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Implementation of IoT Edge Computing for Control and Monitoring System of Hydroponic Plant Water Quality Using Raspberry Pi

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***Abstract*— Hydroponics involves cultivating plants using a water-based medium mixed with mineral nutrients, continuously supplied to the roots 24/7. Factors such as water reserve height, temperature, nutrient content, and pH are crucial considerations in hydroponic farming. Connectivity issues to the internet-based cloud system can disrupt the monitoring and control system. To ensure the effective operation of the hydroponic plant control and monitoring system, IoT edge computing within the Local Area Network is necessary as an extension of the cloud system. Periodically, the system will transmit calculation results from water quality sensors to the cloud-based system through IoT edge computing, enabling decision-making within the Local Area Network and subsequent transmission to Internet of Things devices within the hydroponic system for optimal plant growth.**

Keywords*— Remote control and monitoring, Automatic Control, Internet of Things, Edge computing, Cloud-Based System, Hydroponic water quality

I. INTRODUCTION

Hydroponics, a soilless cultivation technique utilizing water as a medium, is ideal for compact spaces like urban areas or small yards. Nutrient-rich water is continuously delivered to plant roots, requiring regular monitoring of factors like temperature, level, conductivity, and pH for optimal growth.

The integration of cloud-based systems enhances IoT development, enabling efficient processes for sensor modules and systems. Network disruptions affect the hydroponic system's water quality control via the cloud, necessitating IoT edge computing within local networks to ensure uninterrupted monitoring and control. This approach improves overall system performance, meeting plant nutritional needs and maintaining water quality while enabling convenient remote monitoring.

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This research entails AWS cloud integration, IoT Greengrass edge computing implementation, and hardware modules like Arduino, Raspberry-Pi, pH, conductivity, and temperature sensors. The ESP32 microcontroller facilitates application development for sensor data reading and pH/EC dosing pump control, while Raspberry-Pi serves as edge computing, connecting the system to AWS IoT CORE and other services.

The progression of Information and Communication Technology (ICT) and Electronics offers promising avenues for advancing Internet of Things (IoT) technology in hydroponic agriculture. Through sensor integration, real-time water quality monitoring can transmit data to cloud-based systems via edge computing, enhancing hydroponic system performance. Future endeavors involve developing an automated control system with Machine Learning to refine water quality management for hydroponic cultivation. The research aims to bolster food security at the household level by addressing the World Health Organization's (WHO) criteria: food availability, access, and utilization. By optimizing hydroponic practices, the research seeks to contribute to enhancing food security for households.

II. LITERATURE REVIEW

A. Hydroponic Technology

In hydroponic systems, plants grow sans soil, receiving essential mineral nutrients dissolved in water. A pump circulates this water to plant roots, flowing back via pipes. Besides regulating water level, flow, temperature, and conductivity, monitoring water pH is vital [1]. Plants struggle to absorb nutrients if pH doesn't suit their needs. Various hydroponic techniques include Deep Water Culture, Nutrient Film Technique, Aeroponic, EBB and Flow, and Drip System [2]. Hydroponics offers benefits like faster growth and water efficiency compared to soil-based methods. It's eco-friendly and supports food security.

B. ESP32 Development Kit

The ESP32 is an open-source development board designed for both hardware and software applications. It has the

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capability to read input from analog and digital sensors, touch switches, button presses, and even receive information through WiFi networks, which is then processed into an output using the microprocessor support on the board. Additionally, it provides software libraries to facilitate users in creating software applications [3][4].

C. Sensor Module

To measure water pH and conductivity (EC), need this 2 sensors connected to the Analog pins are required, while water temperature measurement is connected to the Digital pin of the ESP32 module [3][5]. Two waterproof DS18B20 temperature sensor is used to measure the water temperature inside a water reservoir of a hydroponic system and air temperature. This sensor can be used in environments up to 125 degrees Celsius and has digital output (9–12bit) [6]. Water temperature measurement is necessary for conductivity calculation, while air temperature measurement is used to determine the environmental temperature of the hydroponic system. The ppm (parts per million) of water can be obtained from the calculation result of water conductivity (EC) measurement [7].

