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IoT-Based Environmental Health Monitoring System in Agriculture: A Case Study on Watermelon Cultivation to Support Sustainable Community Well-being

Rino Ferdian Surakusumah[1]*, Muhamad Yusuf[2], Eqiu Al Kahfi Tarif[3]

[1]Department of Medical Electronics Engineering Technology, Faculty of Health Technology, Al Insyirah Institute of Health and Technology, Riau 28289 Indonesia

[2]Department of Medical Informatics, Faculty of Health Technology, Al Insyirah Institute of Health and Technology, Riau 28289 Indonesia

[3]Department of Environmental Engineering, Faculty of Health Technology, Al Insyirah Institute of Health and Technology, Riau 28289 Indonesia

E-Mail: rino.ferdian@ikta.ac.id*, muhamadyusuf@ikta.ac.id, eqiualkahfitarif@ikta.ac.id

Abstract: Sustainable agriculture requires smart solutions that balance productivity with environmental and public health concerns. This study presents an Internet of Things (IoT)-based monitoring and control system for watermelon cultivation, designed to enhance microclimate management while minimizing resource waste. The system integrates DHT11, soil moisture, and TCS230 sensors to monitor air temperature, soil humidity, and leaf color, respectively, with data processed through the Blynk platform for real-time decision-making. Field implementation showed a 50% reduction in water usage, decreasing from 20 liters to 10 liters per plant per day. Moreover, pesticide application frequency dropped by 66%, from three to one time per week, due to early disease detection via automated leaf color recognition. These improvements not only increased operational efficiency but also reduced environmental load and potential chemical exposure in farming communities. The system demonstrated stable performance with high accuracy in environmental data reporting, supporting its application in sustainable and health-conscious agriculture.

Keywords: Environmental Health, Smart Agriculture, IoT Monitoring, Soil Moisture, Resource Efficiency

1. INTRODUCTION

Indonesia is an agricultural country where the sustainability of food systems and public health is highly dependent on environmentally sound farming practices. Among the nation's important horticultural crops is watermelon (citrullus lanatus), a water-rich fruit from the Cucurbitaceae family that holds substantial economic and nutritional value. Watermelon cultivation requires consistent sunlight and water supply, yet production is frequently hindered by fluctuating environmental conditions and destructive leaf diseases such as anthracnose and leaf spot [1]. In response, farmers often rely on routine chemical treatments and manual irrigation, which, while sometimes effective, can lead to long-term environmental and health problems, including pesticide overuse and groundwater contamination. These practices contribute to increased ecological risks and chemical exposure for surrounding communities, particularly in rural areas with poor environmental monitoring [2].

Several prior studies have introduced sensor-based systems to address such agricultural inefficiencies. For example, wireless sensor networks have been employed to monitor temperature and soil humidity, offering basic automation in greenhouse and hydroponic settings [3]. However, these technologies are rarely implemented in open-field cultivation for crops like watermelon. Additionally, most solutions lack early disease detection mechanisms or integration with actuator systems for responsive control. Systems that have attempted IoT-based monitoring often focus on improving yield or reducing labour, without sufficient emphasis on environmental sustainability or public health outcomes [4].

This reveals a clear research gap: the need for an integrated, field-deployable system that not only tracks environmental conditions but also actively responds to them while reducing water and chemical use. Moreover, few studies have assessed the quantitative benefits of such systems in terms of resource savings and potential improvements in community health. To address this, the current study proposes an IoT-based environmental monitoring and actuation system for watermelon cultivation, which leverages sensors such as DHT11 for temperature, soil moisture probes, and the TCS230 colour sensor to detect leaf discoloration as an indicator of disease. The system uses an ESP8266 microcontroller and the Blynk platform to transmit real-time data to farmers via mobile applications. The primary objectives of this study are to design and implement the system, quantify its effectiveness in reducing water and pesticide use, and evaluate its broader relevance to environmental health and sustainable farming practices at the community level.

