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Prototype of an Internet of Things Based Durian Tree Smart Switch Water and Soil Monitoring System

Nur Syahirah Mohamed Zaki[1], Mohd Hanif Mohd Ramli[1], Zulkifli Mohamed[1], and Nurul Syuhadah Khusaini[1*]
[1]School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam 40450 Selangor, Malaysia.
[*]corresponding author: nurulsyuhadah2089@uitm.edu.my

ABSTRACT

This paper presents an IoT-based monitoring system designed to address the challenges durian farmers face when managing remote orchards. The prototype integrates soil nutrient sensors that measure critical parameters (pH, NPK, humidity, temperature) with water level monitoring and automated irrigation control. Using ESP32 microcontrollers, modbus protocols, and solar power, the researchers created a sustainable system that transmits real-time data to a Node-RED dashboard via MQTT, storing historical information in MySQL databases. The system was validated through comparative testing against laboratory soil analysis, achieving acceptable error margins (6.25% for pH, 13.33% for Nitrogen). The smart water management component successfully automated irrigation based on predetermined thresholds, with both automatic and manual control options available through the user-friendly interface. Beyond the technical implementation, cost analysis revealed significant economic advantages compared to traditional monitoring methods, with one-time installation costs of approximately RM700 plus minimal annual subscription fees replacing monthly labor expenses of RM700-1500. This system represents a practical advancement in precision agriculture for durian cultivation, enabling farmers to make informed decisions about fertilization and irrigation while reducing the burden of managing remote orchards.

Keywords: Internet of Things (IoT); ESP-32; Node-RED; Message Queuing Telemetry Transport (MQTT); MySQL

1.0 INTRODUCTION

Durian tree cultivation has become a captivating venture, attracting investors tempted by the exclusivity and high demand for durians [1]. Limited to specific tropical region and geographical rarity as they are usually planted in a hilly area, combined with meticulous cultivation requirements and a delicate harvesting process, contributes to the premium prices associated with durians [2]. Despite these challenges, the attraction of long-term sustainability and significant returns has driven investments in durian tree farms. Investors are drawn to the opportunity of contributing to the global durian market and capitalizing on the popularity of this exotic fruit.

Durian cultivation is an important agricultural industry in many regions, especially in Thailand and Malaysia; yet durian farmers face numerous challenges in managing their orchards, especially those with farms located far from their homes. One major difficulty is monitoring and delivering the correct amounts of water and fertilizer that each tree requires [3]. Getting these inputs wrong can severely reduce crop yields and fruit quality from suboptimal growth conditions. This is especially problematic because durian trees are expensive long-term investment.

A major difficulty faced by durian farmers is that orchards require huge land, generally only available in remote rural areas far from cities and the farmers' homes. These remote locations pose significant challenges in routinely accessing and managing the orchards on a regular basis. Durian trees are delicate and require proper care including monitoring irrigation and fertilization needs, tasks which typically demand on-site manual verification of soil moisture and nutrient levels for each tree [4]. However, the remoteness makes it burdensome for a single farmer to undertake this labour-intensive work regularly. Thus, essential grove maintenance often suffers, compromising tree health and fruit production capacity [5]. An automated and remotely controlled system is necessary to facilitate affordable precision care of remote durian orchards.

Therefore, this study is conducted to develop a remote durian tree monitoring prototype through IoT technology. The prototype system delivers precise real-time data, helping farmers optimize returns from their valuable orchards while minimizing expenses traditionally associated with manual monitoring and maintenance operations [6][7]. This prototype uses a soil nutrient sensor to provide soil nutrient analysis data to the farmers in terms of Nitrogen (N), Phosphorus (P), Potassium (K), pH, temperature, and humidity. By knowing all these crucial elements, it will help farmers to identify any diseases the trees are facing or to determine the next fertilizer components [8]. Excessive or inadequate levels of pH, N, P, and K can cause diseases in durian trees. By having this system, it allows farmers to know the optimum condition of the soil to ensure the good quality of durian trees

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and fruit [9]. Additionally, it also uses a water pressure level sensor, enabling farmers to monitor and control their water pumps remotely. This eliminates the need for frequent trips to the orchard and reduces the concern of ensuring adequate irrigation when the farmer is away. Therefore, farmers are confident that their durian trees receive sufficient water without the need to hire additional help which will cause money or interrupt their schedules.

IoT, in this context, enhances accessibility and efficiency by automating tasks and enabling remote monitoring [10]. This prototype provides real-time data for better decision-making and cost savings. The system relies on sensors and ESP32 microcontrollers for network connectivity to collect the data. This setup enables efficient data gathering. It utilizes Message Queuing Telemetry Transport (MQTT) for communication and MySQL for cloud-based data storage [11]. This integration, along with soil nutrient and water pressure level sensors, allows for remote monitoring and data analysis to maintain optimum operating conditions for the durian trees. Finally, this study aims to validate the accuracy of the project's data through extensive testing and by comparing it with data from other existing sensors. With the use of Node-RED, farmers can easily analyse the data collected from the sensors. Node-RED is a data flow-based programming tool that has easy to use feature in developing a user-friendly dashboard by using their provided nodes function [12], [13]. Data are transmitted to a database by MQTT and stored in MySQL, allowing farmers to continuously monitor and keep track of data history. A thorough review of IoT system in farming is presented in Table 1.