D. Raspberry-Pi

The Raspberry Pi, a credit card-sized mini computer, was developed by the Raspberry Pi Foundation in the UK under Broadcom's Hardware Architect, Eben Upton. Despite its compactness, it functions similarly to a PC, enabling tasks like email management, document creation, web browsing, and multimedia playback [8]. In this study, the Raspberry Pi will serve as an AWS IoT Greengrass edge computing device, receiving data from hydroponic system sensors via a local TCP/IP network using MQTT protocol in JSON format [9].

E. Amazon Web Service (AWS) IoT

AWS IoT provides cloud services that can be used to connect Internet of Things (IoT) devices or modules to other IoT devices and to AWS cloud services. AWS IoT provides device software that enables each registered IoT device to connect to AWS services using several protocols supported by IoT CORE: MQTT, MQTT over WSS, HTTPS, and LoRaWAN. AWS IoT Greengrass is software provided by AWS as edge computing, an extension of the Cloud system that can be implemented within the local computer network [10][11].

AWS IoT also provides several interfaces as follows [10]: AWS IoT Device SDKs, AWS IoT Core for LoRaWANm AWS Command Line Interface (AWS CLI), AWS IoT API, AWS SDKs

In addition to the AWS IoT interfaces mentioned above, there is also the AWS IoT console equipped with a GUI for configuring and managing thing-objects, certificates, rules, jobs, policies, and other elements as part of an IoT solution [12].

F. Results on previous research

In previous research, a state machine for automatic control functions regarding the water quality of hydroponic plants was successfully developed with the assistance of Detector Models, which are part of the AWS IoT Events data services [13]. Each incoming data input is promptly processed and analyzed automatically to determine decision-making regarding the control function of hydroponic plant water quality. The output of this control function is commands to activate dosing pumps to add pH-Up, pH-Down, or AB-Mix solutions as needed to maintain water quality. The overall state machine can be viewed in Figure 1.

Disruptions in access to AWS IoT CORE over the internet can disturb the automatic control function. This can be addressed by adding AWS IoT Greengrass as edge computing using Raspberry Pi, which will be implemented in this research. With the presence of AWS IoT Greengrass, it is expected that the performance of the hydroponic system will be improved in decision-making to maintain water quality stability.

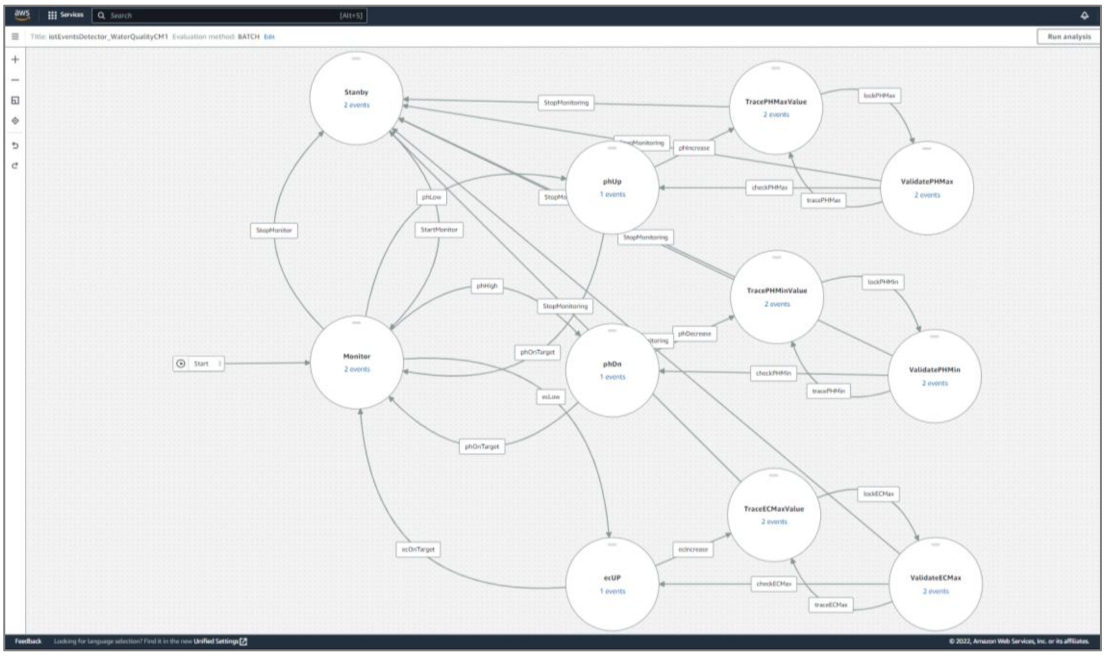

Fig. 1. Detector Models for Automatic Water Quality Control

III. Proposed Method

Research methodology is the set of stages that must be established before conducting the research, ensuring that the research is conducted in a directed, clear, efficient, and effective manner. The following, Figure 2 is a fishbone diagram of the research depicting what will be done in this study.

