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SMART GARDEN TECHNOLOGY IN THE IMPLEMENTATION OF REAL TIME AUTOMATION IN SMART FARMING-BASED STRAWBERRY CULTIVATION

Sahrul Gunawan, Muhamad Muslihudin, Sephia Nuraini
Study Program of Information Systems, Institut Bakti Nusantara
Wisma Rini Street No.09 Pringsewu, Lampung, Indonesia

*Corresponding author
sg2153789@gmail.com, mmuslihudin@ibnus.ac.id, Sephianuraini33@gmail.com

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Abstract
This research aims to design and implement a Smart Garden system based on the Internet of Things (IoT) in the cultivation of strawberry plants in real-time. The background of this research is the need for farmers for automation solutions in managing the growing environment of strawberry plants that require certain temperature and humidity conditions. The developed system utilizes the ESP32 microcontroller, soil moisture sensor, and Blynk application as automatic watering monitoring and control media. The method used is a prototyping approach that involves the stages of designing, testing, and evaluating system performance. The test results showed that the system was able to monitor soil conditions and activate the water pump automatically based on the read humidity value. In addition, the Blynk app is capable of displaying data in real-time and providing remote control to users. This system is considered effective in improving watering efficiency, saving water, as well as reducing manual involvement in plant care. Thus, the Smart Garden system built is feasible to be applied to small- to medium-scale horticultural agriculture, especially in areas such as Tanggamus Regency which has high agroclimatic potential but has not been integrated with modern technology.

1.0 INTRODUCTION

Modern agriculture in Indonesia faces significant challenges due to climate change and reliance on conventional methods that are less responsive to environmental conditions in real-time. Smart garden comes from the word smart which means smart and garden which means garden or garden which if we combine can be interpreted as a garden or smart garden [1]. These challenges drive the need for innovation in crop cultivation practices, especially horticultures such as strawberries, which require specific growing conditions such as temperatures between 17–28 °C and air humidity of 80–90% [2]. Strawberry plants are native to subtropical regions and are plants that can adapt to tropical areas with rainfall of 600-700 mm/year and irradiation that is carried out for 8-10 hours per day. In the tropics, this condition is difficult to achieve consistently without technological intervention. As the Internet of Things (IoT) develops, the concept of smart farming and smart garden is becoming a potential solution, as it allows environmental monitoring and control to grow automatically and in real-time using sensors and microcontroller-based control devices such as ESP32 and NodeMCU.

Conventional strawberry cultivation in Indonesia, especially in lowlands or temperaments, still faces obstacles in controlling environmental factors such as temperature, soil moisture, and watering intensity. Several studies have developed IoT-based systems to address these challenges, Technology plays an important role in people's lives, facilitating easy access to information without being limited by distance, place, or time. The impact of this technology has created transformations in various industrial sectors in Indonesia, including in the agricultural sector [3]. such as an automatic watering system based on humidity and temperature sensors that is integrated with applications such as Blynk. However, most of the research is still limited to one or two aspects of control, and has not yet integrated all the critical components holistically and in real-time.

In Lampung Province, especially Tanggamus Regency, the agricultural sector is one of the main pillars of the community's economy. This area has agroclimatic potential that supports the development of horticultural crops, including strawberries, especially in highland areas such as Gisting and Air Naningan Districts. However, many farmers in this region still use traditional methods that are not yet technology-based, so productivity is not optimal and dependence on weather is still high. Traditional gardening often takes a lot of time and effort, and requires a large and open field. Limited land is often an obstacle for many people to grow crops, so they cannot optimize crop cultivation [4]. This condition shows that the implementation of a smart garden system in strawberry cultivation in Tanggamus is very necessary, to increase efficiency and reduce dependence on external factors that are not controlled.