Table 1. Literature Review Matrix

Author, Year	Objective	Finding	Limitation
Soil Content Analysis			
(Raj et al., 2023) [14]	Provide real-time tracking of soil nutrient levels and equip farmers with insights for effective crop management.	The technology has the potential to increase crop yields, lower costs, and encourage sustainable farming practice.	Only focuses on the nitrogen, phosphorus, potassium, and pH of the soil.
(C Othaman et al., 2021) [15]	Create a cost-effective soil nutrient sensing system utilizing IoT technology which focuses on electric conductivity of the soil.	Soil EC is directly linked to nutrient availability and depth, with EC values significantly higher in the presence of fertilizer.	Only focuses on the electrical conductivity of the soil.
(Mary et al., 2023) [16]	Implementing an IoT-based system for analysing soil content to aid farmers.	Using sensors to measure temperature, moisture, pH, and nutrient levels and ESP8266 adaptation.	Soil content does not focus on nitrogen, phosphorus and potassium which are considered crucial things for farmers.
(Saikia D et al., 2022)[17]	Create a smart soil parameter monitoring system using IoT and provide real-time monitoring for irrigation.	Data from soil sensor are successfully transmitted to Thing Speak for remote monitoring.	Only measure soil moisture and temperature. Only tested in a laboratory setting, not the outdoor.
(Anjaneyulu et al., 2024) [18]	Develop IoT system for monitoring and managing plant nutrients.	The system is able to monitors soil NPK in real time and data are stored in Google Firebase.	System only focuses on NPK levels, does not include other parameters.
Water Monitoring			
(Yi Ming et al., 2022) [4]	To design automated water irrigation system that is triggered by soil moisture data to reduce labor costs for farmers.	The system uses solar power generation for the sensor and irrigation system.	The results are based on a single day data analysis.
(Hairudin et al., 2023) [1]	To create a wireless durian tree water irrigation system using IoT and solar energy.	Uses ESP8266 and Blynk application for farmers to monitor the moisture of durian tree soil.	Does not monitor the water tank level and does not enable remote control for the water pump
(Jan et al., 2022) [19]	To study the limitations of manual water tank monitoring in developing countries	Manual monitoring is unsuitable for 24/7 operation which leads to undetected water flow and tiresome for manual checks	Costing for IoT water tank monitoring may cost more than manual monitoring.

Existing IoT agricultural systems exhibit several critical limitations. Most soil monitoring solutions provide insufficient parameter coverage, focusing narrowly on specific elements like NPK and pH or only electrical conductivity, rather than offering the comprehensive soil nutrient profile needed by farmers. Many systems remain untested in actual field conditions, with evaluations confined to controlled laboratory environments. Water management implementations suffer from similar constraints, with research often based on inadequate data collection periods and systems lacking essential functionality such as water tank level monitoring or remote pump control capabilities. Economic considerations present additional challenges, as the initial investment for IoT monitoring solutions may exceed traditional manual approaches. These shortcomings highlight the significant gap in agricultural technology for comprehensive, field-tested IoT systems that can effectively monitor multiple soil parameters while simultaneously providing remote water management functionality – a gap this research specifically addresses through the developed durian tree monitoring system.

2.0 METHODOLOGY

Figure 1 shows the Functional Decomposition Diagram (FCD) for this study that presents the sequential process of integrating the hardware and software components of the system. The workflow begins with parallel development of the system prototype for both hardware and software. The hardware part includes development, sensor calibration, and design and fabrication of the case. As for the software side, it only involves dashboard development using Node-RED.

The system utilizes an ESP32 microcontroller combined along with two types of sensors which are soil nutrient sensor and water pressure level sensor. The study uses two hardware systems and one software system. The diagrams in Figures 2 and 3 illustrate the block diagrams for soil monitoring and the smart switch water pump system, respectively.

Figure 2 depicts a soil monitoring system, the soil sensor is connected to an RS485 breakout board since it uses a Modbus protocol, which then interfaces with the ESP32. A solar panel charges a battery that powers the system. The ESP32 transmits data to a Raspberry Pi via Wi-Fi to Node-RED server, which updates the dashboard.

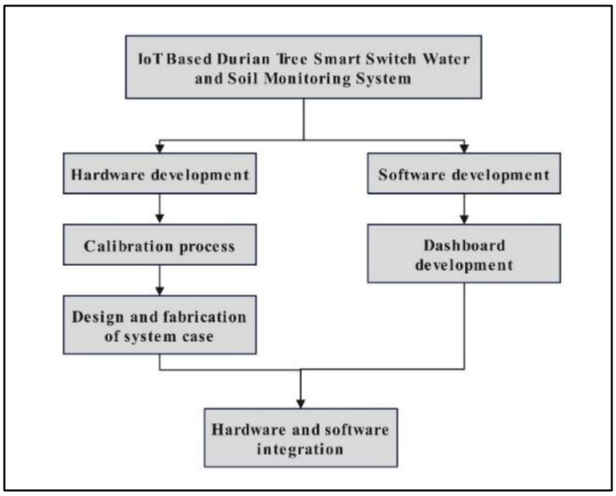


Figure 1. Functional Decomposition Diagram (FCD)

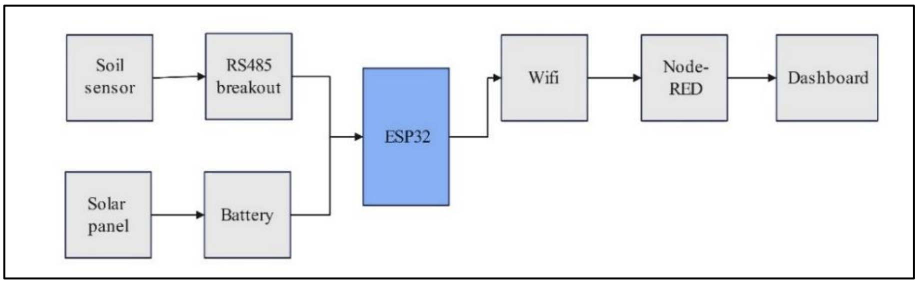


Figure 2. Soil monitoring system block diagram

Figure 3 depicts the smart switch water pump system in which the water pressure level sensor connects to a relay and an RS485 breakout board that interfaces with another ESP32. This system is powered separately. The ESP32 in this setup also transmits data via Wi-Fi to Node-RED, which updates the dashboard and controls the water pump based on water level data.