This research is conducted on a hydroponic cultivation system, with a planned research implementation period of 1 year to complete hardware development, software development, integration with AWS Greengrass, as well as testing the system as a whole.

A. Research Stages

In this study, we will conduct IoT edge computing implementation and integration with the IoT cloud system, as well as hardware and software development enhancements, building upon previous research findings. The research stages are outlined as follows:

1. Collecting data related to hardware modules and their supporting software libraries.
2. Constructing hardware using modules that are still applicable from previous research.
3. Upgrading sensor modules to new versions to improve accuracy and stability.
4. Developing modular software for each functional hardware module.
5. Implementing IoT edge computing using Raspberry Pi.
6. Integrating the hydroponic system with the cloud-based system via internet access.
7. Applying the developed hardware and software modules to a hydroponic cultivation trial system within a local computer network

B. System Development

The development of hardware and software in this research follows the Waterfall Model, which is a classic model characterized by its systematic and sequential nature. According to Pressman, the Waterfall Model consists of 5 stages of development: Communication, Planning, Modeling, Construction, and Deployment [14].

C. Achievement Indicators

Testing essentially is a repetitive process to identify errors in a system that may be caused by various factors, whether related to software, hardware, or errors in the design, implementation, and specification determination processes. Corrections to these errors are continuously made until the target outcomes are successfully achieved. The following are achievement indicators for this year's research:

1. The hydroponic system successfully integrates with the AWS IoT cloud-based system and AWS IoT edge computing using Raspberry Pi.
2. Periodic monitoring of water pH and conductivity operates effectively.
3. Water quality determined by pH and PPM values can be maintained according to the specified values.
4. Control and observation of water quality can be conducted via a TCP/IP-based network.
5. The dashboard functions properly.

IV. Experimental result

A. Hardware Development

In this research, hardware and software have been developed from the previous study to enhance the overall system performance. To reduce latency, additional IoT edge computing hardware and software need to be added so that IoT devices do not have to connect to the IoT CORE located in the cloud.

B. Raspberry Pi as AWS Greengrass IoT Edge

The Raspberry Pi is utilized as the AWS IoT Greengrass CORE Device, which includes the AWS IoT Greengrass and AWS Lambda software modules. Events originating from IoT Devices do not need to be forwarded entirely to the AWS Cloud; the majority of processing can be done locally with the assistance of AWS Lambda [15]. The operating system used is Raspbian, a Linux-based OS that is free and open-source software.

C. System Architecture Design

The architecture depicted in Figure 3 showcases the implementation of IoT devices in hydroponic systems using the ESP32 minimum system. Data regarding water quality, derived from temperature, pH, and EC sensor modules, is processed by the ESP32 module and sent to the AWS IoT Greengrass CORE Device via MQTT protocol in JSON format over the Local Area Network WiFi. Automatic pH and nutrient control functions are handled by the AWS IoT Greengrass CORE service. Meanwhile, all hydroponic IoT devices are linked online to AWS IoT CORE, accessible via web browsers on the internet, allowing clients to access them anytime from TCP/IP-connected networks.

D. Hardware Implementation

In the previous research, the minimum system operated effectively. Data from the pH sensor and conductivity (EC)

