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Precision Agriculture System with IoT: An Approach to Increase Production and Efficiency

Mochammad Rif'an
Department of Informatics, Faculty of Industrial Technology, Universitas Islam Indonesia, Yogyakarta City, Special Region of Yogyakarta Province, Indonesia.
Email: 20523021@students.uii.ac.id.

Kurniawan D. Irianto *
Department of Informatics, Faculty of Industrial Technology, Universitas Islam Indonesia, Yogyakarta City, Special Region of Yogyakarta Province, Indonesia.
Corresponding Email: k.d.irianto@uii.ac.id.

Abstract: The application of IoT technology in the agricultural industry has significantly increased efficiency and productivity. In this study, a smart irrigation system that utilizes soil temperature and humidity sensors and NodeMCU ESP8266 and ESP32 units will be explained for its implementation. The NRF24L01 module is a wireless sensor module used to transmit data wirelessly and allows it to cover a wide range. Now, farmers can monitor and control the irrigation system remotely through the Blynk application. Tests show that crops managed through the IoT system have more consistent soil and air conditions and more efficient temperature and humidity control. Therefore, this precision agriculture system utilizes IoT and NRF24L01 to improve water and energy efficiency and encourage sustainability efforts in addressing climate change and increasing global food demand.

Keywords: Internet of Things; Smart Farming; Greenhouse; Agricultural; Real-time Data Collection.

1. Introduction

Internet of Things (IoT) technology is emerging as a major trend for many industries, including the Agriculture sector. IoT stands for the idea of connecting smart devices via the internet to communicate and control. In the agriculture sector, the demand for IoT is huge, in terms of automation processes, food production, distribution, more affordable product offerings, more efficient use of resources, and so on. IoT applications can be customized to address various agricultural applications such as efficiency, effectiveness, and sustainability of the farming system [1]. The first internet-connected toaster (supporting TCP/IP and limited control via SNMP MIB) was created by John Ramkey and Simon Hackett in 1990. In 1999, they perfected the device with an autonomous robotic crane, while Kevin Ashton coined the term Internet of Things (IoT) while working on international RFID technology, which some consider a major step in the commercialization of IoT. In 2000, LG announced plans to develop a smart refrigerator; In 2003, RFID was adopted by the US military and also began to be used in commercial retail. The growth of IoT continues with several milestones such as covering some of the most famous newspapers in 2005, the birth of the IPSO Alliance in 2008 to facilitate IoT protocols, and the FCC's approval of the white space spectrum. IPv6 was launched in 2011 which further expanded the Internet of Things with support from companies such as IBM, Cisco, and Ericsson [2].

Electronic devices called sensors (also known as transducers) translate physical quantities into electrical signals. Sensors are essential in sensing and measuring physical phenomena such as temperature, humidity, pressure, and air quality. The basic operation in measurement and instrumentation is sensing, which provides a means to view the measurement results through an integrated system that is often IoT-based. In addition, the integration of sensors and the Internet of Things (IoT) facilitates access to real-time data, thus enhancing advances in environmental management and many others [3].

The DS18B20 is a high-precision digital temperature sensor with an accuracy of 9 to 12 bits. This sensor is capable of measuring temperature values from -55 °C to 125 °C, with an accuracy of ±0.5 °C between -10 °C and +85 °C [4]. It operates via a 1-wire communication protocol and has a power supply range of 3.0V to 5.5V. To detect humidity accurately in different climatic conditions, it combines a potentiometer along with an LM393 comparator [5]. Relays are electromagnetic devices that turn electrical circuits on and off. They have normally open and normally closed contacts [1]. The NRF24L01+ wireless module uses a 2.4 GHz RF frequency, operates via an SPI interface with very low power consumption, and is suitable for peripherals, gaming devices, and other equipment [6]. Temperature and humidity are detected by a resistive humidity sensor and a thermistor that sends data to a microcontroller. The module operates from 0°C–50°C at 20-90 percent RH, making it ideal for home automation and environmental management in greenhouses [7]. The heart of this project is the NodeMcu ESP8266, a LUA-based firmware that allows the use of 11 GPIO pins supporting PWM over a WiFi Network (2.4 GHz, WPA/WPA2). The board has 4 MB of flash memory and has two UART pairs for serial connections [5].