Research conducted by (Agnesia et al., 2024) [1], (Komang & Made, 2023) [3], and (Al, 2024) [2] have a common focus in the development of an Internet of Things (IoT)-based automation system to support the cultivation of horticultural crops, especially strawberries. The three studies show that the application of environmental sensors for air temperature and humidity, as well as soil moisture sensors, can improve the efficiency of real-time monitoring of plant conditions. (Agnesia et al.,2024) developed an ESP32-based automatic watering system that connects to the Blynk mobile app to monitor and control garden conditions remotely. The test results show that the integration of the system is able to adjust watering based on actual soil conditions, thus saving water and increasing productivity [1]. (Komang & Made, 2023) also implemented a similar concept on strawberry greenhouses with sensor accuracy of up to 99%, demonstrating the reliability of IoT systems in precision farming practices [3]. In addition, (Al, 2024) emphasized that the adoption of this technology is part of the digital transformation of agriculture which is urgently needed to answer the challenges of climate change and land limitations [2]. Based on these findings, it can be concluded that an IoT-based Smart Garden system is not only relevant but also crucial to be applied in sustainable and adaptive strawberry cultivation management, especially in areas such as Tanggamus, which has high agroclimatic potential but has not been maximized in the use of modern technology.

Therefore, a more comprehensive and integrated automation system is needed in the form of IoT-based Smart Strawberry Gardens. IoT systems have often been used to help the agricultural sector because of the many new technologies and tools or materials that can facilitate the activities of farmers [5]. The system is expected to be able to combine environmental data collection (temperature, soil moisture, pH, light intensity), real-time data processing, and automated decision-making to manage irrigation, ventilation, and plant nutrients. With this approach, strawberry cultivation can be carried out more efficiently, precisely, and sustainably, while opening up opportunities for the wider implementation of smart farming in Indonesia's horticultural agriculture sector.

2.0 LITERATURE REVIEW AND TEORY

2.1. Literature Review

The literature review in this study is a comprehensive summary of various previous studies selected based on relevant themes. Various previous studies have pointed to the application of Internet of Things (IoT) technology in strawberry cultivation, such as the automatic watering system based on the KNN algorithm [6], temperature and humidity control with ESP32 [7], IoT greenhouses for irrigation and fertilization [8], Implementation of Smart Garden IoT Irrigation

System in Strawberry Plantations [1], Designing an IoT-Based Lowland Strawberry Crop Monitoring System [9]. Although effective in their respective functions, most of these studies still have limitations, such as the need for big data, narrow system coverage (only focusing on watering or monitoring), and not yet supporting real-time and integrated monitoring and control. This research is present as a solution by developing an IoT-based Smart Garden system that is able to monitor and control various important aspects of strawberry cultivation automatically and in real-time. The system integrates temperature, soil moisture, pH, and sensors and connects to a mobile app for automated decision-making. The impact of the development of automation technology is felt in various aspects of human life today. The safety and convenience offered by this technology have a positive influence, especially on the aspect of using electrical energy [6].

2.2. Theoretical Framework

2.2.1. Smart Farming

Smart Farming, or smart farming, is an innovative approach that utilizes advanced technology to increase efficiency and productivity in the agricultural sector. By utilizing technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data, drones, and robotics, Smart Farming is able to provide effective solutions in facing the challenges faced by modern agriculture, such as climate change, land limitations, soil quality degradation, and the need to increase food production [10]. A modern farming method that combines digital technology to optimize efficiency, production yields, and sustainability. This approach uses tools such as sensors, actuators, robots, and artificial intelligence to obtain and analyze data in real time and in real time. The data is used for automatic decision-making, such as optimal watering, fertilization, and pest control time. With smart farming, agriculture no longer relies on forecasts or intuition, but data-driven agriculture, so that the risk of crop failure can be minimized and the use of resources becomes more efficient.

