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IoT Implementation for Hydroponic Water Monitoring Using Web-Based *pH* and *TDS* Sensors with Node-Red

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Abstract – Due to land scarcity, rapid urbanization, and shrinking agricultural space, urban environments such as Jakarta face increasing agricultural challenges. By enabling efficient, soil-free cultivation in limited areas, hydroponics has emerged as a promising solution to address these issues. However, ensuring the consistency of the quality of hydroponic water systems, especially in terms of *pH* and total dissolved solids (*TDS*), is often done manually, which is ineffective and prone to human error. Several *IoT*-based solutions have been proposed; however, many rely on cloud services or mobile platforms, which limit accessibility in offline environments. This study introduces a scalable, internet-independent hydroponic water quality monitoring system that uses *pH* and *TDS* sensors connected to an *ESP32* microcontroller. A *Node-RED* dashboard, accessible by a browser on a local network, is used by the system to display data in real time, using the *MQTT* protocol. The system, developed using the *IoT* Platform Design Methodology, underwent *black-box testing* to ensure that its data acquisition, transmission, and visualization were accurate. The results showed reliable performance without any functional errors. Classified as a Level 2 *IoT* system, it allows real-time monitoring without automation and the possibility of future expansion such as data storage and actuator control. The proposed system provides a practical and scalable solution for urban hydroponic farmers working in areas with limited internet connectivity.

Keywords – IoT, Sensor, TDS, pH, Node-RED, IoT Platform Design Methodology, ESP32

I. INTRODUCTION

Natural population growth in recent decades has led to an increase in food demand in many places, including big cities like Jakarta. Jakarta faces major problems in terms of food distribution and availability because it is a capital city with a high level of urbanization. The city is vulnerable to food crises due to dependence on supplies from outside the region, limited agricultural land due to land conversion into organizational and commercial areas, and rapid population growth [1]. To overcome these problems, one alternative solution that is starting to be developed is hydroponic farming, a plant cultivation technique that uses nutrient-enriched air media without soil. Because it can be used in narrow areas, hydroponics supports the concept of urban farming and is efficient and environmentally friendly, making it very suitable for application in urban environments. In addition, it has been proven that this technique can increase plant productivity while reducing our dependence on excessive pesticides and chemical fertilizers [2][3].

Hydroponics is an alternative for people to grow plants that use little land. Hydroponics uses water as a substitute for soil [4]. This is one of the efforts to implement an urban farming system [2]. Hydroponic farming requires more care compared to conventional farming methods that use soil as a medium. As a result, more attention is needed to the plants [5]. Currently, the parameters of the widely used hydroponic system are still manually regulated by humans, with parameters such as nutrient concentration, *pH*, and water level being monitored [6]. The process of water evaporation is a separate problem in hydroponics, because low water levels in the nutrient solution can affect plant growth. Therefore, the control system must provide water automatically when the amount of water in the nutrient solution tank increases [7].

In recent years, research has shown that Internet of Things (*IoT*) technology is very useful for agricultural environmental monitoring systems, such as air quality measurement. *IoT*-based systems enable real-time monitoring of environmental parameters for the needs of conventional and hydroponic farming systems. Collaborating with microcontrollers such as *ESP32*, ESP8266 and ATmega328 can improve the accuracy and efficiency of air quality monitoring [8][9][10]. Such systems can read sensor values periodically and send them to a data processing platform via lightweight communication protocols such as *MQTT* [11][12].

Monitoring water parameters is very important in hydroponic farming. According to many studies, manually operated hydroponic systems face a number of problems, including inaccuracy in maintaining *pH* and *TDS* levels, which can inhibit plant growth. As a result, to improve the efficiency and stability of nutrients in hydroponic solutions, sensor-based and Internet of Things-based automated systems have been widely used [9][13]. Some studies even combine simple regression models and fuzzy logic-based control techniques to control nutrient pumps and stabilize *TDS* levels [14][15].

For data visualization and management, platforms such as *Node-RED* are widely used as monitoring dashboards because they are flexible and open-source, supporting various protocols such as *MQTT* and HTTP. *Node-RED* has been proven to have the ability to display sensor data in real-time in the form of labels, system indicators, or graphs that can be accessed via a local network [12][16][17]. With this implementation, users, especially farmers or managers of home-scale hydroponic systems, can monitor and

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understand the condition of the solution easily without having to do manual measurements every time.