Support of agriculture remains the basis of food production and therefore also serves as one of the largest contributors in development of the nations economy due to countries like Indonesia where a large segment of the population depends on agriculture for their income. Agriculture not only sustains the food, it also generates employment, mitigates unemployment and serves as an income for millions of families. In addition, agriculture is also important in providing dietary diversity, which is important for public nutrition [8]. As an innovation, Smart Farming + IoT changes the traditional way because most of the farming is supported with monitoring and irrigation systems that can simply be controlled using smartphone apps. OSF: Overview Smart farming includes the use of components such as ESP8266, temperature, humidity, soil moisture sensors that are aimed toward sustainability, cost effectiveness, and ease of use thereby causing an increase in efficiency, productivity, and food supply [9].

IoT based soil moisture monitoring is one of the ideal applications of IoT in agriculture. Managing soil moisture improves crop growth and increases yields. These systems to automate soil moisture monitoring and irrigation based on the data are imperative for creating water pumps, such that the use of water is minimized, excessive use is avoided and the environmental problems are mitigated. Through this technology farmers are able to monitor soil remotely and act accordingly which widdles down the monitoring efforts and guarantees effective functioning of agriculture.

Soil Moisture Monitoring System using Internet of Things(NRF24L01) This module is a 2.4 GHz wireless communication module, which enables long-distance transmission with low power consumption. Soil Moisture Monitoring: The module can be used to transmit data from moisture sensors in the field, to a control center or a monitoring device in real-time. The long-range allows the NRF24L01 to connect many sensors situated

over a large field without the hassle of physical wiring, which increases flexibility and ease for farmers in installing monitoring systems. The NRF24L01 used to develop technology-based agriculture can be made with a low-cost, and it is also compatible with many types of microcontroller platforms, such as ESP32 or ESP8266, providing an affordable solution that allows farmers to check greenhouse conditions accurately and make use of water usage. IoT in precision agriculture is an interesting solution to the challenges faced by farmers. In reality, farmers often face challenges in maintaining irrigation, especially if their fields are far from their homes. The periodic movement of farmers from home to fields and vice versa for manual irrigation management further damages productivity and efficiency. The application of the Internet of Things allows flexible and efficient management of irrigation systems anytime and anywhere, as long as the network is available. This increases work efficiency while saving time.

This study aims to eliminate farmers' concerns by analyzing a modern IoT-based irrigation and soil monitoring system. A smartphone application will be used by farmers to control irrigation gates remotely using NodeMCU ESP8266, a microcontroller that can be accessed via the internet. The results are expected to make a significant contribution to increasing agricultural productivity, reducing the adverse effects of climate change, and resource management efficiency to support global initiatives to meet the increasing global food demand. Current IoT applications in precision agriculture not only represent real-time solutions for farmers but also provide long-term benefits in terms of increasing productivity and sustainability in agribusiness. IoT-enabled Smart Farming is the transformation of traditional farming processes into more modern & efficient processes. Not only will the agricultural sector meet the growing international demand for food, but it can also do so with less impact on the environment through the use of these technologies. Understanding this will help mitigate some of the challenges our agricultural sector is expected to face in the future.

Users can view and monitor data on the Blynk server whenever the system is connected to the internet from their smartphones using a mobile application. One of the unique challenges to scaling up precision agriculture is the aging population in Southeast Asia, especially in Indonesia. To address this issue, we need to develop a smart farming system that incorporates IoT technology [10]. With the help of IoT, farmers can now remotely monitor the energy consumption used in various farming processes such as automatic irrigation or the use of heavy machinery through a mobile application, making the farming process more efficient and environmentally friendly. This mechanism facilitates closer monitoring of resource consumption, leading to more efficient and sustainable farming benefits [11].

2. Research Method

2.1 Requirement Analysis

These phases outline the process of developing the requirements for an automatic irrigation system, including functional requirements analysis, input requirements analysis, hardware requirements analysis, and software requirements analysis.

Table 1. Hardware and Software Requirements

Category	Component/Device	Description
Hardware	ESP32	Microcontroller with Wi-Fi and Bluetooth connectivity, used as the central control unit of the system.
	NodeMCU ESP8266	An alternative to ESP32, providing Wi-Fi connectivity and easy programming.
	nRF24L01 Module	A 2.4 GHz wireless communication module for long-distance communication between devices.
	DHT11 Temperature Sensor	Sensor used to measure air temperature and humidity.
	FC-28 Soil Moisture Sensor	Sensor used to measure soil moisture levels.
	DS18B20 Temperature Sensor	High-accuracy sensor used to measure soil or environmental temperature.
	1-Channel Relay	Relay used to control high-power devices such as water pumps.
	Power Supply	Provides electrical power to all system components.
	Breadboard	A tool for assembling and testing electronic circuits without soldering.