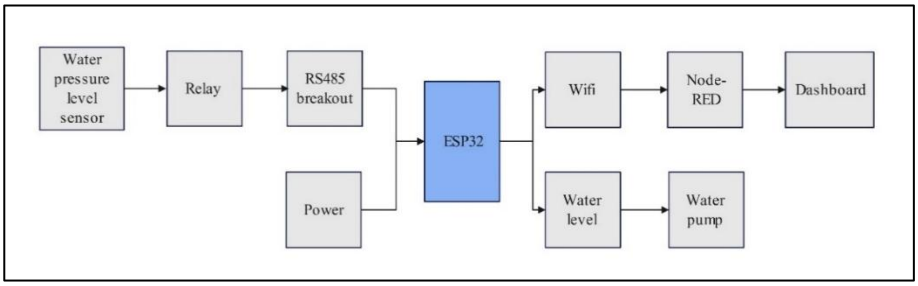


Figure 3. Smart switch water system block diagram

2.1 Hardware development

To design a reliable prototype of the IoT device for smart switch water and soil monitoring system, several crucial steps must be done, including component integration, testing, and installation. The stages involved in developing the hardware for the system are as below:

Table 2. List of Hardware

No.	Component	Description
1	ESP32 Microcontroller	ESP32 is utilized for storing programs, controlling device functions, and providing Wi-Fi connectivity.
2	Soil nutrient sensor	The soil sensor is used as it can detect six elements in the soil: temperature, humidity, pH, nitrogen(N), phosphorus(P), and potassium(K). It works using modbus protocol, ensuring accurate data transmission for effective soil monitoring [20].
3	Water pressure level sensor	The water pressure level sensor measures water level up to a maximum depth of 5 meters. This industrial type of sensor provides precise readings, making it ideal to use at the durian orchard.
4	Current to voltage converter	The current-to-voltage converter is utilized with the water pressure level sensor, which outputs readings in current. This converter converts the current signals into voltage signals, enabling the microcontroller to read the data from its analog pin.
5	BOB-10124 breakout	The breakout board is utilized to read modbus serial data from soil sensor and the modbus relay to give a readable output.
6	Modbus relay	The relay is used to automate control the water pump, switching it on when the water tank reaches a certain level and off when the tank is full.
7	Solar panel	Solar panel is utilized to charge the battery that powers the microcontroller in soil monitoring system. This ensures a sustainable and continuous power supply to the system [21].
8	Voltage steps up converter	In the soil monitoring system, a converter boosts the voltage from 3.3V to 5V for the soil sensor. In the water tank management system, two converters are utilized, one is 5V to operate the relay and the remaining is 12V for the water pressure level sensor.

2.2 System configuration

Both systems employ ESP32 microcontrollers from TTGO due to its optimal integration of hardware and software components. They are connected to the same Wi-Fi network through a shared wireless router. Proper wiring is implemented to ensure precise data transmission from the soil moisture and water pressure sensors. Thorough testing is conducted to ensure seamless operation.

Both sensors send their data to a Raspberry Pi that runs Node-RED server via the MQTT protocol. This server stores the data in a MYSQL database, enabling farmers to easily monitor and analyse their trees. Farmers can view soil nutrient trends for their trees every 10 minutes, hourly, or weekly and download the data in a csv form. A custom dashboard, designed for both laptop and mobile devices, displays the soil nutrient and water level data which allows farmers to control their water pumps remotely. This system particularly improves monitoring and provides valuable insights for farmers [22]. Figure 4(a) illustrates a snippet of the program code for smart water switch system. The code switches on the water pump via modbus relay when the water level reaches below 20% of the 5 meter depth, until the tank is full. Figure 4(b) displays the code that is responsible for displaying the six soil nutrient elements detected by the sensor to the dashboard.

```
void ControlLogic() {
  if (depth < THRD_on)
  {
    Pump_ON();
    state = "ON";
    Serial.println ("state:" + String(state));
    String message = "{\"TID\":";
    message += (String)txId;
    message += ",\"state\":";
    message += (String)state;
    Serial.println("Data: "+ String(message));
    client.publish (pubTopic, (String)message);
    delay (10000);
  }
  if (depth > THRD_off)
  {
    Pump_OFF();
    state = "OFF";
```

```
  Serial.println("===========================
  String message = "{\"TID\":";
  message += (String)txId;
  message += ",\"TMP\":";
  message += (String)Temperature;
  message += ",\"RH\":";
  message += (String)Humidity;
  message += ",\"pH\":";
  message += (String)pH_Value;
  message += ",\"Nitrogen\":";
  message += (String)Nitrogen;
  message += ",\"Phosphorus\":";
  message += (String)Phosphorus;
  message += ",\"Potassium\":";
  message += (String)Potassium;
  message += "}";

  client.publish(pubTopic, message); // Publi
  Serial.println("Data: " + String(message));
}
```

Figure 4. (a) Water pressure level sensor coding (b) Soil sensor coding

2.3 Experimental setup

The prototypes for both systems are assembled as presented in the figures below. A comprehensive circuit is designed according to components schematic diagram and tested before the final installation that involves soldering process to ensure the system functions accordingly. During this process, calibration for both sensors must be done to ensure accuracy and validity of the data collected. Figure 5 shows the experimental setup for water management system and Figure 6 shows for the soil nutrient monitoring system.