2.2.2. Internet of Things (IoT)

Internet of things (IoT) is a concept that aims to expand the benefits of continuously connected internet connectivity. The Internet of Things (IoT) can be used in buildings to control electronic equipment such as room lights that can be operated remotely through a computer network [11]. This technology refers to the concept in which physical devices such as sensors, actuators, and microcontrollers are connected to each other through an internet network to automatically collect, transmit, and receive data. In agriculture, the application of IoT allows monitoring and control of environmental conditions such as temperature, humidity, light, and soil acidity levels in real time and in real time. IoT devices can be configured to send notifications, enable automated irrigation systems, or store data on a server/cloud for further analysis. IoT presents a huge opportunity in the digital transformation of agriculture as it enables remote monitoring of land and rapid response to environmental changes.

1. **Arduino IDE**

   Arduino is an open-source software developed by Arduino to write programs using the Java programming language consisting of: Program Editor, Compiler and Uploader. The IDE allows us to write a program step by step and then upload the instructions to an Arduino board [12].

   Software used to write, upload, and run programs on microcontroller boards such as Arduino, ESP32, and NodeMCU. The programming language used is C/C++-based. The Arduino IDE provides a simple and lightweight interface for developers, both beginners and professionals, to control sensors, motors, actuators, and other devices. In the Smart Garden system, the Arduino IDE is used to set the working logic of the soil moisture sensor, activate the water pump, and send data to the monitoring platform via Wi-Fi.
2. **ESP-32**

   ESP32-CAM is one of the microcontrollers that has functions in the form of bluetooth, wifi, camera, and micro SD slot. ESP32-CAM can be used for IoT (Internet Of Things) projects. The ESP32-CAM has little I/O because many pins are used internally as a camera function. The Esp32 Cam does not have a USB port so to program the ESP32-CAM must use USB TTL or FTDI to program it [12].

A low-power yet very powerful microcontroller that comes with Wi-Fi and Bluetooth connectivity. Compared to its predecessor such as the ESP8266, the ESP-32 has advantages in terms of processor speed, a higher number of input/output pins, and multitasking capabilities. The ESP-32 is particularly suitable for use in IoT applications because it can connect sensors to the internet directly without the need for additional devices. In a smart garden system, the ESP-32 serves as a control center that reads data from sensors (such as soil moisture and temperature), controls devices (such as water pumps), and sends data to mobile applications or cloud servers.

3. **Soil Moisture Sensor**

   The system uses a Soil Moisture sensor to measure soil moisture levels and an RTC (Real-Time Clock) to set an automatic watering schedule twice a day. When the soil moisture is below the predetermined threshold, the system will automatically activate watering. Users can monitor soil moisture conditions and watering status through connected IoT apps [13].

   A tool used to measure the moisture content in the soil. These sensors are essential in automated irrigation systems because they can detect drought or soil moisture conditions and signal the microcontroller to take action. There are two general types of soil moisture sensors: resistive and capacitive. Resistive sensors work based on changes in resistance as the soil becomes wetter or drier, while capacitive sensors measure changes in capacitance due to moisture content in the soil. These sensors are typically embedded in the growing medium and calibrated to provide accurate data. With this data, the smart garden system can determine when it is the right time to water the plants automatically.

3.0 RESEARCH METHODS

3.1. Data Collection Methods

In this study, data collection techniques are carried out as the basis for designing and implementing Smart Garden systems based on the Internet of Things (IoT). The data collected aims to understand system requirements, test device functionality, and evaluate overall system performance. The data collection methods used include:

1. Literature Study

   This study was conducted by examining various scientific references such as journals, articles, books, and research reports relevant to the topic of smart farming, IoT, and soil moisture monitoring systems. Literature studies help researchers understand the theoretical foundations, technological developments used, and solutions that have been applied to previous research.
2. Field Observation

   The researcher conducted direct observations at the location of the system implementation, namely the strawberry cultivation area. This observation aims to find out real environmental conditions such as soil type, average humidity, and plant water needs. The observation results are used as a basis for adjusting the system to suit the needs in the field.
3. Interview

   Interviews were conducted informally with local farmers or agricultural actors in the study area. The goal is to get information related to problems that often occur in the process of watering plants and the need for agricultural automation technology.

