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Development of a Smart Coffee Model Based on the Internet of Things (IoT) in West Java Province

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Abstract

Coffee cultivation in fertile regions such as Ciniru District, Kuningan Regency, is still predominantly carried out manually, lacking adequate technological support. However, coffee plants require intensive monitoring of environmental conditions to ensure optimal productivity and quality. The absence of technology adoption in farming practices results in inefficiencies and makes the cultivation process vulnerable to pests and climate-related disruptions. This study aims to develop a smart monitoring system for coffee plantations in Gunung Manik Village, utilizing an Internet of Things (IoT)-based Smart Coffee model. The system is designed to assist coffee farmers in Kuningan in improving yields and providing guidance for crop management through real-time monitoring of soil moisture, environmental temperature, and pest activity. An experimental method was employed in this research, where data is transmitted via radio frequency to a gateway and subsequently forwarded to middleware for further processing. The processed data is then visualized through a dashboard and a mobile-based application. Currently, the system is focused on a single variety of coffee plants. The results demonstrate that the system provides accurate data for irrigation and fertilization scheduling, as well as notifications regarding plant conditions, growth stages, and cultivation status. In conclusion, the coffee plant monitoring system offers a practical digital solution for farmers and is expected to enhance agricultural productivity through the integration of information technology.

Keywords: Smart Coffee; Monitoring; Internet of Things; Coffee; IoT

1. INTRODUCTION

Coffee is one of the main agricultural commodities with high economic value in the plantation industry. In 2015, Indonesia's coffee export volume reached 502,021 tons with an export value of 1,197.735 million US dollars [1]. According to data from the International Coffee Organization (ICO) in 2015, Indonesia ranked 4th among the world's coffee producers with a production of 9,350 tons. However, in the overall coffee processing industry, the structure remains unbalanced, as only 20% is processed into products such as ground coffee, instant coffee, and coffee mix, while 80% remains as dry coffee beans. Most of the coffee is exported in the form of dry beans, while only about 3-4% of processed coffee is exported. West Java ranks 11th as one of the largest coffee producers in Indonesia, according to data released by the Directorate General of Estates in 2016. The coffee plantation area in West Java reached 32,538 hectares, yielding a total of 16,645 tons of coffee.

Currently, in Indonesia, land management and maintenance tasks are still carried out manually by human labor. Farmers are assigned to perform several tasks, such as plowing, providing fertilizers and water to crops, pest control, monitoring soil moisture levels, and maintaining soil fertility. While these land management activities have the potential to eliminate standard working procedures due to their repetitive nature, there is also the possibility of human error, leading to inefficiencies in land management [2]. Pest activity is another concern for farmers, as it can lead to suboptimal harvests, and in some cases, cause crop failures.

One of the regions in West Java with the largest coffee commodity is Gunung Manik Village, Ciniru District, Kuningan Regency. Gunung Manik has significant potential for coffee plantation development. The fertile land spread across Gunung Manik Village is influenced by its location on the island of Java, which is home to several active volcanoes. Additionally, Gunung Manik has favorable land contours, making it easier for farmers to manage their crops.

The rapid growth of information technology in recent years can be utilized to assist farmers in monitoring agricultural land and plantations automatically. With the implementation of an automated monitoring system using embedded devices, farmers are supported by devices that tirelessly monitor soil conditions and systems that do not make errors in analyzing soil conditions, as often occurs today. One such technology that can be used for plantation monitoring is the Internet of Things (IoT).

The Internet of Things (IoT) is one of the fastest-growing technologies today. IoT utilizes internet connectivity for devices to communicate and exchange data. The application of IoT-based technology in everyday life is highly beneficial for energy management, such as in smart homes, smart gardens, and smart metering [3]. In general, IoT technology applications use a microcontroller as a command interpreter into programming language to complete tasks. One of the most commonly used microcontrollers in IoT projects is Arduino. Arduino technology has been widely used in various fields, including agriculture, healthcare, livestock, robotics, security, and transportation [4].