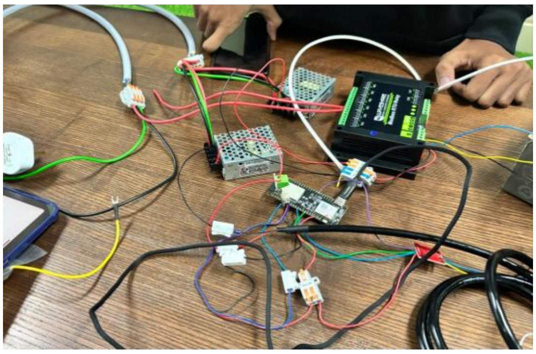


Figure 5. Water pressure level sensor setup

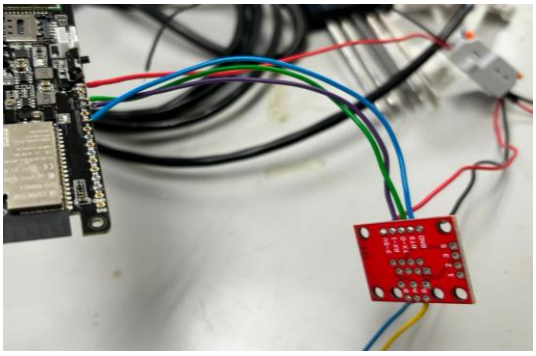


Figure 6. Soil sensor setup

After completing the calibration process and the desired results have been achieved through testing, the fabrication process begins. It starts with soldering to secure connections and ensuring smooth electric current flow. A custom casing for the soil sensor is designed using Fusion360 to fit its size, protecting the components from outdoor weather. The casing is 3D printed using ASA material, due to its UV and moisture resistance which is perfect for the outdoor application [23]. Figure 7 shows the printing process of the casing.

All wires are carefully measured and neatly wrapped with a cable organizer to maintain tidiness and prevent short circuits as can be seen in Figure 8.

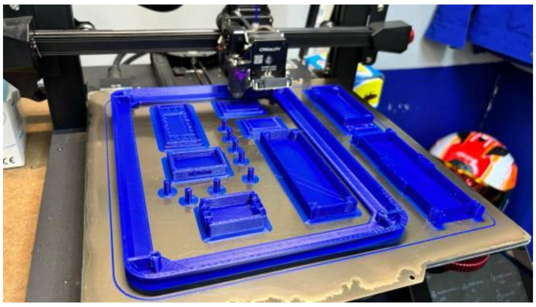


Figure 7. 3D printing process of soil sensor casing

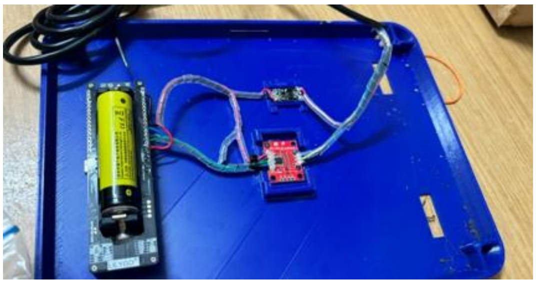


Figure 8. Wire neatly wrapped with cable organizer

2.4 System software development

Table 3 shows the list of software used to create the dashboard of the system.

Table 3. Software components list

No.	Component	Description
1	Arduino IDE	Utilised for writing, compiling, and uploading C++ programs to the microcontrollers.
2	Node-RED	A free programming tool for connecting hardware devices together, creating workflows and dashboard developing for IoT application.
3	MySQL	A free database management system that is used to manage and organize data from the sensors and web.
4	Docker Desktop	Application that allows user to run docker containers on local host.
5	Raspberry Pi	To run the node-red server so that data can always be transmitted to the dashboard.

2.5 Device description

The IoT-based prototype of smart switch water and soil monitoring system for durian trees integrates both hardware and software components to ensure effective and reliable farm monitoring. The hardware setup includes an ESP32 microcontroller, a soil sensor for detecting soil nutrients, and solar panels to power the monitoring system. It also uses a water pressure level sensor to monitor tank levels, a relay to control the water pump based on programmed instructions, and a wireless router to provide Wi-Fi connectivity for the microcontrollers. This ensures perfect monitoring and control of the durian tree's irrigation and soil health condition.

The sensors provide a real-time data from the soil and water tank based on the program stored in the microcontroller. The soil sensor measures temperature, humidity, pH, Nitrogen (N), Phosphorus (P), and Potassium (K) while the water pressure sensor monitors the water tank level. Data obtained from the soil sensor help the farmers in planning fertilizer schedules and evaluate the soil condition of the durian trees. This information enables farmers to identify any potential diseases and determining the trees optimal growing conditions. Meanwhile, the water pressure level sensor allows farmers to monitor the water tank level and remotely control the water pump. If the water level drops below a set threshold, the system automatically activates the pump until the tank is full.

The process of real time data monitoring happens due to the data being transmitted and displayed on Node-RED dashboard via MQTT protocol. The data are stored in a data storage called MySQL which enables farmers to keep track with the history record. The dashboard is designed with a user-friendly interface for ease of use. Figure 10 depicts the setup of the system.