3.2. System Development Methods

This study uses the prototyping method as an approach in system development. This method was chosen because it provides flexibility in building the system in stages, allows for direct testing of prototypes, and speeds up the repair process based on feedback from test results. This approach is very suitable in the development of IoT-based systems that involve the interaction between hardware and software. The stages in the prototyping method applied are as follows:

1. Identify Needs

At this stage, interaction is carried out between users and researchers to discuss in detail the expected system, main objectives, functional needs, and an overview of the required components.

2. Creating a Prototype
The second stage involves the preparation of an initial design that provides a general illustration of the system to be developed. The design process is done quickly and includes hardware, software, and programming elements. This design is then used as a reference in making prototypes.
3. Testing and Repairing Prototypes
The next step is testing and refining the prototype. This stage aims to ensure whether the developed prototype has met the needs and expectations of users. If it is not suitable, then repairs are made by repeating the previous process. However, if the prototype is in place, the process can proceed to the next stage.
4. Implementation and Improvement
Once the prototype has been adapted to the needs of the user at the previous stage, the process proceeds to the implementation and maintenance stage. In this final stage, the researcher will build the system based on the final prototype that has been approved. The system is then tested, handed over to the user, and enters the maintenance phase to ensure the system runs smoothly without a hitch.

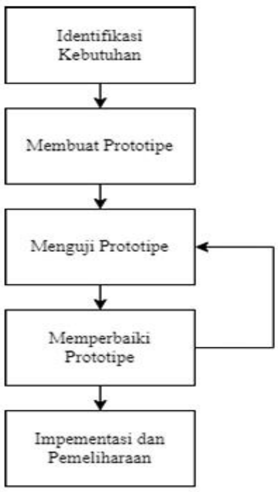

Figure 3. Prototype Flow

4.0 RESULTS

4.1. System Diagram Block Design Flow

A block diagram describing the entire system can be seen in the following illustration:

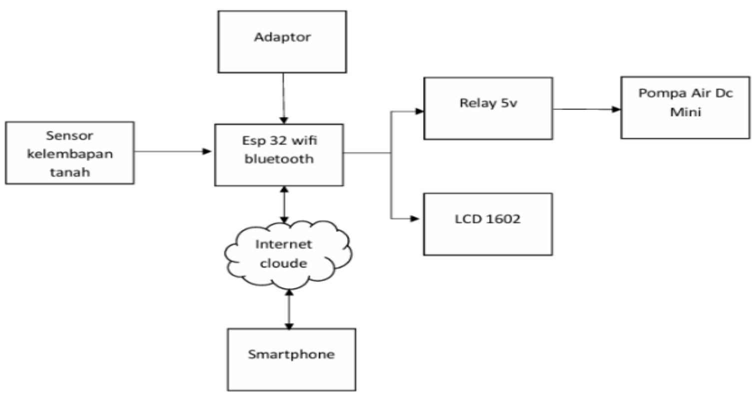

Figure 4. Flow Block Diagram

In figure 4 Design Explanation of the system work process during research will be submitted in the system design section. The explanation from Figure 4 is as follows:

1. Soil Moisture Sensor
   This component is used to measure soil moisture levels. The moisture data obtained is sent to the ESP32 as the main input of the system. If the value is below the predetermined limit, the system will automatically run the watering process.
2. ESP32 WiFi + Bluetooth
   As a data processing center, the ESP32 receives data from humidity sensors, processes watering logic, and controls actuators such as relays and water pumps. In addition, the ESP32 connects to an internet network to send data to the cloud and allows users to access information through smartphones.
3. Adaptor 5V
   Serves as the main power source that supplies voltage to the ESP32 and other components, such as relays and water pumps.
4. Relay 5V
   The relay works as an electronic switch controlled by the ESP32. If the soil is detected to be dry, the ESP32 will activate the relay to power the mini DC water pump.
5. Air DC Mini Pump
6. The pump is active when the relay is turned on, and will automatically drain water to the plant until the moisture level returns to normal.
7. LCD 1602
   This screen is used to display the system status in real-time, such as soil moisture level and pump status (active or not).
8. Internet Cloud dan Smartphone
   The ESP32 has the ability to send data to the cloud, allowing users to monitor and control the system remotely using a smartphone. This feature makes it easy to monitor plant conditions flexibly, anytime and anywhere.