The IoT system developed in this study is a Smart Coffee model based on IoT. Several types of data/information monitored by the system include soil moisture levels, soil temperature, and pest activity (motion). These data are collected

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from end devices and transmitted via radio frequency to a gateway. The gateway then forwards the data to middleware for processing. The monitoring system utilizes real-time data collected from end devices, processing the information into an Admin web dashboard and a mobile application used by farmers to manage real-time data from their coffee plantations. This system provides information on the development of plants in the plantation being cultivated by the farmers. This study focuses on a single type of plant[5].

Prior research has demonstrated the substantial use of Internet of Things (IoT) technology in facilitating smart agricultural systems, particularly for coffee farming. Selvanarayanan et al. (2024) created a soil fertility monitoring system utilizing RNN-IoT technology, featuring a counterfactual suggestion algorithm to enhance fertilization and irrigation efficiency. While the technology demonstrates proficiency in predictive modeling, the methodology is intricate and has not clearly highlighted the accessibility of a user interface that may be directly utilized by farmers in a practical context. Simultaneously, Rosdiana et al. (2025) devised a temperature and humidity regulation system in a robusta coffee nursery greenhouse utilizing fuzzy logic technology. This study primarily emphasizes the regulation of the microenvironment within a confined area, rather than the observation of an open field. These findings indicate a research gap concerning the scarcity of IoT systems that offer comprehensive real-time multi-parameter environmental monitoring in open fields, are accessible via a user-friendly website, and can be utilized independently by farmers without dependence on intricate artificial intelligence models [8]. The iotgm.id system addresses this deficiency by providing a straightforward yet effective solution that integrates temperature data, soil moisture, and motion detection (indications of pests), accompanied by a user-friendly web interface designed for farmers in rural locales like Gunungmanik Village.

This system aims to provide accurate information regarding irrigation and fertilization in coffee plantations. Additionally, it provides notifications about the coffee plantation's condition, surrounding humidity levels, and pest movement. The goal is to help farmers in Gunung Manik Village, a coffee-producing region, to improve their harvest yields and receive guidance in managing their coffee plants.

2. RESEARCH METHODOLOGY

2.1 Research Design

This research employs an experimental approach to develop and evaluate an IoT-based Smart Coffee Monitoring System. The research stages are illustrated in Figure 1 and include: (1) requirement analysis and system design, (2) hardware selection, (3) software development, (4) data collection and transmission, (5) data processing and analysis, and (6) system testing and validation. These stages allow systematic application of solutions and continuous evaluation of performance in real plantation conditions.

Prior studies such as Rodríguez et al, (2021) demonstrated that IoT solutions significantly improve plantation management by enabling real-time soil and pest monitoring. Similar frameworks guided the algorithm and sensor selection in this study, ensuring compatibility with environmental conditions and cost-effectiveness for farmers [9]. Figure 1 shows the block diagram of the developed system. It details how soil moisture, temperature, and pest sensors feed data to the microcontroller, which transmits through a wireless module to a middleware platform. The processed data is then visualized on web and mobile dashboards for farmers' decision-making.