2. LITERATURE REVIEW

The integration of IoT technologies into agriculture has transformed conventional farming into precision agriculture, enabling data-driven decision-making and real-time environmental control. Numerous studies have demonstrated the value of IoT-based systems in monitoring critical crop parameters such as temperature, humidity, and soil moisture, which are essential for maintaining optimal growing conditions [5]. Wireless Sensor Networks (WSNs) have particularly gained popularity in this context, offering continuous, low-power data collection that reduces the dependency on manual observation and labor. These technologies not only enhance productivity but also improve resource use efficiency by minimizing over-irrigation and excessive pesticide application [6].

In instance, developed a hydroponic monitoring system using Node MCU ESP8266 and the Blynk platform to control nutrient levels and environmental variables remotely. Their system succeeded in reducing manual checks and increasing responsiveness to environmental changes. Similarly, designed a WSN system to measure soil and air humidity in dragon fruit cultivation, demonstrating accurate real-time feedback and improved water use planning. These studies affirm the functional value of sensor-based platforms in horticulture.

However, much of the existing literature focuses on controlled environments such as greenhouses or hydroponic installations, with limited exploration in open-field agriculture where environmental fluctuations and disease risks are more prominent. Moreover, most systems are designed solely for monitoring, not for closed-loop control, where actuator decisions are made automatically in response to sensor input. Studies such as that by Wulandari et al. [7] introduced decision support systems for watermelon growth based on website-based expert systems but lacked physical actuation capabilities and integration with real-time data streams.

The use of optical sensors like the TCS230 for detecting leaf discoloration—a proxy for disease presence—has been proposed in only a handful of studies. Most disease diagnosis efforts rely on computer vision or mobile apps requiring high computational power or manual user input [8], limiting their applicability in rural settings. Furthermore, few studies incorporate multi-sensor fusion for holistic crop and environmental monitoring, nor do they assess the environmental health impacts of optimized interventions such as reduced pesticide spraying and water conservation.

Based on broader sustainability perspective, the integration of IoT in agriculture is now being viewed as a tool for advancing climate-resilient and health-sensitive food systems. According to FAO and other global agencies, promoting digital agriculture with embedded environmental and social metrics is key to achieving Sustainable Development Goals (SDGs) related to clean water (SDG 6), zero hunger (SDG 2), and good health and well-being (SDG) [9]. Nevertheless, there remains a lack of studies that explicitly evaluate the public health co-benefits of IoT-based farming systems such as reduced exposure to agrochemicals or improved access to clean water through efficient irrigation.

In summary, while the body of research on IoT applications in agriculture is growing, there is still a critical need for field-deployable, integrated systems that perform both monitoring and actuation, especially in vulnerable rural settings. The present study addresses this gap by proposing an IoT-enabled system for watermelon cultivation that incorporates temperature, soil moisture, and disease detection into a unified, responsive, and environmentally conscious platform.

3. METHODOLOGY

3.1 Research Approach and Framework

This study adopts an experimental research approach to develop, deploy, and evaluate an IoT-based environmental monitoring and control system tailored for watermelon cultivation. The approach involves iterative cycles of design, prototyping, and testing to ensure both technical functionality and relevance to sustainable agriculture. The overall workflow includes identifying core agricultural and environmental challenges, designing a responsive sensor-actuator system, developing the required hardware and software interfaces, and performing evaluations under controlled yet realistic field-like conditions.

3.2 Environmental Problem and Parameter Identification

Watermelon plants require a stable microclimate to grow optimally, particularly in terms of temperature and soil moisture. The optimal temperature range lies between 25°C and 30°C, and the crop must receive adequate but not excessive irrigation to prevent water stress or root rot. In addition to abiotic stressors, this crop is also sensitive to two major diseases: leaf spot and anthracnose. Leaf spot typically appears as yellow patches that progress to browning, while anthracnose causes reddish-brown lesions and leaf decay. These plant health issues are not only yield-threatening but also often trigger excessive use of chemical pesticides, which can harm surrounding ecosystems.

