced resource utilization and offered insightful information for well-informed decision-making, according to the test results.

Nevertheless, some problems were found, like sporadic Wi-Fi disconnections in bad weather. Future improvement ideas are also covered.

Fig. 7 illustrates the communication flow from the soil sensor to the final dashboard. The ESP32 microcontroller collects data from the RS-485 soil sensor and publishes it via MQTT to the Raspberry Pi, which acts as the MQTT broker using the Mosquitto service. The data is then processed and displayed on the Node-RED dashboard in real-time. This flow ensures efficient communication, enabling farmers to make informed decisions through continuous data updates on soil conditions.

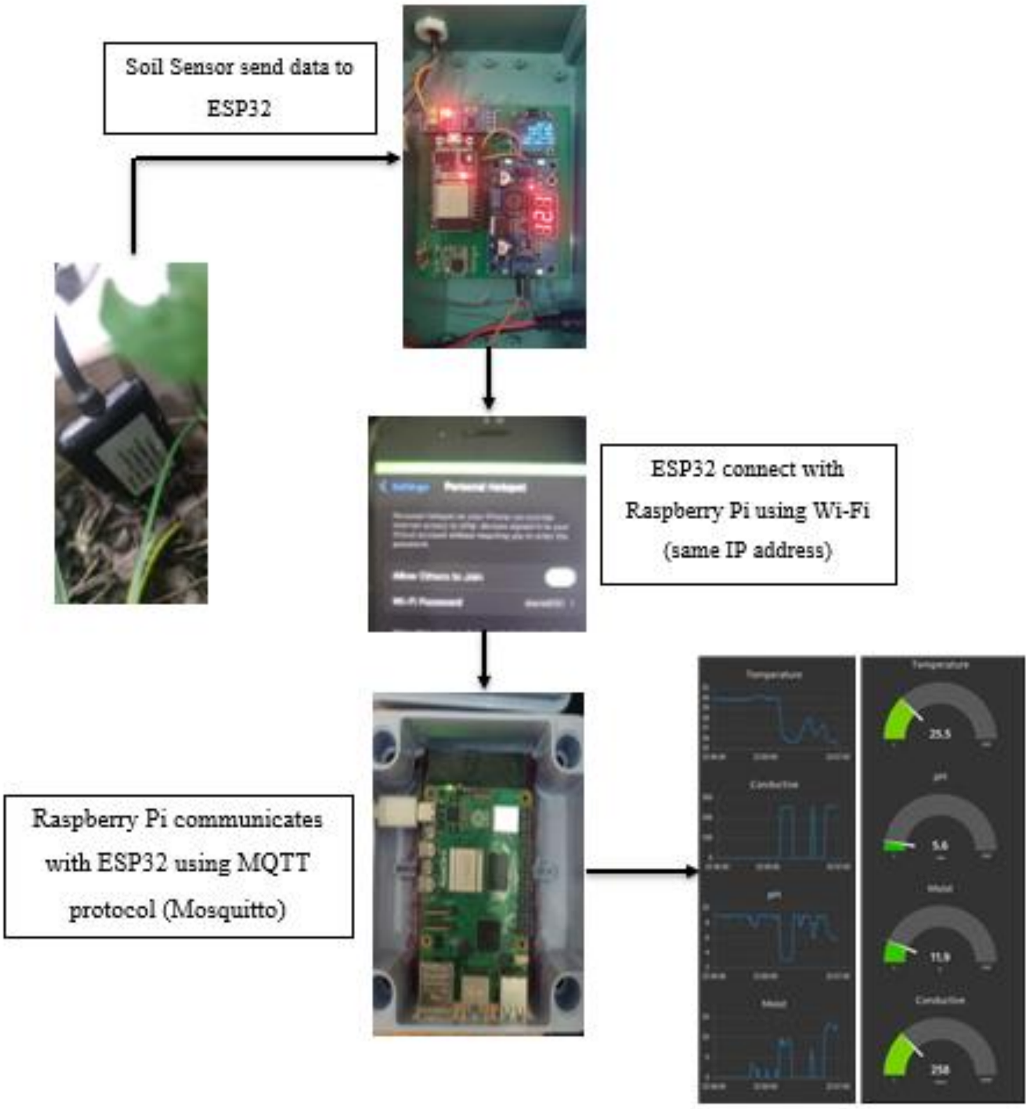

Fig. 7 *Sensor to dashboard communication flow*

3.1 Real-Time Soil Sensor Data Stored in InfluxDB Cloud

Fig. 8 illustrates the data transmission flow from the ESP32 to InfluxDB Cloud. The development of the fertigation monitoring system using InfluxDB Cloud allows real-time sensor data to be stored in an organized and efficient way. The soil sensor, connected to the ESP32 microcontroller, measures four key parameters: moisture, temperature, pH, and conductivity. These readings are important for monitoring soil health and improving farming practices. ESP32 formats the data using InfluxDB Line Protocol and sends it directly to the InfluxDB Cloud using an HTTP POST request. The data is stored under the user's organization called Fertigation Data, in a bucket named Monitoringbuckets. A status code 204 appears in the serial monitor for each successful data upload, confirming that the data was received even though no content is returned.