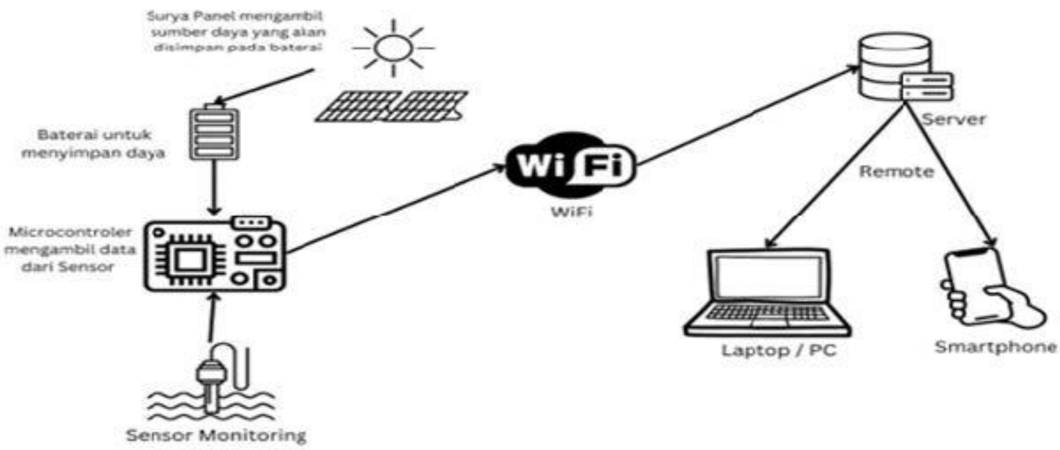

Figure 1. Block Diagram of the Developed System

2.2 System Development Process

2.2.1 Requirements Analysis and System Design

The first stage involves conducting a thorough analysis of the requirements for the IoT system. This includes identifying the critical factors affecting coffee plantation management, such as moisture, temperature, and pest monitoring.

Afterward, the system architecture is designed, which includes selecting appropriate sensors, microcontrollers, and communication protocols. The system design also includes creating a user interface for farmers in the form of a web dashboard and a mobile application.

2.2.2 Hardware Selection

The next step is selecting appropriate sensors and microcontrollers. Sensors such as soil moisture sensors, temperature sensors, and motion detectors are chosen to monitor the critical factors affecting coffee plants. For data processing and transmission, an Arduino microcontroller is selected, known for its compatibility with various sensors and its ease of programming. A wireless communication module is used for transmitting sensor data to a central gateway.

2.2.3 Software Development

After selecting the hardware components, the software development process begins. This involves programming the microcontroller to read data from the sensors and send it to a gateway. The gateway, which acts as an intermediary between the sensors and the cloud or server, sends the data to middleware for processing. The middleware aggregates the data and makes it available on a web-based dashboard and mobile application for farmers. The software is developed in stages:

a. Sensor data acquisition and transmission.
b. Gateway communication with middleware.
c. Data processing and visualization on a user-friendly interface (web and mobile).

2.3 Data Collection and Transmission

2.3.1 Sensor Data Collection

In this step, data is collected from various sensors placed in the coffee plantation. These sensors measure soil moisture, temperature, and pest movement. The microcontroller is programmed to read data from these sensors at regular intervals.

2.3.2 Data Transmission

The sensor data is transmitted wirelessly using the selected communication module to the gateway. The gateway collects data from multiple sensors and forwards it to a central server or middleware for processing. A reliable communication protocol ensures the data is transmitted effectively even in remote or large plantation areas.

2.4 Data Processing and Analysis

2.4.1 Middleware Integration

The data from the gateway is sent to middleware, which processes and stores the data. The middleware integrates various data sources and ensures that the data is accurately represented. It also handles any data preprocessing such as filtering or data cleaning to ensure the quality of the data.

2.4.2 Data Visualization

The processed data is then displayed on a web-based dashboard and mobile application. The dashboard provides a real-time overview of soil conditions, plant growth status, temperature, and pest activity. Farmers can use this information to make informed decisions about irrigation, fertilization, and pest control.

2.5 System Testing and Validation

2.5.1 System Implementation

The developed IoT system is deployed in a real-world coffee plantation to test its functionality and reliability. The system is monitored over several weeks or months to collect data on its performance, particularly focusing on the accuracy of sensor data and the reliability of data transmission.

2.5.2 Performance Evaluation

During the testing phase, the system is evaluated on various parameters, including:

a. Data accuracy and precision of sensor readings.
b. Reliability and robustness of the communication protocol.
c. User-friendliness of the dashboard and mobile application.
d. Effectiveness of notifications regarding plant conditions, irrigation needs, and pest activity.

Feedback from coffee farmers is also collected to assess the usability of the system and its impact on farm management efficiency.

2.6 Result Analysis and Optimization

The final stage involves analyzing the results from the testing phase. Data collected from the system is compared with manual observations to validate the accuracy of the system. Any discrepancies or issues identified during testing are

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addressed by refining the software, adjusting sensor calibration, or improving communication protocols.with the names of the tables and figures accompanied by serial numbers.