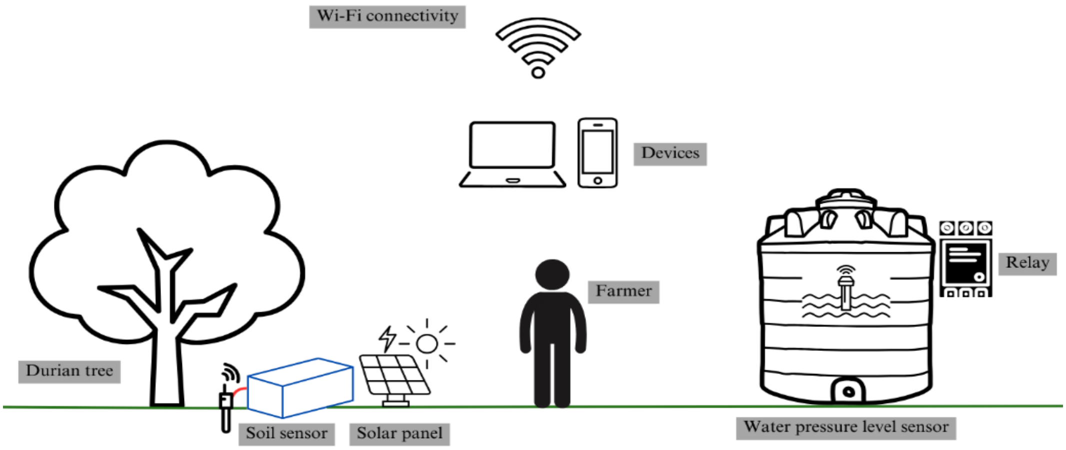


Figure 9. System setup

2.6 Test description

The testing procedure for the soil nutrient monitoring system is carried out by placing the sensor on a soil sample. The same sample is sent to MARDI for a soil nutrient lab testing. However, due to some instruments being under maintenance, not all parameters could be tested. Hence, to ensure a detailed comparison and determining the sensor's reliability, an additional soil tester sensor and soil kit tester are purchased for further data collection and validation.

As for the smart switch water system, the initial testing is conducted in the laboratory before finally installing it at the farm. In this setup, a standing fan acts as water pump for simulation purpose, and a pail of water acts as the water tank. The coding for the water tank depth is adjusted following the pail depth. During testing, the water pressure level sensor measures the water depth and sends the signal to the modbus relay to switch on the fan when the water level falls below 20% of the set threshold. As the fan runs, water is added gradually until the pail reaches certain level, at which point the sensor sends a signal again to the modbus relay to automatically turn off the fan. In addition, the dashboard button for manually switching the water pump on and off is also tested and confirmed to be functioning correctly. Figure 10 depicts the initial testing of the smart switch water system.

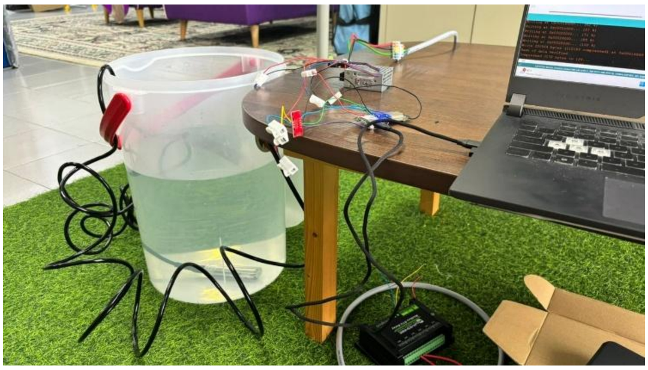


Figure 10. Testing process of smart switch water system

3.0 RESULTS AND DISCUSSION

3.1 Test description

Figure 11 depicts the dashboard for Durian Tree Smart Switch Water & Soil Monitoring system. The dashboard provides real time data of the soil's nutrient and tank's water level. There are six crucial soil parameters displayed for the durian trees' health and growing conditions. As can be seen, the parameters display the current values of temperature, humidity, pH, Nitrogen (N), Phosphorus (P) and Potassium (K) at that moment. The water level indicator currently shows 0mm; hence. data are sent to a modbus relay to automatically switch on the water pump resulting to the pump status indicator showing "ON". This helps farmers in tracking water availability and provides real time feedback on the farm's irrigation activity. If the water level is not full but not below the pre-set threshold, farmers can simply click the "PUMP ON" button to turn the water pump. The farmers can also switch the water pump off below the set threshold by clicking the "PUMP OFF" button.

Figure 12 shows the line chart and bar chart of the soil parameters. Each chart shows the trend over time and there is also a data table that summarizes the minimum and maximum values of the soil parameters. Each chart shows constant value over time as a single type of soil is used at that time; thus, showing uniform values at different times. There are buttons for hourly and weekly queries that allow farmers to analyse the soil data trends over different period. The purpose of "CLEAR ALL" button is to reset the data for the soil parameters. A "Download CSV" button is also provided for famers to easily export the soil nutrient data for further analysis.