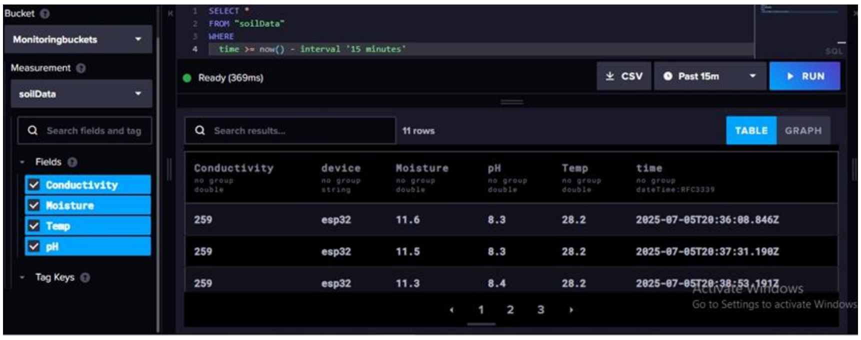

Fig. 8 *Query Results displaying live soil data in InfluxDB Cloud*

3.2 Exporting Sensor Data from InfluxDB Cloud to Excel

Fig. 9 shows the exported sensor data from InfluxDB Cloud that opened in Microsoft Excel. Exporting data from InfluxDB Cloud as a CSV file and opening it in Excel provides a clear and organized view of the sensor readings. Each row in the Excel file represents a data entry recorded at a specific time. The columns include important information such as the measurement name (e.g., soilData), timestamp, and sensor values like temperature, moisture, conductivity, and pH. This format makes it easy to review, compare, and analyze the data using Excel features such as charts, filters, and basic statistics.

4	Conductiv	Moisture	Temp	device	pH	time
5	259	10.6	28.2	esp32	8.2	2025-07-05T20:32:01.349811165Z
6	259	12.4	28.2	esp32	8.3	2025-07-05T20:33:23.990979009Z
7	259	11.5	28.2	esp32	8.3	2025-07-05T20:34:46.509439499Z
8	259	11.6	28.2	esp32	8.3	2025-07-05T20:36:08.846956745Z
9	259	11.5	28.2	esp32	8.3	2025-07-05T20:37:31.190748439Z
10	259	11.3	28.2	esp32	8.4	2025-07-05T20:38:53.191628482Z
11	259	11.4	28.2	esp32	8.4	2025-07-05T20:40:15.029449739Z
12	259	11.3	28.3	esp32	8.4	2025-07-05T20:41:37.042025332Z
13	259	11.5	28.2	esp32	8.4	2025-07-05T20:42:59.998476466Z
14	259	12.3	28.2	esp32	8.4	2025-07-05T20:44:22.321544115Z
15	259	11.5	28.3	esp32	8.5	2025-07-05T20:45:44.86447085Z
16						
17						

Fig. 9 *Exported CSV sensor data from InfluxDB Cloud viewed in Microsoft Excel*

4. Conclusion

Using IoT technology, this study successfully created a fertigation monitoring system. Real-time data transfer via the MQTT protocol was made possible by the ESP32 microcontroller and Raspberry Pi. Temperature, pH, moisture, nitrogen content, and conductivity—all crucial for precision agriculture—were precisely measured using a single RS485 multi-parameter soil sensor. Real-time monitoring, data logging, and remote access via VNC were all made possible by the interactive and intuitive Node-RED dashboard. The system provided trustworthy environmental data to enable intelligent fertilizer and irrigation management through appropriate hardware design, sensor calibration, and software integration. By decreasing manual labour, increasing resource efficiency, and providing users with insightful information, it accomplished its primary goals.

Although there were some challenges, such as connectivity issues and maintenance costs, the system remained affordable and practical. Overall, this project shows the potential of low-cost, open-source technologies to support sustainable and efficient farming, with room for future upgrades like AI integration and use on different types of farms.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Muhamad Syamil Daniel Bin Mohd Darus, Maisara Binti Othman, Muhammed Akram Irfan Bin Mohd Rizalhanafi;* ***data collection:*** *Muhamad Syamil Daniel Bin Mohd Darus;* ***analysis and interpretation of results:*** *Muhamad Syamil Daniel bin Mohd Darus;* ***draft manuscript preparation:*** *Muhamad Syamil Daniel bin Mohd Darus, Maisara Binti Othman. All authors reviewed the results and approved the final version of the manuscript.*

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