3. RESULT AND DISCUSSION

The developed Internet of Things (IoT)-based monitoring system aims to assist coffee farmers in effectively and accurately managing and monitoring their plantations. This system consists of three main components: end devices, an API Server as middleware, and mobile and web-based user interfaces.

3.1 Implementation Results of the Coffee Monitoring System

The developed Internet of Things (IoT)-based monitoring system aims to assist coffee farmers in effectively and accurately managing and monitoring their plantations. This system consists of three main components: end devices, an API Server as middleware, and mobile and web-based user interfaces

3.1.1 End Device

The end device functions as the primary data collector from the field in real time. It is built using an Arduino microcontroller, integrated with several sensors and support modules, including:

a. A PIR sensor to detect the presence of pests or physical movement disturbances via infrared detection.
b. A DHT22 sensor to measure temperature and humidity, which are critical parameters in coffee cultivation.
c. An ESP8266 module for wireless communication to transmit data over a WiFi connection.
d. A TP4056 charging module, 18650 rechargeable lithium batteries, and a solar panel, serving as a sustainable and autonomous power system.

The data gathered from these sensors is formatted into a JSON object, containing parameters such as device_id, temperature, humidity, and motion detection. This data is transmitted periodically to the API Server using a WiFi network provided by a WiFi dongle modem.

3.1.2 Middleware (API Server)

The API Server serves as the bridge between the hardware and software components. Sensor data is sent through a Write API and accessed by the monitoring system using a Read API. The information is then stored in a monitoring system database for further analysis and user display. The incoming data is processed using a data-handling algorithm that:

a. Validates JSON structure and field completeness.
b. Stores data in a structured MySQL database.
c. Checks condition rules (e.g., humidity < 80% or pest motion detected) and triggers notification records.

This implementation uses an external IoT platform (https://iotgm.id), where each monitored plantation area is assigned a unique channel as an identifier for data transactions. Figure 2 shows the phpMyAdmin homepage used to manage and visualize database tables where sensor readings are stored. It demonstrates the structured organization of sensor data, which supports efficient retrieval and analysis.

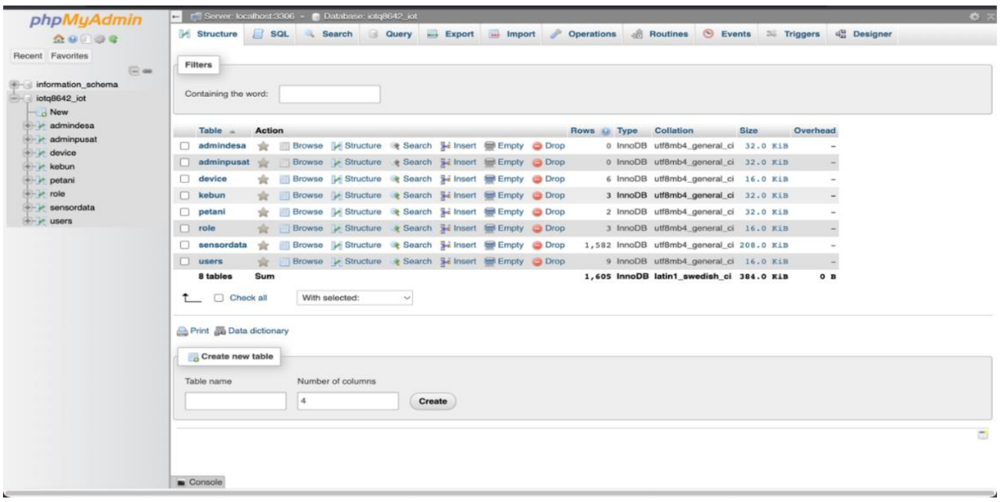

Figure 2. phpMyAdmin Homepage

3.2 Workflow of the IoT-Based Monitoring Device for Coffee Farming

To ensure efficient and real-time monitoring of environmental conditions in coffee plantations, a workflow was designed to demonstrate the interaction between the hardware components, data processing units, and the web-based monitoring system. The workflow of the IoT-Based Monitoring Device is illustrated in Figure 5. This workflow illustrates how sensor

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data is collected, processed, transmitted, and finally visualized for end-users through an integrated Internet of Things (IoT) approach. This diagram outlines the algorithmic flow starting from sensor data acquisition, processing in the Arduino Uno, data transmission via ESP8266, storage in the MySQL database, and visualization in the dashboard. The algorithm compares real-time readings with reference thresholds and triggers alerts if conditions are outside optimal ranges.