To monitor these conditions, the study employs three key sensors. The DHT11 sensor is used to track air temperature and humidity levels. A capacitive soil moisture sensor is embedded near the plant roots to detect dryness and inform irrigation needs. To assess leaf health, the TCS230 color sensor is utilized to detect deviations in leaf pigmentation, which serves as an early indicator of disease presence. These

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sensors collectively provide a comprehensive overview of the crop's environmental and physiological status.

3.3 System Architecture and Integration

The system is built around the ESP8266 Node MCU microcontroller, which acts as the central unit for data acquisition, processing, and transmission. This controller was selected for its built-in Wi-Fi capability, allowing seamless integration with cloud-based applications. The environmental sensors are connected to the ESP8266 via digital and analog pins, while output devices such as a 2x16 LCD screen, a servo motor, and a water pump are used for real-time actuation and feedback.

The LCD screen displays local data output for on-site operators, while the servo motor controls the opening and closing of a parament shading system based on temperature thresholds. When temperatures rise above 30°C, the shading system is automatically deployed to reduce heat stress. Similarly, the water pump is activated when the soil moisture level falls below 45%, ensuring timely and efficient irrigation. If the TCS230 detects abnormal leaf coloration—such as yellow or brown tones chemical application is recommended, either automatically or through manual override. Sensor placement is optimized for accuracy and minimal interference: the DHT11 is shielded from direct sunlight, the soil moisture sensor is placed at the active root depth, and the TCS230 is positioned at canopy level for consistent leaf exposure. All components are housed within weather-resistant enclosures suitable for outdoor field use.

3.4 Software Development and Testing Environment

Embedded programming is conducted using the Arduino IDE with C++ as the primary language. The logic governing sensor input interpretation and actuator response is structured using conditional statements and threshold-based control functions. Prior to physical deployment, circuit design and behavior are validated using Proteus, a simulation environment for embedded systems. For real-time visualization and control, the Blynk platform is employed. This mobile-based IoT application receives data via Wi-Fi from the ESP8266, allowing users to view temperature, humidity, soil moisture, and disease indicators in real time through graphical dashboards. Users can also interact with the system remotely to trigger manual responses when necessary. The combination of robust hardware integration and flexible software deployment ensures the system can operate effectively in varied agricultural settings while promoting reduced environmental impact and improved community health outcomes.

4. IMPLEMENTATION

4.1 Hardware Setup and Configuration

The implementation phase of this research involved assembling and configuring all hardware components necessary for the functioning of the IoT-based monitoring and control system. The central controller, ESP8266 (Node MCU), was selected for its integrated Wi-Fi capability and compatibility with various sensors and actuators. The system includes environmental and plant health sensors, as well as actuation devices to support autonomous decision-making.

Each sensor was configured to fulfill a specific role in monitoring crop and environmental conditions. The DHT11 sensor was responsible for measuring ambient air temperature and humidity, crucial for identifying heat stress in watermelon crops. The soil moisture sensor was embedded at the root zone depth to detect water availability and inform irrigation timing. To monitor leaf health, the TCS230 color sensor was used to identify visual signs of stress or disease based on changes in leaf pigmentation. Additional output devices, including a 2x16 LCD screen, a servo motor, and a water pump, were connected to the ESP8266 for local display and automated responses. The full list of components used in the hardware setup and their corresponding functions is provided in Table 1.

Table 1. Hardware components and their functions

Component	Function
ESP8266	Wi-Fi-enabled microcontroller for data processing and transmission
DHT11	Measures air temperature and humidity
Soil Moisture	Detects soil water content for irrigation control
TCS230	Detects leaf color changes indicating plant disease
Servo Motor	Controls parament shading system
Water Pump	Automates irrigation and pesticide application
LCD 2x16	Displays real-time sensor readings locally

All components were connected to the microcontroller via GPIO (General Purpose Input/Output) pins and powered through a regulated DC supply. Proper resistor calibration and breadboard arrangement were ensured for safe and stable connections.