	Jumper Wires	Wires used to connect components on the breadboard or between the breadboard and microcontroller.
	4.7k Resistor	Used as a pull-up resistor on sensor data pins to ensure stable and accurate signals.
Software	Arduino IDE	Platform used to write, compile, and upload code to the microcontroller.
	Blynk	IoT platform providing a user interface for remote control via mobile application.
	Proteus	Circuit simulation software used to design and test circuits before physical implementation.
	Fritzing	Circuit design tool used to create circuit diagrams and printed circuit board (PCB) layouts.

2.2 System Design

This phase involves the planning and design of a sensor control system that will eventually be capable of performing autonomous irrigation. The design stages are system design, software design, hardware design, and interface design.
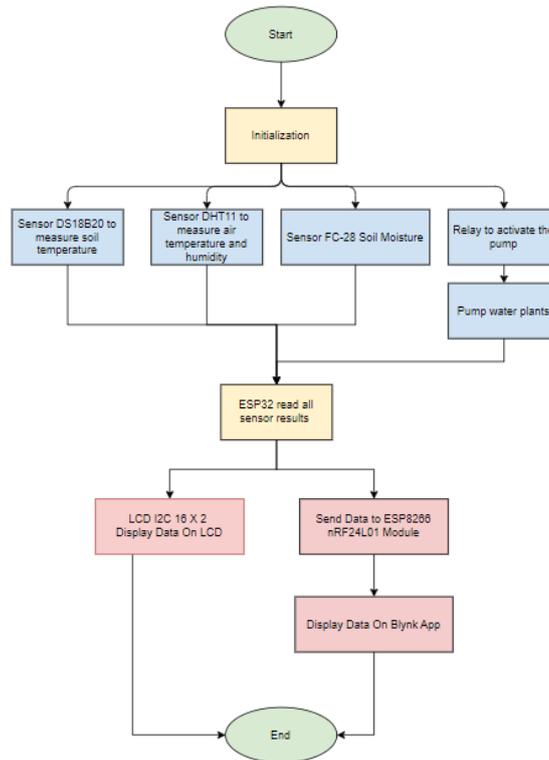

Figure 1. Flowchart of the System Design

The adoption of Internet of Things (IoT) in agriculture entails installing sensors in agricultural regions to monitor various soil variables such as nutrient content, moisture, and temperature. The nRF24L01 module wirelessly transmits data collected by these sensors from the greenhouse to the farmer's or user's nRF24L01 module. This method provides farmers with real-time information regarding agricultural conditions. The benefit of using this technology is its capacity to provide continuous and accurate monitoring of agricultural conditions. This allows farmers to make faster and more educated decisions based on actual data, increasing efficiency and crop yields. As a result, IoT technology in agriculture not only improves resource management, but also assures that crops grow under optimal conditions.
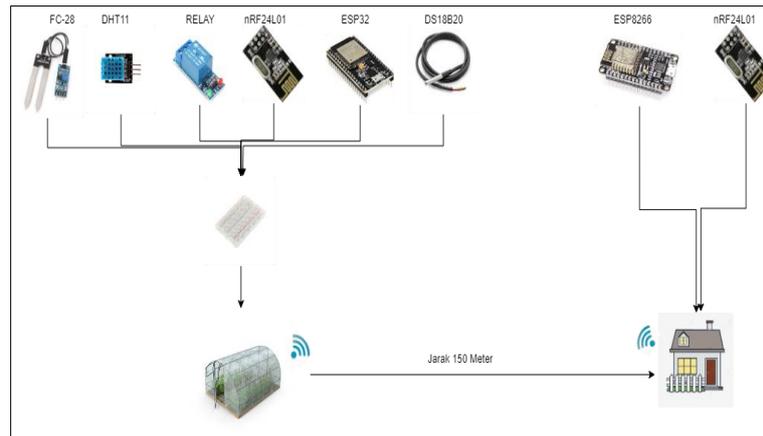
Figure 2. System Design