4.2. Tools and Materials

The selection of tools and materials is adjusted to the needs of the research and the system to be developed. The components used support the performance of the system and are selected based on field conditions and references from previous research and other sources. The list of tools and materials needed in this study is as follows:

Table.2 Tools and Materials

No	Tool Name	Information
1.	ESP32 Wifi Bluetooth	Microcontroller with WiFi & Bluetooth connectivity, used as the system control center.
2.	LCD 1602	16-column × 2-row display screen to display humidity and pump status.
3.	Adaptor 5V	Power supply to supply voltage to the ESP32 and other components.
4.	Mini Pump Dc Pompa Air	Low voltage water pump to drain water during automatic watering.
5.	Kabel Jumper Male to Female	The connecting cable between the male (ESP32) to the female pin (module or sensor).
6.	Kabel Jumper Femele to Femele	Connecting cables between components with female pins, such as sensors and breadboards.
7.	Kabel Jumper Male to Male	The connecting cable between two male pins, is usually used on breadboards.
8.	Relay 5V	ESP32 controlled electronic switch module to activate the water pump.
9.	Soil Moisture Sensor	Sensors to measure moisture content in the soil, as system input.
10.	Breadboard Mini	Trial board for assembling components without soldering.
11.	Pump Hose	The medium of water distribution from the pump to the plant.

No	Tool Name	Information
12.	Software Arduino IDE	Microcontroller programming applications such as ESP32, for writing and uploading code.

4.3. Overall Tool and System Design Results

The design of IoT-based automatic watering tools and systems has been successfully realized using several key electronic components that are assembled and programmed to work in an integrated manner. The system is built to run automatic plant watering based on the soil moisture level detected by the sensor. The following is a description of the results of the overall design of the tool and system.

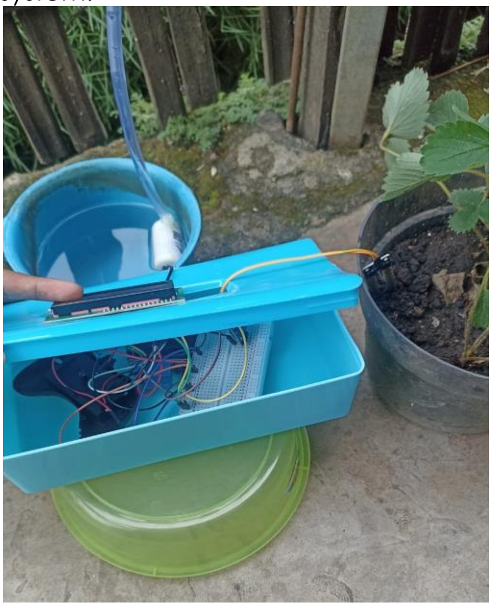

Figure 5. Tool Design

4.3.1. System Diagram

A system diagram is a visual representation of the system workflow that is designed. This diagram aims to provide a comprehensive overview of how the components of the system interact with each other, as well as how data flows within the system. With the existence of system diagrams, the analysis and design process becomes more structured, clear, and easy for developers to understand. The following system as a whole can be described as follows:

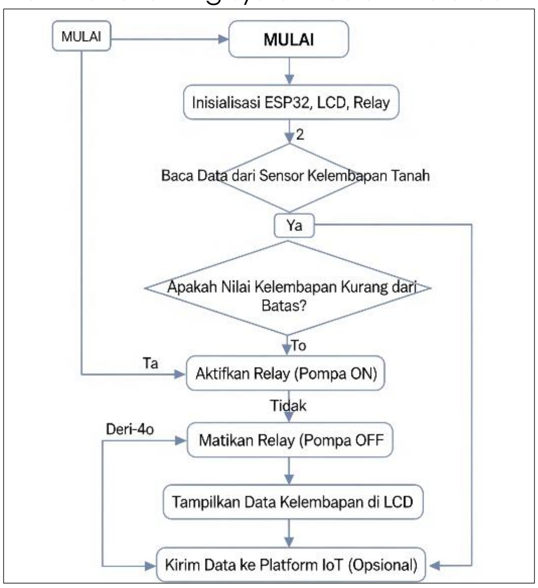

Figure 6. Flow Block Diagram

This flowchart illustrates the logical flow of your automated irrigation system from start to finish, and it will continue to repeat automatically.

1. START
   This is the starting point of the entire system process.
2. Initialization ESP32, LCD, Relay
   In this step, the ESP32 microcontroller will perform the initial setup. This includes initializing the pins connected to the soil moisture sensor, the 1602 LCD (to display the data), and the relay module (to control the pump). This ensures all components are ready for operation.
3. Read Data from Soil Moisture Sensors
   After initialization, the ESP32 will read the soil moisture value from the moisture sensor. This data is usually in the form of analog values which are then converted into digital representations.
4. Is the Moisture Value Less than the Limit? (Decision)
   This is the main decision point in the system. ESP32 compares the moisture value of the soil that has just been read with a predetermined minimum moisture threshold (e.g., if the humidity is below 40%).
   Yes (True): If the soil moisture value is less than the specified limit (meaning dry soil), the groove will proceed to the "Activate Relay (Pump ON) step.
   No (False): If the soil moisture value is not less than the limit (meaning the soil is sufficiently moist or wet), the groove will proceed to the "Turn off Relay (Pump OFF) step.
5. Activate the Relay (Pump ON)
   If the soil is dry, the ESP32 will send a signal to the relay module to activate the water pump. The pump will start watering the soil.
6. Turn off the Relay (Pump OFF)
   If the soil is sufficiently moist, or after the pump is turned on and the humidity returns to normal, the ESP32 will send a signal to the relay module to turn off the water pump.
7. Display Humidity Data on LCD
   Once the pump is set (either ON or OFF), the currently detected soil moisture value will be displayed on the LCD display 1602. This allows users to monitor humidity conditions directly.
8. Send Data to IoT Platform (Optional)
   If the system is further developed with IoT features (using platforms such as Blynk, ThingSpeak, etc.), at this step, humidity and pump status data can be transmitted wirelessly to that platform. It allows remote monitoring through a web interface or mobile app.
9. Back to "Read Data from Soil Moisture Sensor
   Once all of the above steps are complete, the process flow will return to the "Read Data from Soil Moisture Sensor" step. This creates a repetitive cycle that allows the system to continuously monitor soil moisture and automatically control the pump as needed.

4.4. System Planning

The system design section presents a description of the system plan to be developed, based on the results of observations and literature studies that have been carried out. This stage aims to provide a comprehensive overview of the entire planned system.

4.4.1. Automatic Watering Temperature Humidity System

This IoT-based automatic watering system uses soil moisture sensors to monitor the level of water content in the soil in real-time. The system uses ESP8266 NodeMCU microcontrollers as the main controller brain. Soil moisture sensors measure the moisture content of the planting medium and transmit data to the NodeMCU. Based on the humidity value, the microcontroller will make a decision to turn the water pump on or off. If the soil is detected to be dry, the NodeMCU sends a signal to the 5V relay module to activate the DC water pump, so that the water flows to the plant. On the other hand, if the soil moisture is sufficient, the system will deactivate the pump. The data display is shown via the LCD 1602, which displays system status information such as humidity values and pump conditions (ON/OFF). The whole circuit is powered by a 5V adapter as an external power source. The system is highly efficient for smart farming applications because it can work automatically without human intervention and supports water saving.

