Soedirman Accounting, Auditing, and Public Sector Journal (SAAP)
Volume 5 Issue 1, June 2026: 91-99
ISSN: 2962-2336

IMPLEMENTATION OF IOT-BASED SMART FARMING FOR OPTIMIZING PLANT WATERING BASED ON MOISTURE AND PH IN DURIAN SEEDLINGS

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Abstract

This The rapid development of Internet of Things (IoT) technology has significantly impacted agriculture by enabling automation and real-time monitoring. This study aims to design and implement an IoT-based Smart Farming system to optimize irrigation of durian seedlings based on soil moisture and pH levels. The system uses an ESP32 microcontroller connected to soil moisture and pH sensors, with data transmitted via the MQTT protocol to a Flutter-based mobile application. The application allows users to monitor soil conditions and control a water pump both automatically and manually. In addition, the system integrates a durian leaf disease detection feature using a machine learning model trained with Google Teachable Machine and deployed with TensorFlow Lite on the mobile application. System evaluation was carried out using the Dimension of Quality for Goods (DQG) to assess product quality and the Usability, Learnability, Efficiency, Acceptability (ULEA) method to measure user benefits. The results show that the system operates stably, provides real-time monitoring, and achieves a leaf disease detection accuracy of 93.33%. Furthermore, the product feasibility score reached 86.95%, while the system benefit score was 87.13%, both classified as acceptable. These findings indicate that the proposed system can help farmers improve water efficiency, reduce manual labor, and support the modernization of durian cultivation practices.
Keywords: *Internet of Things, Smart Farming, MQTT, Flutter, Automatic Irrigation.*

Citation: Listyanto, A. R., Purnomo, J., Kisworini, R. Y., Andayani, M. & Rini, E. P. (2026). Implementation of IOT-Based Smart Farming for Optimizing Plant Watering Based on Moisture and PH in Durian Seedlings. *Soedirman Accounting, Auditing, and Public Sector Journal (SAAP),* 5(1), 91-99.

INTRODUCTION

The rapid development of information and communication technology has significantly influenced various sectors, with the agricultural sector being one of them. Furthermore, research by Huafeng Pang et al. demonstrates the efficient utilization of the MQTT protocol for real-time communication, although it has not yet been applied to the agricultural field. Fatah Ridho Perdana and Niki Ratama also developed an IoT-based soil pH and moisture monitoring system using a time series method; however, their study focused strictly on monitoring without integrating automatic watering features or plant disease detection.

Based on these previous studies, a gap remains, particularly regarding the integration of automatic irrigation based on soil moisture and pH with a mobile application-connected leaf disease detection feature powered by machine learning. Therefore, this study proposes the development of an IoT-based Smart Farming system for durian seedlings. This system is capable of performing automatic watering while simultaneously detecting leaf diseases, supported by a Flutter-based mobile application using the MQTT protocol. This system is expected to assist farmers in improving water efficiency, reducing manual labor, and supporting the modernization of durian cultivation in Indonesia.

RESEARCH METHOD

This study utilizes an experimental method by designing and implementing an Internet of Things (IoT)-based Smart Farming system. The developed system functions to monitor the soil moisture and pH of durian seedlings in real-time, control a water pump both automatically and manually, and perform leaf disease detection using machine learning.

The research phases began with a literature study, hardware and software design, system implementation, testing, and final evaluation. The literature study was conducted by reviewing previous research related to IoT, soil sensors, and the application of machine learning in agriculture. The insights gained from the literature review served as the foundation for the system design.

The design phase involved constructing system block diagrams and operational flowcharts. Implementation included programming the ESP32 microcontroller, integrating sensors, developing the Flutter-based mobile application, and deploying the Message Queuing Telemetry Transport (MQTT) communication protocol.

System testing was carried out across two main aspects: hardware and software. The hardware was tested through the measurement accuracy of the soil moisture and pH sensors, as well as the performance of the water pump. The software was tested via MQTT data communication, mobile application interface display, and leaf disease detection accuracy. The final evaluation of the system was conducted using the Dimension of Quality for Goods (DQG) method and the Usability, Learnability, Efficiency, Acceptability (ULEA) framework.

TOOLS AND MATERIAL

Hardware:

a) Controller: ESP32 as the primary microcontroller.
b) Sensors: Soil moisture sensor and soil pH sensor + DMS module to monitor soil conditions.
c) Output: 1-channel relay, R385 water pump, and 16x2 I2C LCD for control and data display.
d) Connection & Support: Jumper wires, 12V/5V power adapter, and a Lenovo ThinkPad X13 laptop for programming and mobile application development.

Software:

a) Programming & Development: Arduino IDE, Visual Studio Code, Android Studio, Flutter SDK, and Dart SDK.
b) IoT Communication: MQTT Box and Adafruit MQTT Broker.
c) Machine Learning: Teachable Machine for training the durian leaf classification model (exported to .tflite).