2.3 Implementation

The IoT system in agriculture can be coupled with the Blynk platform, allowing users to quickly view and control agricultural conditions through a mobile application. Once the NodeMCU ESP8266 receives data from the ESP32 via the nRF24L01 module, it can be presented in Blynk, where users may monitor temperature, soil moisture, and greenhouse temperature using widgets like as gauges or graphs. Additionally, Blynk's buttons or switches allow for the control of devices such as irrigation relays as needed. The Blynk software has a simple interface that allows farm owners to efficiently and practically monitor and manage crops via mobile devices, hence improving the ease and operational efficacy of agricultural methods.
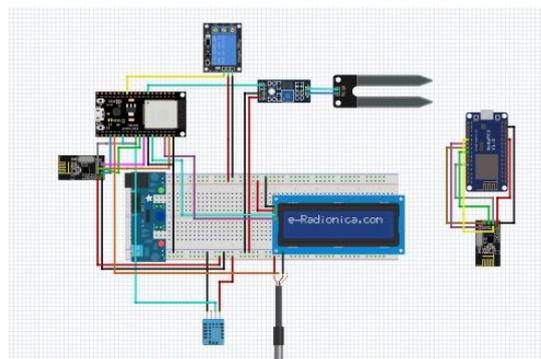

Figure 3. Schematic of the Design System

In an IoT greenhouse management system, the ESP32 serves as the primary control hub, managing sensors such as the FC-28 for soil moisture and the DS18B20 for soil temperature. It uses sensor data to make judgments based on environmental factors. The nRF24L01 module handles wireless communication, with the ESP32 sending data to the NodeMCU ESP8266, which functions as a gateway to the Blynk application. The NodeMCU ESP8266 sends the data to the Blynk server, where soil temperature, moisture, and air temperature data are graphically displayed on the Blynk dashboard for real-time monitoring. The sensors are directly connected to the ESP32, which also shows the data on a 16x2 LCD for on-site monitoring. To maintain constant functioning, the system requires a reliable power source. A 1-channel relay is used to operate the water pump based on soil moisture data. Integration with Blynk improves greenhouse management efficiency by allowing for accurate, real-time monitoring and adjustment of environmental conditions, hence promoting optimal plant development.
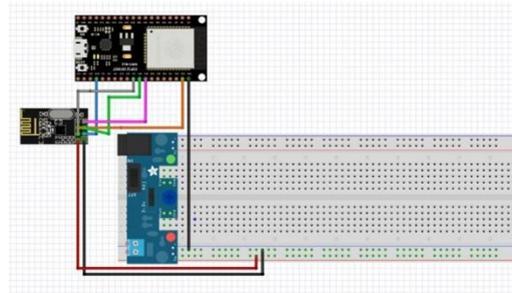
Figure 4. NodeMCU ESP8266 Circuit

The ESP32 maintains and regulates all of the system's components, ensuring that each sensor and module functions properly and is integrated to offer accurate and responsive environmental monitoring in the greenhouse. Data from the ESP32's sensors is wirelessly transferred to the NodeMCU ESP8266 via the nRF24L01 module. The NodeMCU ESP8266 serves as a gateway, accepting data from the ESP32 and uploading it to the Blynk platform. Blynk displays real-time data on soil temperature, soil moisture, and air temperature, allowing for effective monitoring and control of the greenhouse environment.

2.4 Testing

A variety of tests will be carried out in the greenhouse to check that all sensors and gadgets work properly. The testing will comprise the DHT11 sensor for air temperature and humidity, the DS18B20 sensor for soil temperature, the FC-28 sensor for soil moisture, and the ESP32-controlled 1-channel relay. Sensor data will be sent from the nRF24L01 module to the NodeMCU ESP8266 and presented in the Blynk app. Testing will also involve soil fertility checks and data transmission range measurements of up to 150 meters. The test results will be reported in a table to show the system's efficiency and the correctness of data in the Blynk application.A variety of tests will be carried out in the greenhouse to check that all sensors and gadgets work properly. The testing will comprise the DHT11 sensor for air temperature and humidity, the DS18B20 sensor for soil temperature, the FC-28 sensor for soil moisture, and the ESP32-controlled 1-channel relay. Sensor data will be sent from the nRF24L01 module to the NodeMCU ESP8266 and presented in the Blynk app. Testing will also involve soil fertility checks and data transmission range measurements of up to 150 meters. The test results will be reported in a table to show the system's efficiency and the correctness of data in the Blynk application.
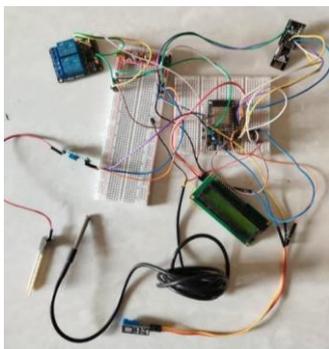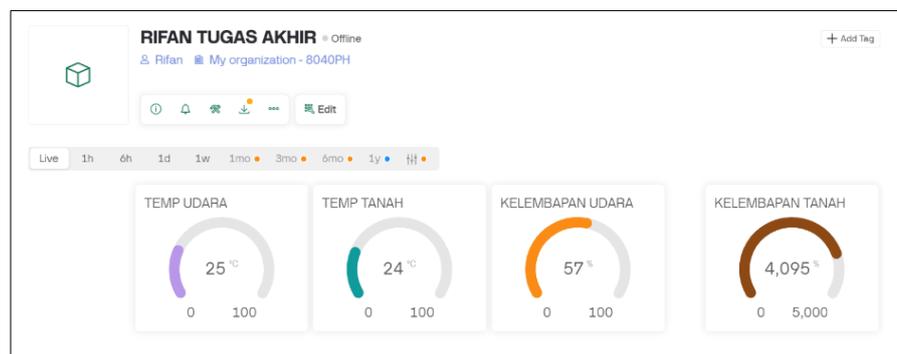