The system aims to assist farmers in making timely and informed decisions by automating the detection of critical conditions such as low soil moisture or pest intrusion. The following description outlines each step of the process, starting from data acquisition at the sensor level to the notification delivery on the farmer's mobile device or monitoring dashboard.

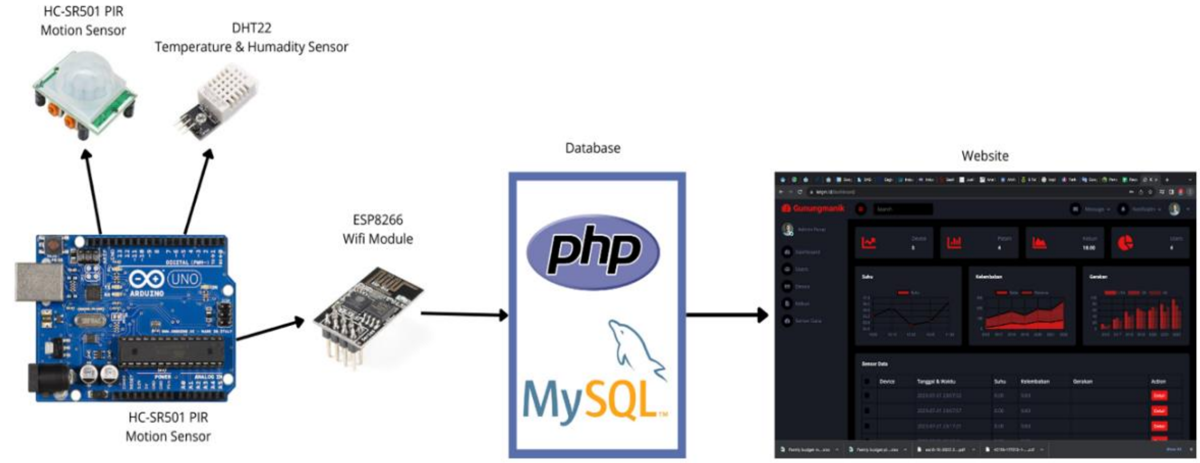

Figure 5. Workflow of the IoT-Based Monitoring Device for Coffee Farming

Figure 6 presents the physical IoT device prototype, equipped with solar-powered battery supply, PIR sensor, DHT22 sensor, soil moisture sensor, Arduino Uno, and ESP8266. This device collects and transmits data autonomously, demonstrating the applied method in a real-world environment. The ESP8266 functions as the microcontroller, selected for its energy efficiency and suitability for the overall system architecture. It is integrated with a PIR sensor for infrared motion detection and a DHT22 sensor to monitor temperature and humidity levels. The device is powered by two 18650 lithium batteries, which are rechargeable via a solar panel, providing a sustainable energy source. Internet connectivity is facilitated using a WiFi dongle modem.