Overall, the systems developed in various studies show a tendency to combine *pH* and *TDS* sensors with lightweight data processing systems and wireless microcontrollers. Real-time water quality monitoring, data-driven parameter control, and easily accessible information dissemination for users are the main focuses of these studies. However, only a few systems can optimize web-based visualization without cloud, and most current systems still use monitoring without sophisticated automatic control. Considering these differences, this study develops a web-based hydroponic water quality monitoring system that uses *pH* and *TDS* sensors with *Node-RED*. It is expected that this system will provide an effective and efficient solution that can be accessed locally by hydroponic users.

In this study, an Internet of Things-based hydroponic water quality monitoring system using *pH* and *TDS* sensors was built and integrated into a web-based platform called *Node-RED*. *Node-RED* is a web-based tool that allows real-time data processing and displays data from Internet of Things devices in a format that is easier for users to understand [18]. Users can monitor water quality remotely and get information about plant conditions instantly with this system [19].

This study uses the *IoT Platform Design Methodology* approach. To design and ensure that the hydroponic water quality monitoring system works well. A literature study was conducted to learn how the Internet of Things, *pH* and *TDS* sensors work, and how to build a web-based monitoring system using *Node-RED*. Meanwhile, the experiment was designed to test the accuracy of the sensor in reading water parameters and evaluate the system's ability to display data in real-time. This method is expected to enable the system to provide more accurate results and be more accessible to users.

The purpose of implementing the Internet of Things (*IoT*) is to ensure that water quality can be monitored in real-time and improve the quality of the harvest. The use of the Internet of Things (*IoT*) as a solution to overcome this challenge, which allows monitoring of water quality using *pH* sensors and *TDS* sensors in real-time, can be monitored through a web-based application using *Node-RED*.

II. RESEARCH METHODOLOGY

This study uses the *IoT Platform Design Methodology* approach, a method designed to build an Internet of Things (*IoT*) system systematically, from the needs stage to implementation and evaluation [20]. This methodology was chosen because it is in accordance with the research objectives, namely to develop an *IoT*-based hydroponic water quality monitoring system using *pH* and *TDS* sensors that can be accessed via the web via *Node-RED*. This study was conducted by following the *IoT Platform Design Methodology* which consists of ten stages, which can be seen in *Figure 1*.

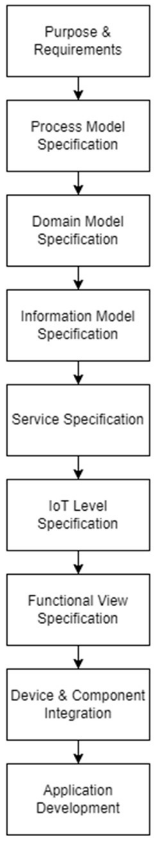

Fig 1 IoT Platform Design Methodology

A. *Purpose & Requirements Specification*

The purpose of this stage is to identify the main objectives of the system and the specifications of the needs that must be met. This system is intended to integrate air quality in hydroponic cultivation based on two main parameters: *pH* and *TDS*. This system needs to collect data from sensors in real-time, transmit data via wireless communication, and present data in graphical form via a web platform. In addition, the system also requires scalability, local network security, and simple data processing capabilities.

B. *Process* Model Specification

At this stage, the system process flow is designed to show the relationship between components. The system starts with an *ESP32* microcontroller that tracks the *pH* and *TDS* sensors. The *MQTT* protocol is used to send the collected information to the local broker. Next, the data is processed and displayed by *Node-RED* on the web dashboard. This process takes place cyclically and in real-time.

C. *Domain* Model Specification

In this stage, the main system components are explained. The physical entity consists of a hydroponic nutrient solution measured by *pH* and *TDS* sensors, while the virtual entity sends *pH* and *TDS* data to the *Node-RED* platform. Devices in this system include *ESP32 pH* and *TDS* sensors, and other resources

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include Wi-Fi connectivity, *MQTT* protocol, and firmware. Using the dashboard, the monitoring service sends and displays data in real-time to the user.

D. *Information* Model Specification

At this stage, defining the data structure, such as *pH* value and *TDS* value are two type of numeric data. Information is structured based on sensor attributes and displayed in dynamic visualizations on the web dashboard. This model helps map the relationship between sensors, devices, and data delivery to users.