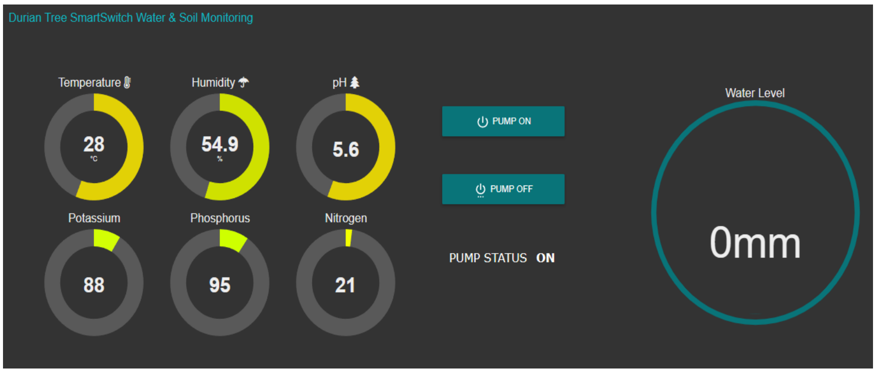


Figure 11. System's dashboard

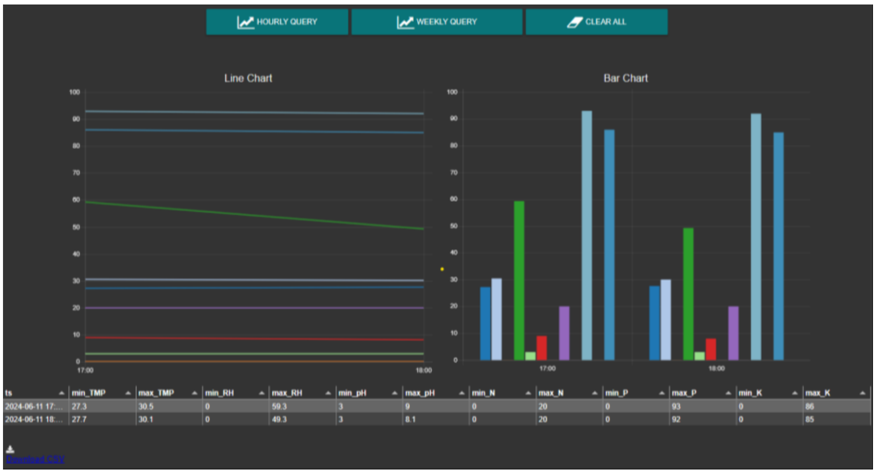


Figure 12. Line chart and bar chart of the soil parameters

3.2 System testing

3.2.1 Soil Nutrient Content

Table 4 presents the data collected from different type of testing of the soil parameters to determine the reliability of the data collected from the system soil sensor. The parameters measured by the soil sensor include temperature, humidity, pH, Nitrogen, Phosphorus and Potassium. It compares results obtained from the system soil sensor, a soil test kit and a 3 in 1 soil sensor bought from online together with a lab test result from MARDI as shown in Figure 13.

From the formula of the percentage error, it is obtained that the percentage errors for pH and Nitrogen parameters between the system soil sensor and MARDI lab results are 6.25% and 13.33%, respectively. As for the temperature and humidity, the percentage errors are 0.66% and 4.21% respectively when compared to 3 in 1 soil sensor. These errors indicate that the system soil sensor is fairly accurate in measuring soil parameters such as temperature, humidity, pH, Nitrogen, Phosphorus and Potassium.

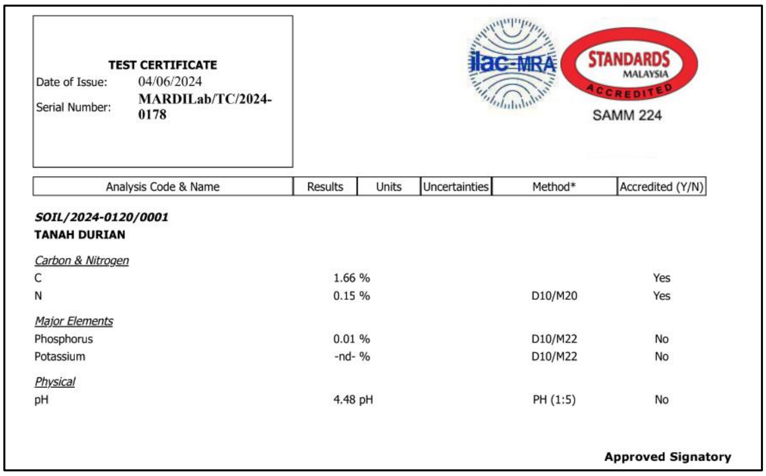
Despite the low percentage errors obtained from the system, it may degrade over time because the sensor's sensitivity might be affected by variations in voltage and current it receives. Therefore, it is important to maintain the battery of the soil sensor at a good level. The provided solar panels on the soil monitoring system can fully charge the battery within a day.

The percentage error of the system soil sensor is calculated using the formula below:

$$Percentage\ error: \frac{(|Experimental\ Value - Actual\ Value|)}{Actual\ Value} x100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [1]$$

Table 4. Soil nutrient data

Type of testing	Soil Parameters					
	Temperature, °C	**Humidity, %**	**pH**	**Nitrogen, mg/L**	**Phosphorus, mg/L**	**Potassium, mg/L**
System soil sensor	30.5	18.2	4.20	13	76	69
Soil test kit	-	-	4.00	20	70	50
3 in 1 soil sensor	30.3	19.0	4.30	-	-	-
MARDI lab	-	-	4.48	15	1	-


TEST CERTIFICATE
Date of Issue: 04/06/2024
Serial Number: MARDILab/TC/2024-0178

SAMM 224

Analysis Code & Name	Results	Units	Uncertainties	Method*	Accredited (Y/N)
SOIL/2024-0120/0001 TANAH DURIAN					
Carbon & Nitrogen					
C	1.66 %				Yes
N	0.15 %			D10/M20	Yes
Major Elements					
Phosphorus	0.01 %			D10/M22	No
Potassium	-nd- %			D10/M22	No
Physical					
pH	4.48 pH			PH (1:5)	No

Approved Signatory

Figure 13. MARDI's lab test result

3.2.2 Validation of Smart Switch Water System Prototype

The smart switch water management system is tested and approved to be functioning correctly. Figures below depict the functionality of the system. In this setup, a standing fan acts as water pump for simulation purpose, and a pail of water acts as the water tank. As shown in Figure 14 below, the pump status displayed “ON” indicating the standing fan (acting as water pump) is switched on as it is now fell below the set threshold value of 1 metre to switch the water pump on.