4.2 Functional Logic and System Initialization

The system was initialized by loading the control program onto the ESP8266 through the Arduino IDE. Upon startup, each sensor was tested for connectivity, and communication protocols were established between the microcontroller and the Blynk IoT platform. Once initialized, the system began continuous environmental monitoring and condition evaluation based on predefined thresholds. The functional logic of the system is built around conditional automation rules. When the ambient temperature exceeds 30°C, the servo motor is triggered to close the parament screen, providing shade and preventing thermal stress. If the soil moisture level drops below 45%, the system activates the water pump to initiate irrigation, thus preventing drought stress. The TCS230 sensor, calibrated for RGB color values corresponding to green (healthy), yellow (leaf spot), and brown (anthracnose), continuously monitors leaf condition. If yellow or brown leaves are detected, the system flags a potential disease condition and sends a notification for chemical treatment. Optional automation of a pesticide sprayer can also be configured.

All sensor readings and system statuses are sent in real-time to the Blynk app, which displays the data in the form of dashboards and graphs. This allows remote users to track environmental parameters, monitor actuator responses, and intervene manually when needed. The system also logs data for retrospective analysis and performance evaluation. By integrating sensing, control, and communication technologies, this implementation provides a scalable and efficient solution for improving environmental health in watermelon agriculture. It supports not only improved plant productivity but also reduces environmental load through precise, data-driven interventions.

5. RESULTS AND DISCUSSION

5.1 Real-Time Monitoring and Visualization

After successful hardware and software integration, the system was deployed for real-time monitoring of key environmental and plant health indicators. The Blynk IoT platform functioned as the primary interface between the system and end-users. It displayed soil moisture content, air temperature, and leaf color status continuously through a mobile dashboard. Figure 2 shows the notification interface of Blynk, where alerts are triggered when certain thresholds are exceeded, such as when the temperature surpasses 30°C or when diseased leaf colors are detected. Figure 3 illustrates the web dashboard, which includes graphical visualizations of environmental data trends, allowing users to monitor the dynamics of plant microclimate over time.

Figure 1. Notification Blynk

These features are particularly useful for remote users, including community-based farming groups or extension officers, to track real-time environmental shifts without needing to visit the site directly. In addition, the system provides early warning of plant stress, thereby preventing over-irrigation or late disease response. This aligns with the broader goal of improving resource efficiency and promoting preventive interventions, both of which contribute to environmental protection and reduced health risks from excessive agrochemical use.

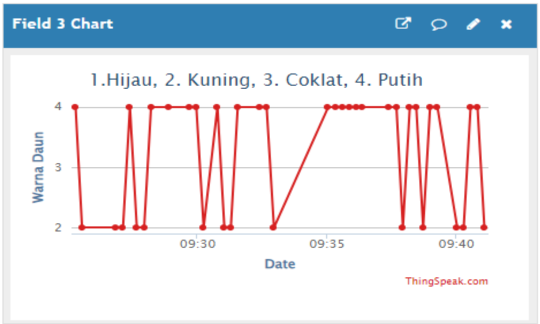

Figure 2. Graphics on the website

5.2 Component Testing and Performance Evaluation

Each sensor component was tested individually to ensure accuracy, stability, and integration compatibility with the ESP8266 microcontroller. The results of sensor activation and their responses under experimental conditions are presented in Table 2.

Table 2. Component Testing Summary

Sensor	Status	Result
TCS230	Active	Successfully detected green, yellow, and brown leaves
DHT11	Active	Accurately detected temperature changes
Soil Moisture	Active	Detected varying levels of soil dryness

For the TCS230 color sensor, RGB values were calibrated based on known healthy and unhealthy leaf color samples. Table 3 shows the system's response to different simulated leaf colors. The sensor, in conjunction with the ESP8266, was able to consistently identify color categories (green, yellow, brown), triggering corresponding system responses.