Figure 5. Complete Device Setup

Figure 6. Blynk Display

3. Result and Discussion

3.1 Results

The testing results indicate that the IoT-based system continuously maintained more stable environmental variables, such as soil temperature, wetness, and air humidity. This shows that the IoT system improves control and efficiency in greenhouse management when compared to manual techniques.

Table 2. Research Data

Parameter	Day 1		Day 2		Day 3	
	IoT Plant	Non-IoT Plant	IoT Plant	Non-IoT Plant	IoT Plant	Non-IoT Plant
Soil Temperature (°C)	23	25	29	30	22	24
Soil Moisture	2354	3202	2412	3202	2221	2542
Air Temperature (°C)	23	25	27	31	26	27
Air Humidity (%)	65	58	84	79	68	70

3.2 Discussion

This study evaluates the effectiveness of plant management with and without IoT devices over a three-day period. The following are the test results for Plant 1 (with the IoT system) and Plant 2 (without the IoT system) for soil temperature, soil moisture, and air temperature. Throughout the three-day observation, there was a continuous difference in soil temperature between the IoT-enabled and non-IoT plants. On the first day, the soil temperature of the IoT-enabled plant was approximately 23°C, somewhat lower than that of the non-IoT plant, which reached 25°C. On the second day, the soil temperature of the IoT-enabled plant rose to roughly 29°C, although it remained lower than the non-IoT plant, which reached 30°C. On the third day, the soil temperature dropped, with the IoT-enabled plant at 22°C and the non-IoT plant at 24°C. Overall, the soil temperature of the Non-IoT plant was higher than that of the IoT-enabled plant, possibly due to the IoT-enabled plant's usage of an autonomous irrigation system, which helped to keep the soil temperature steady and prevented excessive heat.
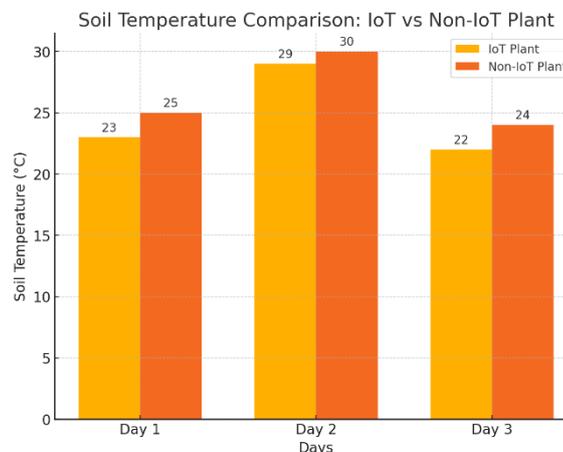