This is shown in Figure 15, where the standing fan is running. When the depth reached 4.5 metres, it successfully turns off the water pump. It is programmed to switch off the water pump at 4.5 meter to avoid water spillage as there are delays in the Modbus relay to automatically shut down the water pump. During the testing simulation, the standing fan turns off the standing fan when it reaches 0.3 meters of the water pail.

Although the system is functioning as intended, there is still instability in the sensor readings, which may likely be due to the cable not properly insulated and the system is not properly grounded. Poor insulation is one of the biggest contributions that contribute unstable readings. Since the sensor uses an analogue signal, it is very sensitive to noise especially when the cable is long and exposed to other electrical activities. For future applications, in order to make the smart switch water management system more robust and suitable to be applied on the farm or any industrial use, it is essential to ensure that the analogue cable is properly insulated, and the sensor grounding must be properly done to eliminate noise. Before installation, it is advisable to let the system run for at least a month to ensure stability of the system and to verify that no errors occur over an extended period.

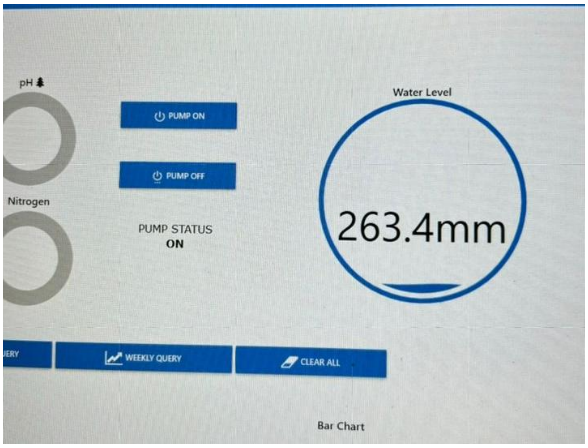


Figure 14. Water management dashboard

Figure 15. Water pump simulation

4.0 CONCLUSION

In conclusion, the IoT-based smart switch water and soil monitoring system developed for durian farms represents a significant advancement in agricultural technology. Testing confirmed the system's reliability, with error percentages remaining consistently low when compared to laboratory results. This validates the accuracy of the system in measuring crucial soil parameters including temperature, humidity, pH, nitrogen, phosphorus, and potassium levels.

The integration of solar panels addresses the energy requirements of remote orchards, ensuring sustainable operation of the soil monitoring component. By enabling remote monitoring and control capabilities, the system effectively overcomes geographical challenges faced by durian farmers who manage distant plantations, eliminating the need for frequent on-site visits that consume both time and resources [25].

From an economic perspective, the system offers compelling advantages. With installation cost of approximately RM700 and an annual data subscription fee of just RM60, the smart switch water system proves to be significantly more economical than hiring part-time labour, which typically costs farmers between RM700 to RM1,500 monthly. These substantial cost savings, combined with improved consistency in orchard management, make a strong case for technology adoption.

The system also streamlines farm documentation by providing downloadable data of soil parameters, eliminating tedious manual record-keeping. Through real-time monitoring and automated irrigation control, the technology optimizes resource utilization while potentially enhances durian tree health and fruit quality. This makes durian cultivation not only more efficient but also a more attractive and manageable investment prospect.

The positive results from this research confirm that targeted IoT applications offer viable, cost-effective solutions for advancing precision agriculture practices in durian farming [26].

AUTHORS CONTRIBUTION

Nur Syahirah Mohamed Zaki	Data Curation, Writing - Original Draft
Mohd Hanif Mohd Ramli	Supervision, Data Curation
Zulkifli Bin Mohamed	Writing - Review & Editing, Resources
Nurul Syuhadah Khusaini	Supervision, Project Administration, Writing – Review & Editing

DECLARATION OF COMPETING OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

[1] M. I. Hairudin, M. Zaid Mustafa, and R. Ahad, "Durian Tree Watering System Uses IoT and Solar Energy," vol. 3, no. 1, pp. 12–022, 2023, doi: 10.30880/ritvet.2023.03.01.002.

[2] S. Sugiyarto, L. Kurniasari, I. Harlianingtyas, and R. R. Wijayanti, "Identification agronomic character of local durian parent trees as a step to develop a durian center in Sukowono and Sumberjambe," in IOP Conference Series: Earth and Environmental Science, Institute of Physics, 2023. doi: 10.1088/1755-1315/1168/1/012014.

[3] J. G. M. A et al., "Microclimate monitoring system for irrigation water optimization using IoT," Measurement: Sensors, vol. 27, Jun. 2023, doi: 10.1016/j.measen.2023.100727.

[4] T. Yi Ming and M. Shamian Zainal, "IoT Based Durian Tree Monitoring System MALAYSIA *Corresponding Author Designation," Progress in Engineering Application and Technology, vol. 3, no. 1, pp. 604–613, 2022, doi: 10.30880/peat.2022.03.01.060.

[5] M. Pužin, "Soil monitoring technologies on Internet of Things." [Online]. Available: https://urn.nsk.hr/urn:nbn:hr:204:848186

[6] S. Neubauer, "The place of data in precision agricultural data asset management," Institutiones Administrationis, vol. 1, no. 2, pp. 52–61, 2021, doi: 10.54201/iajas.v1i2.23.