System Design

The system design developed in this research consists of three main components: hardware, software, and a mobile application. The hardware functions as a data collector and controller, the microcontroller software processes and transmits data, and the mobile application displays real-time data while serving as the interface for watering control and disease detection.

- System Block Diagram: (Refer to Figure 2.1 IoT Diagram)
- Image Processing Block Diagram: (Refer to Figure 2.2 Image Processing Block Diagram)

The ESP32-based monitoring system integrates data from the pH sensor and soil moisture sensor, connecting to the application via the MQTT protocol. If the moisture level drops below 30%, the pump activates automatically and stops once the soil is sufficiently moist. Data is sent to the MQTT broker and can be monitored or manually configured through the application.

Additionally, the system analyzes leaf images using machine learning. Images captured via the smartphone camera or uploaded from the gallery undergo preprocessing (resizing, normalization, and format conversion). Then, the TensorFlow Lite model extracts features (color, texture, and shape) for classification into four categories: Healthy, Wilted, Fungus, or Pest. The results are displayed with a confidence percentage and corresponding plant care recommendations.

System Implementation

System implementation was executed after the design phase was completed. The system comprises the integration of hardware, software, and a Flutter-based mobile application.

Microcontroller and Sensors

The ESP32 microcontroller was programmed using the Arduino IDE to read data from the soil moisture and pH sensors. The sensor readings are converted into numerical values representing the soil condition. The ESP32 also controls a relay module that functions as a switch to activate the water pump.

Data Communication

The sensor data read by the ESP32 is transmitted to a Message Queuing Telemetry Transport (MQTT) broker. The broker used is HiveMQ, which operates online so it can be accessed remotely by the mobile application. This communication process enables real-time data transmission with low latency.

Mobile Application

The mobile application was developed using Flutter and connected to the HiveMQ broker. It displays sensor data through real-time charts and easily readable numerical values. The application is also equipped with controls to manually activate or deactivate the water pump.

Irrigation Control

The watering system operates in two distinct modes:

- Automatic: The water pump turns on if the soil moisture value falls below a predefined threshold.
- Manual: Users can turn the water pump on or off directly through the mobile application interface.

Leaf Disease Detection

An additional feature of the system is durian leaf disease detection. The machine learning model was trained using Teachable Machine with a dataset of healthy and diseased durian leaf images. The model was then deployed within the mobile application using TensorFlow Lite. The detection process is carried out by capturing a leaf image through the smartphone camera, after which the system displays the classification result on the screen.

Data Collection Techniques

a) Real-time sensor data consisting of soil moisture and pH values sent from the ESP32 microcontroller to the mobile application via the MQTT protocol.
b) Leaf disease detection data obtained from image classification results using the TensorFlow Lite machine learning model.
c) Product quality testing data collected using the Dimension of Quality for Goods (DQG) method, which assesses performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality.
d) System benefit data gathered using the Usability, Learnability, Efficiency, Acceptability (ULEA) framework via questionnaires distributed to 20 respondents consisting of durian farmers and the general public.

Testing Methods

System testing was conducted in several stages:

a) Sensor Functionality Testing: Soil moisture and pH sensors were tested by comparing their readings against actual field conditions.

b) Data Communication Testing: The ESP32 transmitted data to the MQTT broker, which was then verified on the mobile application to ensure real-time data reception without significant delay.

c) Pump Control Testing: Tests were performed on both modes: automatic (based on moisture thresholds) and manual (via the mobile app).

d) Leaf Disease Detection Testing: Conducted by capturing images of healthy and diseased durian leaves. The system's classification results were compared with actual conditions to calculate accuracy.

e) Product Quality Evaluation: Evaluated using the Dimension of Quality for Goods (DQG) method with predefined indicators.

$$\text{Product Value} = \left(\frac{\sum \text{Total Respondent Score}}{60 \times \text{Number of Respondents}} \right) \times 100\%$$

f) System Benefit Evaluation: Evaluated using the ULEA framework. Respondents provided ratings via a questionnaire covering usability, learnability, efficiency, and acceptability.

$$\text{Benefit Value} = \left(\frac{\sum \text{Total Respondent Score}}{16 \times 4 \times \text{Number of Respondents}} \right) \times 100\%$$