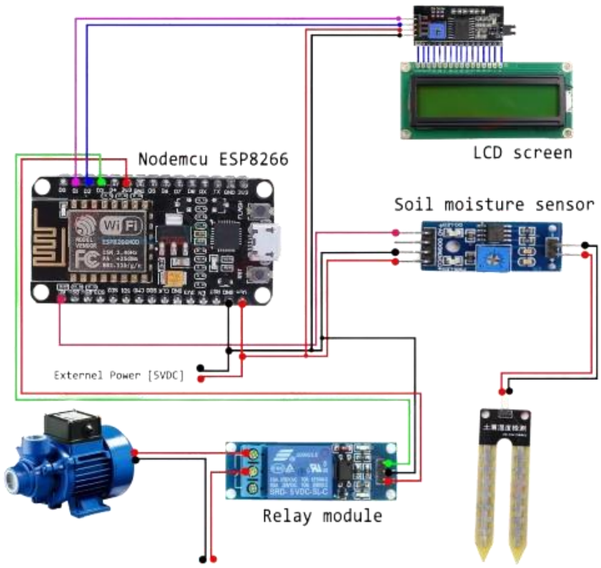

Figure 7. Automatic Watering Temperature Humidity System

The object of the research was carried out in a strawberry orchard located in Talang Padang, Tanggamus Regency. This location was chosen because strawberry plants need a stable level of soil moisture to support optimal growth and good fruit quality. The implementation of the automatic watering system in the garden aims to help farmers manage irrigation more effectively, save water, and increase the productivity of strawberry plants. In addition, this research also aims to educate farmers about the use of technology in agriculture (smart farming) and provide a real picture of water use efficiency, workload reduction, and increased crop yields through Internet of Things-based technology. It is hoped that this system can be a pilot model for other plantations in the Talang Padang area and other agricultural areas in Tanggamus Regency.

4.4.2. Order Information on the Blynk App

The image shown shows the interface of an Internet of Things (IoT)-based automated plant watering system. The system is designed to monitor soil moisture in real-time and automatically regulate watering based on detected moisture values. On the screen, there is a gauge-shaped indicator that shows the soil moisture value, Under the humidity indicator, there is a water pump control button with the status "OFF", indicating that the pump is inactive, and the water pump is "ON" is active. The following is an overview of the system in the blynk application:

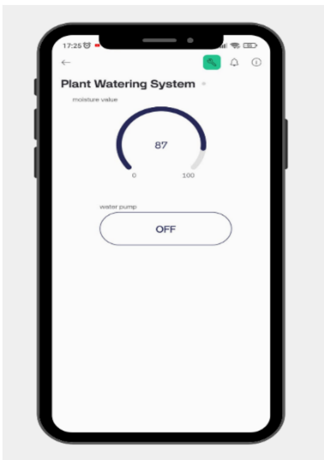

Figure 8. Blynk App

4.5. Testing Results and Discussion

4.5.1. Soil Moisture Sensor Testing

Soil moisture sensor testing aims to evaluate the accuracy and speed of sensor response in detecting moisture content in the planting medium. The interface of the 'Plant Watering System' system shows the results of the moisture reading directly through a numerical indicator and visualization in the form of a gauge.

Figure 9. Soil Sensor Testing

In the image, the moisture value read is 99, which means that the soil conditions are very wet. This value is displayed on a scale of 0 to 100, where the higher the number indicates the higher the moisture content. Overall, the sensor can detect changes in the moisture content in the soil well and provide the appropriate value, which is then used by the system to automatically regulate the watering process. The display of these values on the mobile application also adds to the convenience of users in monitoring plant conditions remotely.