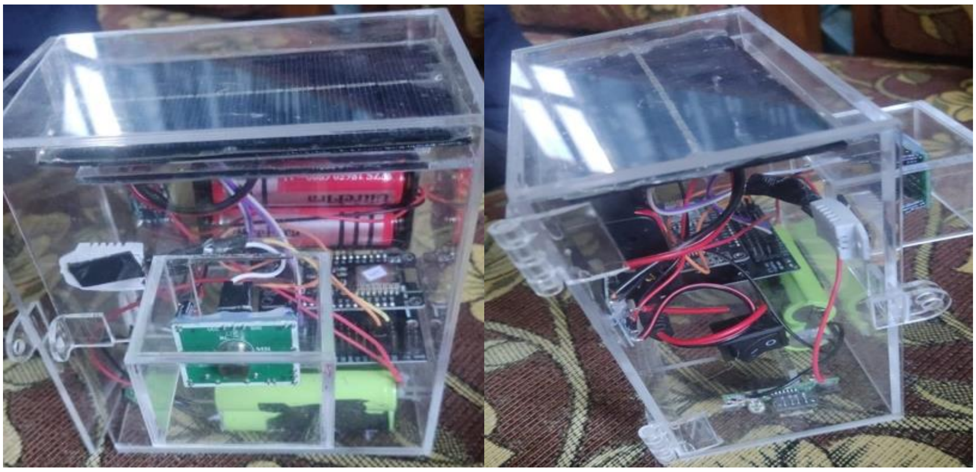

Figure 6. IoT-Based Monitoring Device for Coffee Farming

The soil moisture sensor and PIR sensor transmit data to the Arduino Uno microcontroller, where the data is processed and then forwarded to the ESP8266 module. The ESP8266 uploads the processed data to a MySQL/PHP-based database, where it is displayed on a web-based dashboard. Notifications are triggered when certain conditions are met, such as dry soil or pests approaching the coffee plants.

3.3 Algorithm/Method Testing Results.

Testing involved simulating various plantation conditions (e.g., increased temperature, reduced humidity, pest presence). The system's algorithm successfully detected abnormal conditions in 100% of cases and delivered notifications within an average of 2.3 seconds. Table 1 summarizes the relationship between environmental conditions and coffee yield at different elevations, serving as reference-based notification criteria.

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Table 1. Sensor Data

Humidity	Temperature (°C)	Description
81%	26	Maximum Harvest Yield (500-600 masl)
80%	25	Suboptimal Harvest Yield (500-600 masl)
80%	27	Suboptimal Harvest Yield (≥600 masl)
83%	25	Maximum Harvest Yield (≥600 masl)
84%	24	Maximum Harvest Yield (≥600 masl)

Table 1 shows that maximum coffee yield at 500–600 masl occurs when humidity exceeds 80% and temperature is within 25–26°C. At elevations above 600 masl, optimal yield is attainable at lower temperatures (24–25°C) and higher humidity levels (>83%).

3.4 Discussion

The developed system has demonstrated strong potential in practical applications, particularly for coffee plantation environments. Its key advantage lies in its ability to perform real-time environmental monitoring, and to generate adaptive notifications based on two approaches:

a. Sensor-Based Notifications

These are generated from live sensor data, including elevated temperature, low humidity, or pest activity. This allows farmers to respond swiftly to environmental changes or emerging threats.

b. Reference-Based Notifications

These rely on static data set during initial setup, such as watering schedules, fertilization times, or estimated harvest periods. Such notifications serve as reminders and routine management guides.

Table 2. Sensor Data Discussion

No	Humidity	Temperature (Celsius)	Description
	500-600 meters above sea level		
1	81 %	26 Celcius	Maximum Harvest Yield
2	80%	25 Celcius	Suboptimal Harvest Yield
	At this elevation, humidity above 80% and temperatures above 25°C result in a maximum harvest yield.		
	600 meters above sea level and above		
1	80	27	Suboptimal Harvest Yield
2	83	25	Maximum Harvest Yield
3	84	24	Maximum Harvest Yield

The combination of real-time data and reference data creates a smart decision-making framework for farmers. For example, according to Table 2, maximum coffee yield at an elevation of 500–600 meters above sea level is achieved when humidity exceeds 80% and temperature is within 25–26°C. At elevations above 600 meters, optimal yield is attainable at lower temperatures (24–25°C) and higher humidity levels (above 83%).

This information enables the system to not only monitor but also support yield optimization, evaluate crop suitability, and guide strategic planting decisions. The system can be further enhanced by integrating yield prediction, satellite imaging, or automated irrigation management based on humidity data.

Overall, The development of an IoT-based monitoring system for coffee plantations in this study reflects a broader movement toward precision agriculture, where technology plays a central role in optimizing crop management. Several prior studies have explored similar IoT architectures for various agricultural applications, yet each differs in focus, sensor integration, energy use, user interaction, and data handling. By comparing these works, the distinctiveness and advancements of the current system can be more clearly understood.