[7] G. Doggalli et al., "Exploring big data innovations in food and agriculture research: An in-depth analysis," International Journal of Research in Agronomy, vol. 7, no. 3S, pp. 330–336, 2024, doi: 10.33545/2618060x.2024.v7.i3se.471.

[8] L. A. Cernusak, K. Winter, and B. L. Turner, "Leaf nitrogen to phosphorus ratios of tropical trees: Experimental assessment of physiological and environmental controls," New Phytologist, vol. 185, no. 3, pp. 770–779, Feb. 2010, doi: 10.1111/j.1469-8137.2009.03106.x.

[9] A. B. Edfast, T. Näsholm, A. Aronsson, and A. Ericsson, "Applications of mineral nutrients to heavily N-fertilized scots pine trees: Effects on arginine and mineral nutrient concentrations," Plant Soil, vol. 184, no. 1, pp. 57–65, 1996, doi: 10.1007/BF00029274.

[10] D. Hercog, T. Lerher, M. Truntič, and O. Težak, "Design and Implementation of ESP32-Based IoT Devices," Sensors, vol. 23, no. 15, 2023, doi: 10.3390/s23156739.

[11] H. Irmayanti, T. Tosin, M. L. Mahdi, and B. Yosafat, "Internet of Things-based Street Lighting System with Message Queuing Telemetry Transport and Progressive Web Application," Journal of Engineering Research (Kuwait), vol. 9, 2021, doi: 10.36909/jer.ASSEEE.16097.

[12] M. Blackstock and R. Lea, "Toward a distributed data flow platform for the Web of Things (Distributed Node-RED)," ACM International Conference Proceeding Series, vol. 08-October, pp. 34–39, 2014, doi: 10.1145/2684432.2684439.

[13] Á. Villalba, J. L. Pérez, D. Carrera, C. Pedrinaci, and L. Panziera, "ServIoTicy and iServe: A scalable platform for mining the IoT," Procedia Comput Sci, vol. 52, no. 1, pp. 1022–1027, 2015, doi: 10.1016/j.procs.2015.05.097.

[14] S. Raj, L. Rajput, K. Saxena, and S. Sharma, "IOT BASED SOIL NUTRIENT MONITORING DEVICE," www.irjmets.com @International Research Journal of Modernization in Engineering, vol. 3353, [Online]. Available: www.irjmets.com

[15] N. N. C Othaman, M. N. Md Isa, R. Hussin, S. M. M S Zakaria, and M. M. Isa, "IoT Based Soil Nutrient Sensing System for Agriculture Application," 2021.

[16] N. J. Mary, Y. J. Mary, and S. R. Ponselvi, "Iot-BASED SOIL CONTENT ANALYSIS," Journal of Pharmaceutical Negative Results ¦, vol. 14, doi: 10.47750/pnr.2023.14.04.16.

[17] D. Saikia and R. Khatoon, "Smart monitoring of soil parameters based on IoT," International Journal of Advanced Technology and Engineering Exploration, vol. 9, no. 88, pp. 401–412, 2022, doi: 10.19101/IJATEE.2021.874650.

[18] M. Anjaneyulu et al., “Sustainable practices for plant nutrient control using IoT,” E3S Web of Conferences, vol. 507, 2024, doi: 10.1051/e3sconf/202450701039.
[19] F. Jan, N. Min-Allah, S. Saeed, S. Z. Iqbal, and R. Ahmed, “IoT-Based Solutions to Monitor Water Level, Leakage, and Motor Control for Smart Water Tanks,” Water (Switzerland), vol. 14, no. 3, 2022, doi: 10.3390/w14030309.
[20] X. Yan, J. Yang, and W. Lu, “Design of Remote GPRS-based Gas Data Monitoring System,” IOP Conf Ser Earth Environ Sci, vol. 108, no. 4, 2018, doi: 10.1088/1755-1315/108/4/042091.
[21] M. Alves, J. M. Dias Pereira, and J. P. S. Catalão, “Characterization of solar panels for powering sensor applications,” Renewable Energy and Power Quality Journal, vol. 1, no. 9, pp. 627–630, 2011, doi: 10.24084/repqj09.407.
[22] J. Du, “Real-Time Information Exchange Strategy for Large Data Volumes Based on IoT,” Comput Intell Neurosci, vol. 2022, 2022, doi: 10.1155/2022/2882643.
[23] S. Rimdusit, P. Wongmanit, S. Damrongsakkul, D. Saramas, C. Jubsilp, and I. Dueramae, “Characterizations of poly(vinyl chloride)/acrylonitrile styrene acrylate blends for outdoor applications,” Engineering Journal, vol. 18, no. 1, pp. 105–118, 2014, doi: 10.4186/ej.2014.18.1.105.
[24] IOWA, “Percent Error Formula | Imaging the Universe - The University of Iowa,” itu.physics.uiowa.edu, 2024. https://itu.physics.uiowa.edu/glossary/percent-error-formula
[25] A. S. Oh, “Smart urban farming service model with IoT based open platform,” Indonesian Journal of Electrical Engineering and Computer Science, vol. 20, no. 1, pp. 320–328, 2020, doi: 10.11591/ijeecs.v20.i1.pp320-328.
[26] S. A. B. Anas, R. S. S. Singh, and N. A. B. Kamarudin, “Designing an IoT Agriculture Monitoring System for Improving Farmer’s Acceptance of Using IoT Technology,” Engineering, Technology and Applied Science Research, vol. 12, no. 1, pp. 8157–8163, 2022, doi: 10.48084/etasr.4667.