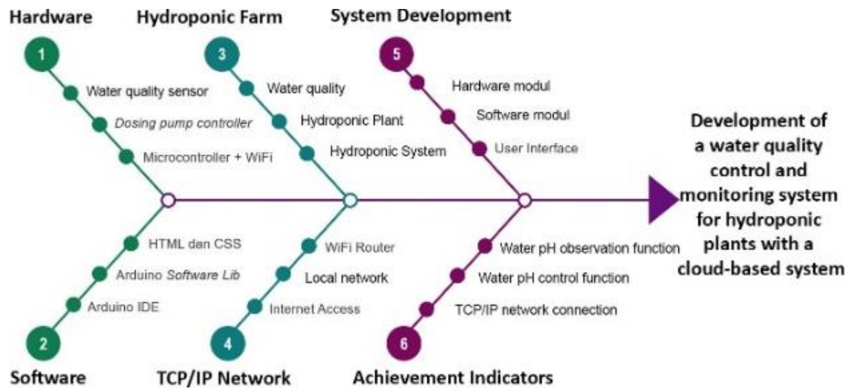

Fig. 2. Research flow based on fish bone diagram

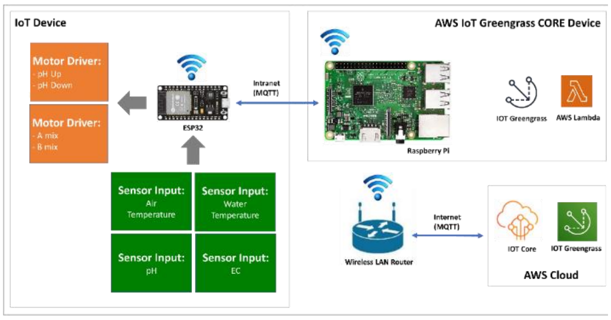

Fig. 5. IoT Hydroponic System Architecture

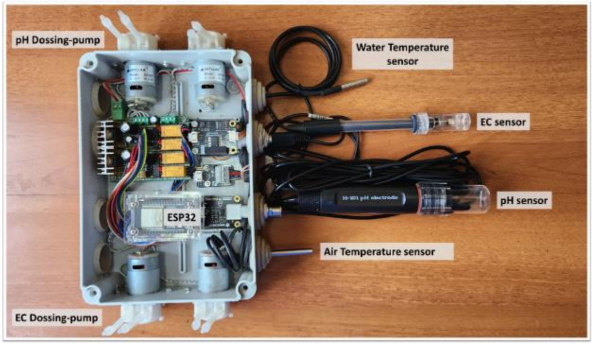

Fig. 3. Hardware of Hydroponic IoT

sensor modules could be forwarded to the IoT Event service, and likewise, control functions from the IoT Event could be received and executed by the minimum system. As depicted in Figure 4, this study involves replacing the "MEGA+WiFi R3 ATmega2560+ESP8266" microcontroller module with the ESP32, which is equipped with the AWS IoT library for communication with AWS Greengrass embedded in the Raspberry Pi as the AWS IoT CORE device.

E. Software Implementation

The software implementation in this study involves configuring AWS IoT CORE for AWS Greengrass, control and monitoring functions for water quality, and data collection functions for sensor data and dosing-pump control.

1) AWS IoT CORE Configuration

Here are some software configurations that need to be prepared within AWS IoT CORE, namely: IoT device registration, IoT device certificate, and policy settings. After successfully registering the IoT devices, they can be viewed in the AWS IoT service menu, then navigate to the "Manage" menu and select "Things". The IoT devices in this study are named "WaterQualityCM" and "RpiWaterQualityCM", while the IoT Greengrass CORE Device is named "RPiGreengrass".

To obtain more detailed information about the configurations that have been made, you can click on "WaterQualityCM" or "RPiGreengrass". As shown in Figure 5, "WaterQualityCM" and "RPiGreengrass" already have Amazon Resource Names (ARN) as unique identifiers for AWS resources. Additionally, there is information about the active Certificate-ID used to ensure security in the use of AWS cloud services.

To ensure that the IoT Device can communicate effectively with the IoT Greengrass CORE Device, the IoT Device needs to be registered to a Greengrass group beforehand. In this study, a Greengrass group named "BNGreengrass_Group" has been created, where the Raspberry Pi acts as the IoT Greengrass CORE Device with several functions such as MQTT broker and MQTT bridge (Figure 6).

2) Control and Monitoring Functions for Water Quality

In the previous study, the control and monitoring functions were located in the cloud-system, which is one of the services of AWS IoT called IoT Event. However, in this study, the state machine for maintaining water quality is placed on the Raspberry Pi as Edge computing using the Python programming language. As seen in Figure 7, to maintain water quality, four states are required:

1. Monitoring:
   - If the pH value of the water is between 5.5 and 6.5, and the ppm is between 600 and 1400.
2. pH Up:
   - The pH of the water will be raised if the pH value is less than 5.5.
   - Addition of pH-Up solution will be stopped if the pH value is greater than or equal to 6.
3. pH Down:
   - The pH of the water will be lowered if the pH value is greater than 6.5.
   - Addition of pH-Down solution will be stopped if the pH value is less than or equal to 6.
4. ppm Up:

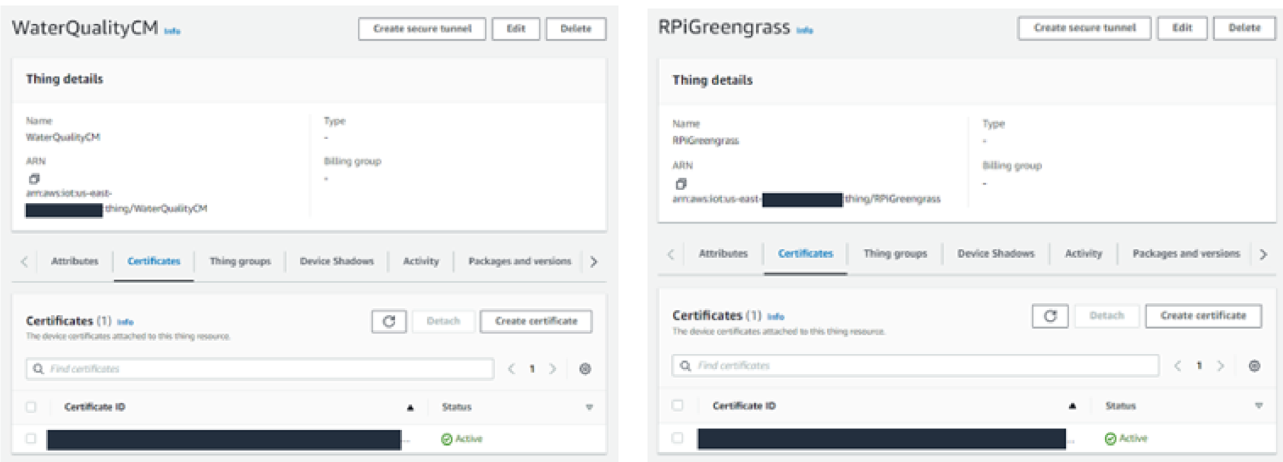

Fig. 4. AWS IoT CORE Certificate

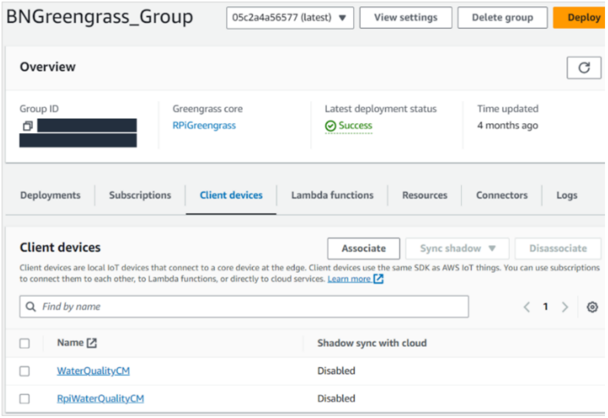

Fig. 7. AWS IoT Greengrass Group

- The ppm of the water will be increased if the ppm value is less than 600.
- Addition of nutrient solutions AMix and BMix will be stopped if the ppm value is greater than or equal to 1000.

3) Sensor Data Collection and Dosing Pump Control Functions

The ESP32 module of the minimum system needs to incorporate the <AWSGreenGrassIoT.h> library to ensure seamless connection between the IoT Device and AWS IoT CORE Greengrass or IoT CORE. Three security certificates need to be embedded in the ESP32: Private Certificate Authority (CA), AWS Device Certificate, and AWS Device Private key. Once the IoT Device has successfully gained access, every event occurrence will be transmitted using MQTT for the designated Topic. The pH water and ppm water measurements will be available every 2 seconds in JSON format. Moreover, the minimum system remains ready to receive commands to raise pH water levels, lower pH water levels, and increase ppm water levels, all in JSON format.

The following describes the results of the IoT Device's testing on access to the local WLAN WiFi, access to AWS IoT CORE Greengrass, connectivity test, MQTT publish test, and MQTT subscribe test.