RESULTS AND DISCUSSION

1. System Implementation Results

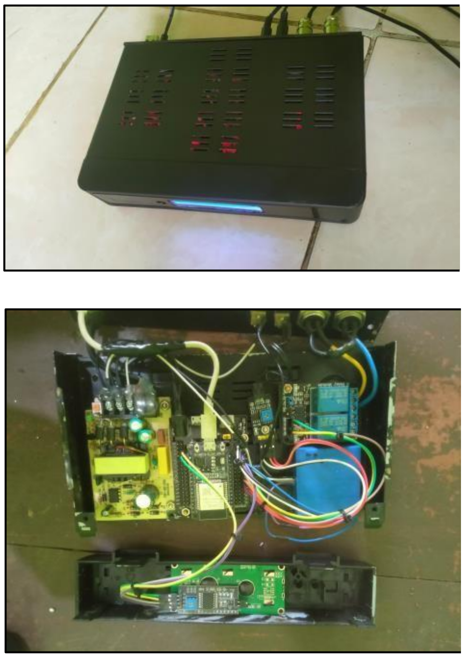

Figure 3.1.implementation of IOT

The Internet of Things (IoT)-based Smart Farming system was successfully implemented as hardware containing an ESP32 microcontroller, soil moisture sensor, soil pH sensor, relay module, and a water pump. All components were integrated to function according to the design.

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The assembled hardware is shown in Figure 3.1. This hardware setup was used to test sensor readings, data communication via the MQTT protocol, and automatic/manual pump controls.

Beyond the hardware, the mobile application developed with Flutter displays real-time sensor data and provides pump control and leaf disease detection interfaces. The application UI is shown in Figure 3.2.

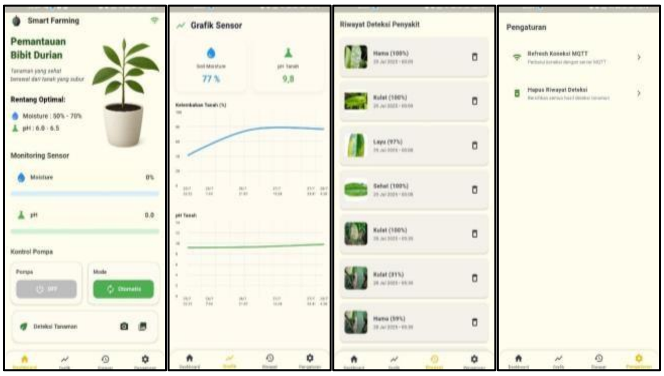

Figure 3.2.Implemetation Mobile Aplication

System Testing

1. Sensor Testing

The soil moisture and pH sensors were tested by comparing their readings with manual measurement tools in the field. The results show that the sensors can read moisture and pH values with a relatively small relative error, making them viable for system implementation.

Table 3.1 Sensore Testing

ondisi Tanah	Sensor *IoT*		Sensor Manual	
	Kele mbapan	h	Kele mbapan	h
ering	32%		30%	
enbap	49%		50%	
asah	80%		80%	
sam	-	.2	-	.0
etral	-	.8	-	.0
asa	-	.9	-	.0

2. Pump Control Testing

Pump control testing was carried out in both automatic and manual modes. In automatic mode, the pump turns on when the moisture value drops below the set threshold and stops when the value rises above it.

Table 3.2 .Pump Response Based on Threshold

Kelemba pan (%)	Status Pompa
24	ON
36	ON
45	OFF
60	OFF

80	OFF

The results indicate that the pump turns on automatically if the moisture falls below 30%. In manual mode, users can seamlessly activate or deactivate the pump via the mobile application.

Table 3.3 Pump Response from Application

Percobaan	Waktu Respon (detik)
1	3 detik
2	2 detik
3	1 detik
4	3 detik
5	1 detik

The testing results confirm that the pump operates reliably according to system commands in both automatic and manual modes.

3. Leaf Disease Detection Testing

The leaf disease detection feature was evaluated using images of healthy and diseased durian leaves. The system classifies the images using the TensorFlow Lite-based machine learning model (as shown in Figure 3.3 Leaf Detection Testing).

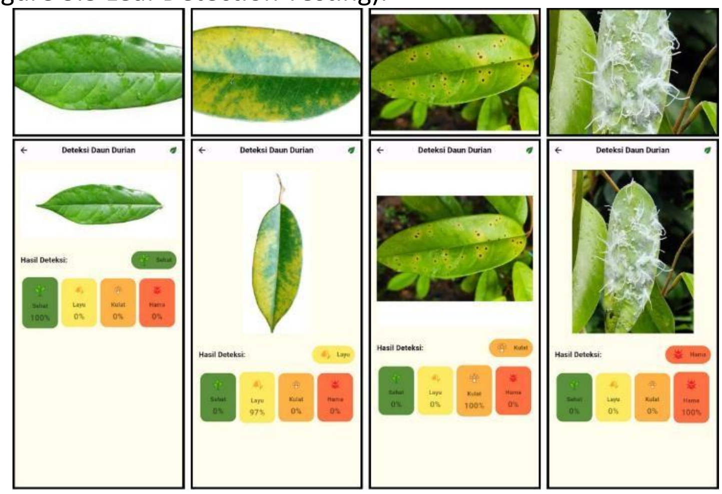

Figure 3.3. Leaf Detection testing

System Evaluation

1. Product Quality Testing

Product quality evaluation was performed using the Dimension of Quality for Goods (DQG) method, covering eight dimensions: performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality.