Figure 7. Soil Temperature Comparison Between IoT and non-IoT Plants

There was a substantial difference in soil moisture data between the IoT-enabled and non-IoT plants after three days of observation. On Day 1, the soil moisture for the IoT-enabled plant was reported at 2354, whereas the Non-IoT plant had a substantially higher moisture level of 3202. This indicates that the non-IoT plant had more soil moisture, probably owing to uncontrolled hand watering. On Day 2, the soil moisture for the IoT-enabled plant grew slightly to 2412, while the non-IoT plant stayed stable at 3202, showing that the non-IoT plant's soil moisture was consistent. However, on Day 3, the soil moisture in both plants began to decline. The IoT-enabled plant plummeted to 2221, while the non-IoT plant fell to 2542, however it still outperformed the IoT-enabled plant. Overall, the results show that the non-IoT plant has higher soil moisture levels than the IoT-enabled plant. This could be ascribed to the IoT-enabled plant's more efficient and controlled automatic watering system, which prevents excessive soil moisture levels, as opposed to the non-IoT plant, which may have been manually watered without proper regulation.
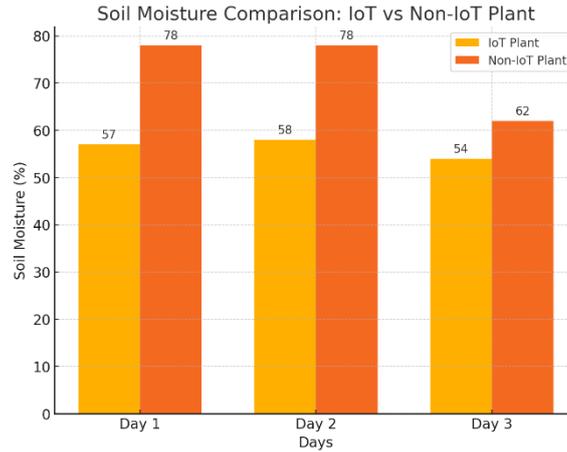

Figure 8. Soil Moisture Comparison Between IoT and non-IoT Plants

Based on air temperature data collected over three days of observation, there was a significant difference in the air temperatures around the IoT-enabled and non-IoT plants. On Day 1, the air temperature around the IoT-enabled plant was 23°C, lower than the air temperature around the non-IoT facility, which was 25°C. On Day 2, the air temperature around the IoT-enabled plant rose to 27°C, whereas the air temperature around the non-IoT plant rose even more dramatically to 31°C. On Day 3, the air temperature around both plants dropped somewhat, with the IoT-enabled plant registering 26°C and the non-IoT plant recording 27°C. On each observation day, the air temperature around the non-IoT facility was consistently higher than that of the IoT-enabled plant. This distinction could be linked to the differing technologies utilized to manage the plant's environment, with the IoT-enabled plant presumably benefiting from more controlled air temperature and humidity management, whilst the non-IoT facility relied on less regulated external environmental conditions.
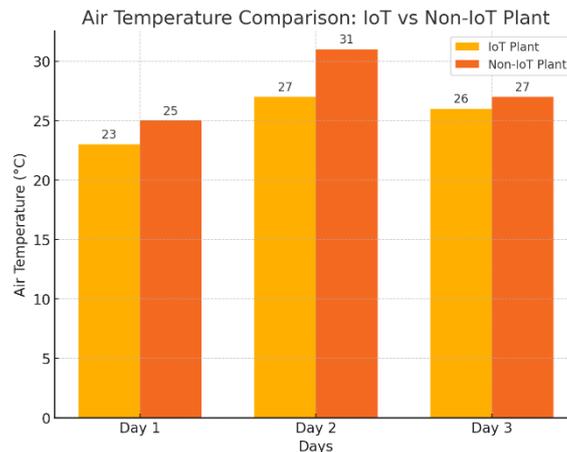

Figure 9. Air Temperature Comparison Between IoT and non-IoT Plants

Based on air humidity data collected during three days of observation, there was a difference in humidity between the IoT-enabled and non-IoT plants. On Day 1, the air humidity around the IoT-enabled plant was 65%, greater than the non-IoT facility, which had 58%. On Day 2, the air humidity for the IoT-enabled plant climbed dramatically to 84%, while the non-IoT plant increased to 79%, but remained lower than the IoT-enabled plant. On Day 3, the air humidity around the IoT-enabled plant dropped to 68%, while the non-IoT plant recorded 70%, which was somewhat higher than the IoT plant. Overall, air humidity around the IoT-enabled plant was greater on the first and second days, but on the third day, the non-IoT plant had somewhat higher humidity. This difference in humidity can be ascribed to the usage of IoT technology, which allows for more control over environmental conditions, resulting in more steady humidity around the IoT-enabled plant, especially on specific days, when compared to the non-IoT plant.
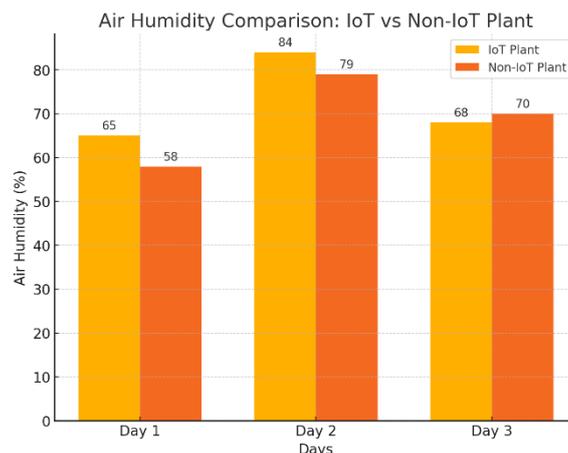
Figure 10. Air Humidity Comparison Between IoT and non-IoT Plants