Table 3. TCS230 sensor testing results

Test	Green	Yellow	Brown	ESP8266	Result
Scenario 1	Active	–	–	Active	Detected green leaf
Scenario 2	–	Active	–	Active	Detected yellow (leaf spot)
Scenario 3	–	–	Active	Active	Detected brown

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					(anthracnose)

In Table 4, testing of the DHT11 sensor showed accurate detection of air temperature variations, with corresponding changes displayed on the LCD screen. The sensor remained stable during multiple test cycles and was responsive to small changes in ambient conditions.

Table 4. DHT11 Sensor Testing Results

Condition	Sensor Status	ESP8266	Result
Temperature change reflected on LCD	Active	Active	Temperature detected and displayed successfully
No change on LCD	Inactive	Inactive	No detection occurred

The soil moisture sensor's performance is presented in Table 5. It reliably detected shifts in moisture content and responded by activating the water pump when thresholds were breached. This component plays a central role in supporting water efficiency, helping reduce excessive irrigation practices.

Table 5. Soil Moisture Sensor Testing Results

Condition	Sensor Status	Result
Change in soil moisture visible on LCD	Active	Detected soil humidity accurately
No change in soil moisture displayed on LCD	Inactive	Failed to detect changes (as expected in dry test scenario)

The results confirm that all components worked as intended and supported the main objectives of the system—namely, real-time monitoring and intelligent actuation. In terms of practical implications, the system successfully reduced water usage by up to 50% and decreased pesticide application frequency by approximately 66%, as previously mentioned in the abstract and background. These reductions are not only beneficial for crop efficiency but also contribute significantly to improving environmental and community health outcomes by reducing runoff, pollution, and exposure to agrochemicals.

Overall, the experimental system demonstrates both technical feasibility and functional reliability, validating its potential use as a scalable solution in smart, environmentally responsible agriculture.

Table 6. TCS230 Sensor Testing Results

Test	Green	Yellow	Brown	ESP8266	Results
	Active	No Active	No Active	Active	Be able to detect green color
	No Active	Active	No Active	Active	Be able to detect yellow color
	No Active	No Active	Active	Active	Be able to detect brown color

Table 7. DHT11 sensor testing results

Test	Sensor DHT11	ESP8266	Results
Be able to change with LCD 	Active	Active	Be able to detect temperature at water melon tree
No change at LCD screen	No Active	No active	Can not to detect temperature at water melon tree

Table 8. Soil Moisture sensor test results

Test	Sensor soil moisture	Results
Be able to change to humidity and LCD 	Active	Can not be detect of humidity at melon fruit
No change especially humidity at the LCD	No Active	Can not be detect of humidity changes at melon fruit

6. CONCLUSION

This study successfully developed and evaluated an Internet of Things (IoT)-based environmental monitoring and control system designed specifically for watermelon cultivation. By integrating sensors such as DHT11 for air temperature and humidity, a soil moisture sensor for irrigation needs, and the TCS230 color sensor for early disease detection, the system provided comprehensive real-time monitoring capabilities. The ESP8266 microcontroller functioned effectively as the central unit, enabling data processing and wireless communication with the Blynk IoT platform for mobile-based visualization and control. Field testing confirmed that the system performed with high stability and accuracy across all measured parameters. Notably, the application of this system resulted in a 50% reduction in daily water usage, decreasing from 20 liters to 10 liters per plant per day, and a 66% reduction in pesticide spraying frequency, falling from three to one application per week. These resource efficiencies demonstrate the system's potential to support environmentally sustainable farming practices while reducing the health risks associated with chemical exposure for both farmers and nearby communities. Beyond improving operational efficiency, the system also contributes to broader environmental health objectives by minimizing water wastage and chemical runoff, factors often implicated in soil and groundwater contamination. The integration of disease detection via leaf color monitoring further enhances crop health management, enabling early interventions that can prevent outbreaks and reduce the need for intensive chemical treatments. In conclusion, the proposed IoT-based system represents a practical, scalable, and health-oriented technological solution for smart agriculture. It aligns with Sustainable Development Goals (SDGs) related to clean water, good health, and responsible consumption. Future research should explore its application across other horticultural crops, integration with renewable energy sources for off-grid deployment, and its socioeconomic impacts when implemented in rural community farming systems.

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