F. AWS IoT CORE Dashboard

When the Hydroponic IoT device is successfully connected to AWS IoT CORE, an automatic monitoring dashboard is provided within the AWS IoT CORE service to view various attributes, as shown in Figure 8. To access this monitoring dashboard, select the "AWS IoT" menu and then

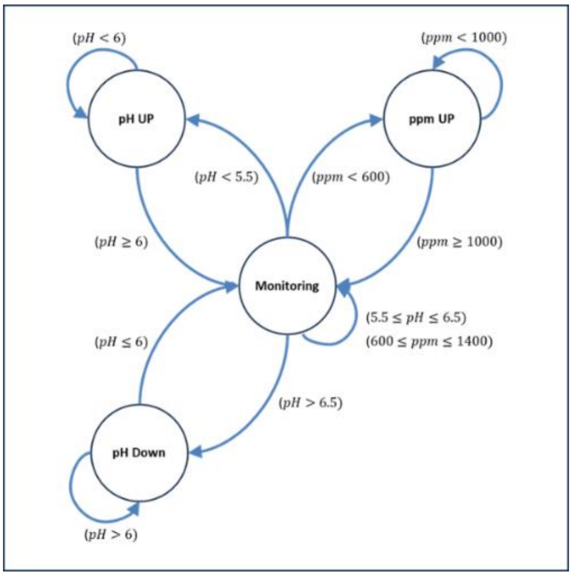

Fig. 6. State Machine

choose the "Monitor" submenu. From the test results, it is observed that there were eight connection events with approximately 120 outbound messages and 221 inbound messages, all of which were utilizing MQTT.

G. Hydroponic IoT Devices

Before accessing the hydroponic IoT device via AWS IoT CORE Greengrass or AWS IoT CORE in the cloud, the ESP32's WiFi module must be activated. After successful WLAN network access, the ESP32 obtains a local IP Address from the Wireless Router connected to the internet via the WAN port. Next, time synchronization with an internet NTP Server is necessary for certificate authentication during access to AWS IoT CORE Greengrass or AWS IoT CORE. After these steps, all installed sensor modules are detected. The machine log output confirms connectivity to AWS Greengrass, Figure 9.

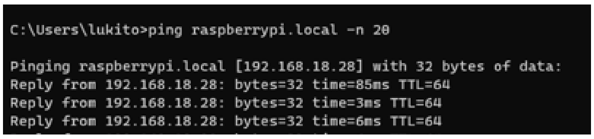

Fig. 9. PING connectivity test

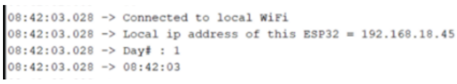

Fig. 10. IoT Device Initiation

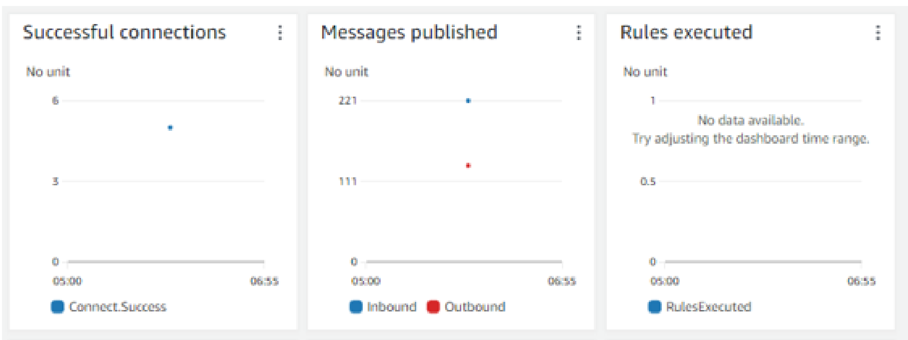

Fig. 8. AWS IoT CORE Monitoring Dashboard

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H. Connectivity Test

In addition to cost-saving on internet connectivity, the implementation of AWS IoT CORE Greengrass aims to reduce latency. Previously, when the IoT MQTT broker was

I. MQTT Publish and MQTT Subscribe Test

The next test involves sending messages to the AWS IoT CORE cloud service through AWS IoT CORE Greengrass,

located in the IoT CORE cloud service, it had an average PING latency value of 257ms. However, by utilizing the AWS IoT CORE Greengrass device, the PING value reduced to 10ms. As shown in Figure 10, there is a latency improvement of 247ms when using the local WLAN network.