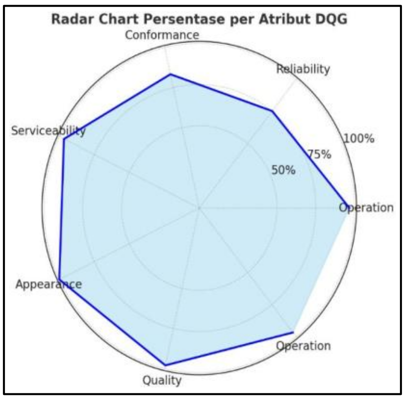

Figure 3.4 Chart Atribut Radar

The evaluation results showed that the developed system scored well in performance and features due to its ability to display real-time sensor data, control the water pump across dual modes, and detect leaf diseases. In terms of reliability and conformance, the system operated stably with low sensor reading errors. Regarding aesthetics and serviceability, respondents rated the mobile application as visually appealing and user-friendly.

Table 3.4 Product Test Results

Total Overall Respondent Score	825
Maximum Score	900
Product Value (%	91.67
Passing Threshold (%)	75
Decision	Passed / Feasible

2. System Benefit Testing

The system benefit test was conducted using the ULEA framework involving 20 respondents (durian farmers and the public).

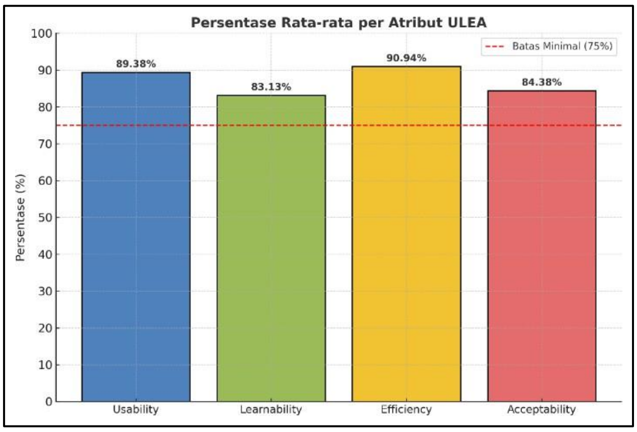

Figure 3.5. Atribut Presentation Graph

The test results demonstrated that the system has high usability because the application is easy to understand. In terms of learnability, respondents were able to grasp the application's functionality rapidly. For efficiency, the system was deemed highly effective in helping farmers save time and effort when monitoring and watering durian seedlings. Regarding acceptability, the majority of respondents expressed satisfaction and willingness to adopt this system on a larger scale.

Table 3.5 Benefit Test Results

Total Score (All Respondents)	Maxi mum Score	valu e(%)	Condition
1113	128 0	6.95	Lay ak

CONCLUSION AND SUGESTION

Conclusion

This study successfully developed an Internet of Things (IoT)-based Smart Farming system for monitoring soil moisture and pH, alongside durian leaf disease detection. The system utilizes an ESP32 microcontroller integrated with soil moisture and pH sensors connected to a Flutter-based mobile application via the Message Queuing Telemetry Transport (MQTT) protocol.

The testing results demonstrate that:

1. The soil moisture and pH sensors can read soil conditions in real-time with a relatively low error rate.
2. Data communication utilizing the MQTT protocol runs efficiently, with an average latency of less than 1 second.
3. The irrigation system operates as intended in both automatic and manual configurations.
4. The TensorFlow Lite-based leaf disease detection feature successfully classifies leaf health with a high level of accuracy.
5. System evaluation using the Dimension of Quality for Goods (DQG) framework indicates high product quality across almost all dimensions.
6. Benefit testing via the ULEA method yielded positive feedback from respondents, who found the system user-friendly, efficient, and highly suitable for durian cultivation.

In conclusion, the developed system successfully helps farmers optimize water efficiency, minimize dependence on manual labor, and support the modernization of durian farming practices in Indonesia.

Suggestions

Several recommendations for future research developments include:

1. Adding a backup power storage system (e.g., UPS or solar power) so the device can continue operating during power outages.
2. Utilizing industrial-grade sensors with higher precision to improve data reliability over long-term deployment.
3. Integrating a push notification feature within the mobile application to automatically alert users when soil conditions reach critical thresholds or when a leaf disease is detected.
4. Expanding the image dataset for machine learning model training to improve the accuracy and variety of leaf disease detection.
5. Developing system integration with cloud computing platforms for long-term data logging and predictive data analytics.

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