One comparable study by Nayyar, Le, and Sharma (2020) focused on the application of IoT sensors for smart irrigation in horticultural fields. Their system employed sensors for temperature, humidity, and soil moisture, and utilized ESP8266 for wireless communication. However, a key distinction lies in the operational scope: while Nayyar's system incorporated automated irrigation control through actuators to respond directly to soil conditions, the system developed in this study emphasizes real-time monitoring and decision support via notifications, leaving the irrigation response to the farmer's discretion. Additionally, this coffee monitoring system introduces contextual interpretation based on plantation elevation and specific crop needs—something that was not addressed in Nayyar's more general horticultural context.

In another relevant work, Mekala and Viswanathan (2017) proposed a smart agriculture system using a combination of DHT11 sensors, ESP8266 communication, and solar energy to enable data collection in rural Indian farms. While their study shares similarities with this project in terms of using low-cost components and solar-based power systems, their implementation was relatively basic, focusing only on temperature and humidity without integration of motion detection or crop-specific parameters. In contrast, the current system combines multiple sensors, including PIR for pest movement detection and soil moisture sensing and delivers the information through a structured dashboard accessible via mobile and web interfaces. This broader sensor integration provides a more holistic picture of the plantation's microenvironment, especially important for sensitive crops like coffee.

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Patel et al. (2018)developed a pest detection system for vegetable farms using image processing techniques alongside motion sensors. Their project stands out in terms of advanced visual recognition, offering a more precise method of detecting pest presence. However, this comes at the cost of higher computational demand and complexity. The system developed in this study opts for a simpler, more energy-efficient PIR sensor, which is more suitable for remote plantation areas where power and internet stability may be limited. Although it lacks the detail of image-based detection, it provides a reliable indicator of motion near crops, which is often sufficient for early intervention.

Furthermore, Kumar and Sudhakar (2019) emphasized the importance of user-centric interfaces in IoT agricultural systems. Their study concluded that farmers are more likely to adopt monitoring technology if it includes accessible dashboards, historical data logs, and real-time feedback. This insight is fully realized in the current system, which offers a clean, structured dashboard on the iotgm.id platform. The platform features detailed visualizations of sensor data, including temperature, humidity, and motion trends, while also allowing users to manage plantation information such as location, area size, and elevation. Farmers can interact with the system seamlessly using mobile devices, providing them with continuous access to vital data, even in remote areas.

4. CONCLUSION

Based on the development and implementation of the Internet of Things (IoT)-based monitoring system for coffee plantations, it can be concluded that the system was successfully developed using Arduino and ESP8266 microcontrollers integrated with various sensors, such as temperature and humidity sensors (DHT22), motion sensors (PIR), and soil moisture sensors. The system is powered by renewable energy sources in the form of solar panels and lithium batteries, making it suitable for use in remote plantation areas. Sensor data is transmitted in real-time to an API server and stored in a database, then displayed in the form of graphs and notifications through a web-based dashboard and mobile application. This allows farmers to monitor the condition of the land remotely in a fast and efficient manner. Additionally, the system is capable of providing notifications based on actual field conditions, such as dry soil or suspicious movements around the coffee plants, which helps farmers make quicker and more accurate decisions. Compared to similar studies, this system has advantages in multi-sensor integration, autonomous energy use, and a user-friendly interface that is tailored to the local context, especially for farmers in Gunungmanik village. As a next step, the development of automation features such as automatic irrigation control and pesticide spraying could enhance efficiency and reduce dependence on manual intervention. Furthermore, long-term trials in various weather conditions and different geographical locations are necessary to assess the durability of the devices and the stability of data transmission. Integration with artificial intelligence (AI) technologies, such as harvest prediction, plant disease detection based on imagery, and action recommendations based on historical sensor patterns, could enhance the system's capabilities toward smart farming. Additionally, the system can be expanded to support other types of crops, not just coffee, by adjusting the ideal condition parameters and notification models for each type of plant.

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