The findings from each observation confirmed a stable difference in soil temperature over three days between the IoT Plant and the Non-IoT Plant. Similarly, the IoT Plant had a lower and more stable soil temperature than the Non-IoT Plant. The soil temperature of the IoT Plant on the first day was 23°C (IoT Plant) lower than the Non-IoT Plant at 25°C, and the same values were observed on the second day with the IoT Plant reaching 29°C, while the Non-IoT Plant reached 30°C. On the third day, both plants showed a decrease in soil temperature, but again the IoT Plant was lower (22°C) than the Non-IoT Plant (24°C). This difference is a sign that the automated irrigation implemented by the IoT Plant allowed for a more stable soil temperature, preventing the soil from overheating. This may be a result of the IoT system being triggered by more specific soil conditions, allowing irrigation to be carried out only when necessary. Data on soil moisture revealed a significant difference between the two sets of plants. For the IoT Plant, Day 1 had a soil moisture score of 2354, and in comparison, a value of 3202 for the Non-IoT Plant. This difference suggests that the Non-IoT Plant was overwatered, most likely due to uncontrolled manual watering. The data shows that on the second day, the soil moisture of the IoT Plant increased slightly to 2412, while the Non-IoT Plant remained the same at 3202. On day 3, the soil moisture of both plants decreased, but the Non-IoT Plant was still at a higher value (2542) than the IoT Plant (2221). So, the overall difference in soil moisture levels can be attributed to the more effective and controlled automated system in the IoT Plant that did not allow the soil to become too moist.

Similarly, air temperature readings were taken over the three days. The temperature on the first day around the IoT Plant was 23°C, compared to 25°C in the Non-IoT Plant; on the second day it was 27°C for the IoT Plant and 31°C for the Non-IoT Plant; and on day 3, the temperature was 26°C around the IoT Plant, compared to 27°C for the Non-IoT Plant. This continued decrease in air temperature shows that the IoT system is able to provide better control over the ambient temperature, while the Non-IoT Plant is more dependent on less controllable external environmental conditions. I noticed some very interesting things with the data for the humidity for the second group of plants. Day 1: The humidity around the IoT Plant was 65%, compared to 58% around the Non-IoT Plant. On day 2, the humidity of the IoT Plant reached 84% while the Non-IoT Plant reached 79% which is lower than the humidity of the IoT Plant. On day 3, the humidity of the IoT Plant was 68% and the Non-IoT Plant was 70% which is slightly lower than the IoT Plant. Overall, the humidity was higher in the IoT Plant on days 1 and 2 but on day 3 it was higher on the Non-IoT Plant. This is due to the nature of the IoT system which is better able to control environmental conditions so that the humidity around the IoT Plant is more stable, especially on certain days.

Various parameters such as soil temperature, soil moisture, air temperature, and humidity are better controlled in IoT-based systems compared to non-IoT systems. The environmental conditions of plants using IoT systems are more stable and controlled, which allows for optimal plant growth. In contrast, manual plants have more variations in environmental factors that are detrimental to growth. This difference highlights a prospective area where IoT technology can improve agricultural management. Using an IoT sensor-based automatic irrigation system will help save water by using as much water as needed to maintain optimal soil conditions. In addition, the IoT system ensures better control of air temperature and humidity, creating a better environment for plant growth. This study provides preliminary evidence of the benefits of implementing IoT systems in agriculture. However, the true potential for agriculture through IoT technology remains

unexplored, and further studies with more diverse crops, and longer observation periods are needed to validate the findings.