4.5.2. Automated Watering Mini Pump Testing

Testing on the mini pump is carried out to verify that the automatic watering mechanism is working properly based on the data received from the soil moisture sensor. This image shows the real implementation of an automatic watering system using a mini pump connected to a water hose and controlled through an IoT-based Plant Watering System application.

Figure 10. Automated Watering Testing

The mini pump will remain active until the soil moisture rises past the threshold specified in the program. After that, the system will automatically turn off the pump to avoid overwatering. From the results of these tests, it can be concluded that the pump works responsively, efficiently, and integrates in real-time with the data received from sensors and monitoring applications.

4.5.3. Blynk App Testing

Blynk application testing is carried out to ensure that the user interface can display sensor data in real-time and can effectively provide commands to IoT devices. The Blynk application is used as the primary control and monitoring platform in IoT-based automated plant watering systems. In this test, the soil moisture sensor embedded in the planting medium sends moisture value data to the microcontroller, which is then passed to the Blynk app via an internet connection. The test results show that the application is able to display moisture values accurately and in real-time in the form of graphs or gauge indicators. In addition, the Blynk app also provides control buttons (such as ON/OFF) to manually turn the water pump on or off. The response from the app is very fast and does not experience significant delays. When the button is pressed, the pump immediately responds as commanded, indicating the system integration runs optimally. In this test, when the soil moisture value is at 35, the system automatically activates the water pump marked with the ON status on the application. The water then flows through the hose towards the plant pot, as seen in the image of the automatic watering test. This proves that the system can respond to low humidity values by enabling watering to keep soil moisture optimal.

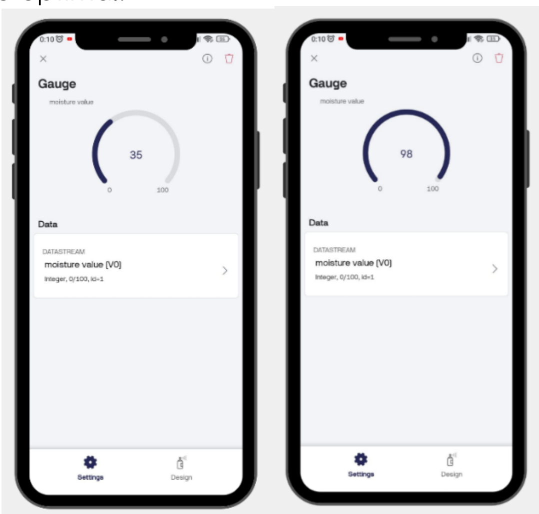

Figure 19. Blynk App Testing

The mini pump will remain active until the soil moisture increases to 98 in the program. After that, the system will automatically turn off the pump to avoid overwatering. From the results of these tests, it can be concluded that the pump works responsively, efficiently, and integrates in real-time with the data received from sensors and monitoring applications.

5.0 CONCLUSION

Based on the results of the design, implementation, and testing, the IoT-based automatic plant watering system has been proven to function effectively in line with its objectives. The soil moisture sensor successfully detects soil conditions in real-time, with data displayed through the Blynk application, which also serves as a remote monitoring and control interface. When the soil moisture drops below a predetermined threshold, the system automatically activates the mini water pump until the soil reaches the appropriate level of humidity. The implementation of IoT using the ESP32 microcontroller, soil moisture sensor, relay, mini DC water pump, and Blynk application provides significant benefits such as full automation, efficient water usage, time savings, and ease of operation. These advantages contribute to improving plant productivity, particularly on a small scale such as household farming or private gardens. However, this study also identified several limitations. The system heavily depends on an internet connection and has power constraints when operated using batteries or power banks. In addition, the accuracy of the soil moisture sensor, which is relatively simple, tends to decrease over time, especially with continuous water exposure. The scalability of the system is also limited, as it is still designed for single pots or small areas. Therefore, although this system has proven feasible for small-scale applications, further development is necessary to optimize its use for wider and more sustainable agricultural practices.

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