Interconnection with AWS Greengrass functions smoothly. Based on the test results, there is an improvement in system performance with a decrease in latency from an average PING value of 257ms to 10ms. With Raspberry Pi acting as IoT edge

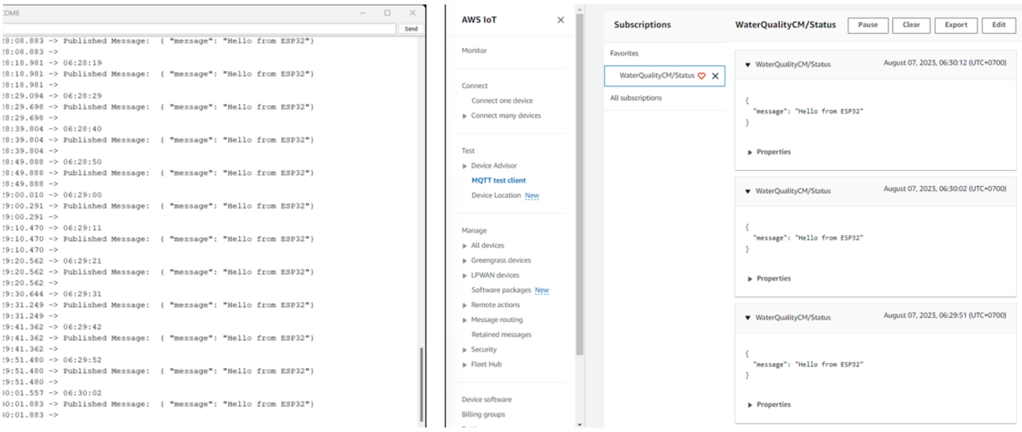

Fig. 11. MQTT Publish test

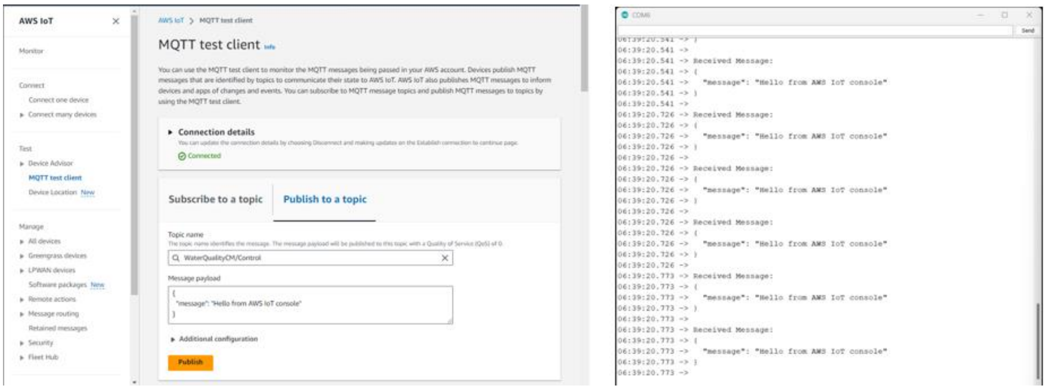

Fig. 12. MQTT Subscribe test

which functions as an MQTT bridge. As seen in Figure 11 and Figure 12, messages from the ESP32 are received successfully by AWS IoT CORE, and likewise, all messages from IoT CORE are perfectly received by IoT CORE Greengrass.

The issue related to the limitations of ESP8266 capabilities can be overcome by using ESP32 as the IoT client. As seen in Figure 13, the water quality for hydroponic plants can be well maintained with pH values consistently between 5.5 to 6.5 and nutrient levels in the water maintained at 1000 ppm. Through direct observation using the serial console to ESP32, it was found that nearly all messages sent

computing, functioning as the CORE device of AWS IoT CORE, the problem regarding internet access disruptions encountered in the previous research can be effectively addressed. Control and monitoring of water quality for hydroponic plants can be conducted simply using the local network.

via the WiFi network were received successfully. The control function operates effectively according to the state machine model, as shown in Figure 14 for automatic adjustment when the pH value of water is above 6.5 and below 5.5. Meanwhile,