4. Related Work

The use of Internet of Things (IoT) technology in agricultural irrigation systems has gained considerable attention recently and is aimed at optimizing the irrigation process to improve water use efficiency and crop yields. Several approaches have been investigated in existing studies but focus on different things and utilize different methodologies. A classic example is the IoT-based automatic irrigation system proposed by Hendrawati and Algifary (2022) which implements fuzzy logic that helps optimize irrigation control for specific crops such as chili plants. The use of wireless nodes to communicate with sensors and controllers is essential to enable farmers to automate the irrigation process and monitor the performance of any system remotely on the internet. A non-major contribution of this study is the fuzzy logic-based adaptive irrigation decision-making to changing environmental factors [12]. Prasetyo et al. (2019), developing a Small-Sized Device for IoT Remote Control on a Smartphone Interface for Janggelan Plant Irrigation [5]. This leads to the creation of a humidity sensor, relay, and NodeMCU ESP8266 microcontroller programmed in C device, where synchronization between the user, hardware, and internet network is essential for the operation of the system. Only 70.28% of the data received in the google firebase application shows the potential that can be achieved and the challenges faced when developing IoT systems in agriculture [13]. Setiadi, Nurdin & Muhaemin (2018) implemented an automatic smart irrigation system that monitors and controls irrigation channels. This system sends data on temperature, weather, water flow, and water level of irrigation channels through sensors. The purpose of this study is to reduce the dependence on human monitoring and control to prevent flooding or overflow in the irrigation system. The analysis of this study highlights the importance of real-time monitoring systems for effective water resource management [14].

An IoT-based automatic drip irrigation data acquisition system that can measure ambient temperature and soil moisture was developed by Suryatini and Fauzandi (2018) [4]. The system was developed to control water flow to plants in real-time by considering the measured soil moisture and temperature values. In addition, the purpose of this study is to develop real-time data access through an Android application where farmers or crop managers can monitor and optimize irrigation procedures instantly. This system focuses on the integration of hardware, software, and user interfaces to develop an effective automatic irrigation system [4]. In the study, Daru et al. (2021) created a model for smart irrigation and soil moisture monitoring rice fields based on Internet of Things (IoT) technology. The model has a moisture sensor to check soil moisture and a small water pump to maintain its water content. By continuously monitoring the land and ensuring sufficient moisture for plant growth, this study aims to assist farmers with real-time monitoring and reduce waste, leading to increased agricultural productivity and minimizing unnecessary water use [15]. Research has also investigated soil sensors, such as capacitive moisture sensors and Time Domain Reflectometry (TDR) based moisture sensors, which have been shown to improve soil moisture measurements to some extent [16][17]. Research has assessed soil and crop conditions and used ML algorithms for crop water requirement prediction, etc [18][19]. Various smart irrigation systems have involved many components, from novel IO devices for remote monitoring and fuzzy logic for adaptive irrigation control [20], to smart systems for managing irrigation channels and remote monitoring of environmental data, thereby increasing agricultural productivity [21], driving improved water use efficiency, and minimizing dependence on human supervision of irrigation systems [22][23].

However, this study also reveals several challenges that need to be overcome for successful implementation of IoT-based irrigation systems. The major challenges include high implementation costs, reliable network infrastructure, and system integration for different environmental and crop conditions. In addition, more studies need to be conducted to develop sophisticated algorithms for crop water requirement prediction and irrigation scheduling optimization along with the accuracy and reliability of the sensors used. However, the reviewed studies lay a strong foundation for the implementation of appropriate and efficient Internet of Things (IoT)-based irrigation systems. Ultimately, more, cheaper, easier to implement, and more flexible systems tailored to different agricultural conditions will be needed in future research. In addition, it is important to study the sustainability and environmental impacts of IoT-based irrigation systems as well. This study will conduct research with the aim of advancing the current literature, focusing on the development of a low-cost and easy-to-implement automated irrigation system for small-scale farms and is expected to make

substantial contributions, towards improving the efficiency and sustainability of agricultural irrigation systems. optimizing irrigation schedules to minimize water wastage and maximize crop productivity.

5. Conclusion

The data shows that a significant difference can be seen in the environmental conditions of the two crops where one is managed using the IoT system and the other is managed manually. The environmental conditions of Crop 1 are more consistent and are close to ideal for crop growth. Then the automatic watering system, managed by the soil moisture sensor, managed to keep the temperature and humidity of the soil within the permissible range. In contrast, the absence of the IoT system in Crop 2 resulted in wider variations in temperature and humidity, which were driven by manual control. These variations in the crop climate are part of a less stable growing environment than Crop 1. The results show that the use of IoT technology helps the crop management process to be efficient and effective. Automatic monitoring and control of temperature, humidity, light, and moisture by the IoT system can result in a more stable and optimal growing environment, leading to better plant health and productivity. In addition, the manual control system, which is the most common practice, is less consistent and can cause variations that can be detrimental to plant growth. Therefore, IoT technology provides a solid way to overcome the constraints of conventional crop monitoring systems.

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