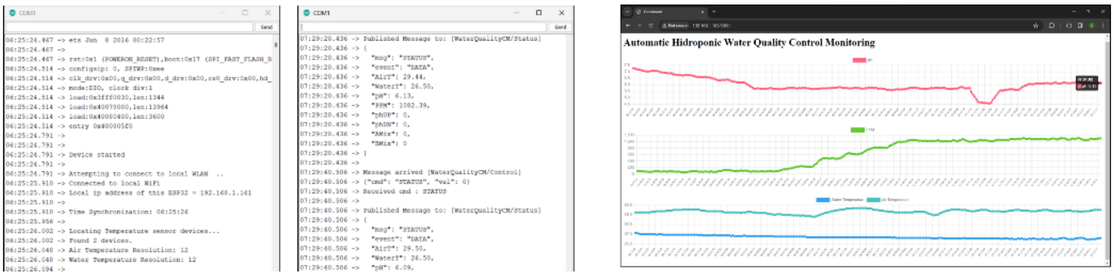

Fig. 13. Automatic Water Quality Control

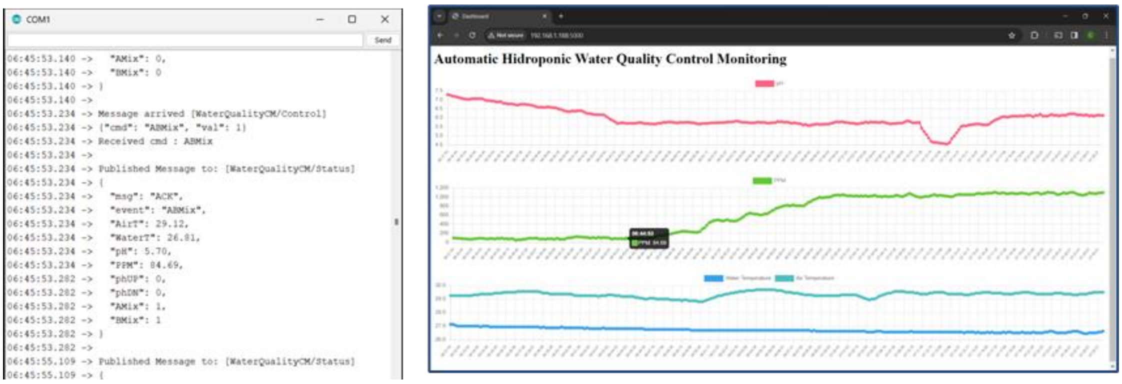

Fig. 14. Automatic Control of Water ppm for 1000 ppm

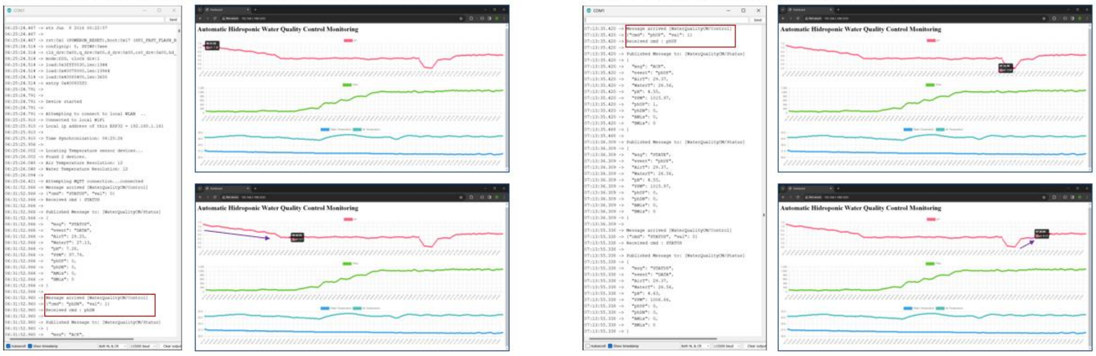

Fig. 15. Automatic pH Water Control

Figure 15 illustrates automatic adjustment when the ppm value is below 600. Monitoring results of water quality control functions can be accessed using a web browser.

V. Conclusion

This research successfully implemented Internet of Things (IoT) technology in hydroponic systems using ESP32 as the main device, leveraging AWS IoT Greengrass as edge computing and integrating with AWS IoT CORE for efficient monitoring and control of water quality. By replacing ESP8266 with ESP32, the system performance improved significantly, reducing latency from 257ms to 10ms. The incorporation of Raspberry Pi as IoT edge computing further resolved previous internet access disruption issues. Moreover, the automatic control and monitoring functions for water quality, following a predefined state machine model, function effectively. The implementation of automatic control functions using AWS Greengrass with MQTT protocol and JSON operates seamlessly, ensuring well-maintained water pH and nutrient levels when activated.

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