E. Service Specifications

Real-time water quality monitoring is the system's core service. The *MQTT* protocol is used to send sensor data to a specific subject on a local broker. The program works with *Node-RED*, which processes and displays the data in the form of graphs and status indicators. Since it does not use public or cloud access, the service endpoint is secure and located locally.

F. *IoT* Level Specification

At this stage, determine the *IoT* level category. This system falls into the Internet of Things Level 2 category according to the Internet of Things taxonomy, which means that they have the ability to monitor in real-time conditions without using automatic control. Although data is sent and displayed directly, it does not perform automatic actions or decisions about the environment (such as turning on a pump). By adding control components, the system can still be developed to a higher level.

G. *Functional* View Specification

At this stage, the main functions of the system are explained, including reading *pH* and *TDS* sensor data; sending data via *MQTT*; receiving data in *Node-RED*; and viewing data on the dashboard. Each function is performed with a specific software and software role: *ESP32* to process data, Mosquitto *MQTT* broker to send data, and *Node-RED* as a visualization manager.

H. *Operational* View Specification

At this stage, it explains the preparation of the operational model of the system used, such as the device used by the user can use their browser to view *pH* and *TDS* data directly on the web dashboard during operation. The system runs locally on a single Wi-Fi network. *ESP32* needs to be connected to the *MQTT* broker consistently, and *Node-RED* must run on a local computer or server connected to the same network. The system does not consume much power and can operate 24 hours a day.

I. Device & Component Integration

At this stage, hardware assembly such as *ESP32*, *pH* sensor, and *TDS* sensor and component connectivity settings using breadboard and jumper cables are carried out followed by microcontroller programming using Arduino IDE, Wi-Fi connection testing, and communication with *MQTT* brokers. Integration is carried out to ensure that all components function properly and can communicate synchronously.

J. *Application* Development

At this stage, application development is carried out using *Node-RED*, and has a dashboard element that displays graphs of *pH* and *TDS* values and water status indicators. *Node-RED* logic flow includes processing JSON payloads, subscribing to *MQTT* topics, and presenting values in UI elements. The application can be accessed via a browser without the need to connect to the internet.

III. RESULTS AND DISCUSSION

A. Purpose & Requirements Specification

a. Purpose

This system aims to monitor water quality in a hydroponic system using *pH* and *TDS* sensors. With this monitoring, the system can ensure that water parameters are always in optimal conditions for plant growth, helping to increase the efficiency of hydroponic farming and minimizing potential plant damage due to changes in water quality.

b. Behavior

The system operates automatically and continuously in real-time. The *pH* and *TDS* sensors will read data at certain intervals. Then, the data is sent to the *IoT* platform via the *MQTT* protocol and displayed in graphical form on the *Node-RED* dashboard and stored for historical analysis. Although the system does not require manual intervention during the data collection process, users can track and monitor the condition of the sensors.

c. Requirements

a. System Management Requirements

The system must provide a management interface to monitor the sensor status and perform calibration and maintenance if necessary. The presence of this feature is essential to ensure the reliability of measurements in the long term. In addition, the system must provide a regular data backup function. This function is intended to protect important data from loss in the event of technical disruptions or device failures.

b. Data Analysis Requirements

The system must have the ability to perform basic analysis on the data collected from the sensors. Calculation of daily average values of *pH* and *TDS* and finding patterns or trends in the changes in these values are part of this analysis. This analysis will greatly help users understand water quality fluctuations

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and make decisions about improvements or adjustments more proactively.

c. Application Deployment Requirement

The system should be able to run locally on a device such as a Raspberry Pi or other minicomputer. This is done to prevent users from having to rely entirely on their internet connection. However, the system should also be designed in a way that allows for further development to support integration to cloud platforms if needed. At this stage, the main focus is on ease of installation, maintenance, and scalability of the system.

d. Security

The system must have authorization and authentication mechanisms to ensure that only authorized users can change configurations or view sensitive data. In addition, encrypting communications between devices (such as *ESP32* and *MQTT* brokers) ensures data security. This is done to prevent unauthorized persons from viewing or changing data.

e. Scalability Requirements

The system must be designed to be modular and flexible so that it can accommodate the addition of new sensors or devices without significantly changing the architecture. In addition, the system must be able to handle increasing numbers of devices and data volumes while maintaining stable and responsive performance. Thus, the system must allow for future development and expansion without compromising the quality of monitoring services.

f. Real-Time Data Processing

To ensure that the information provided is always up-to-date and allows users to make quick decisions, the system must be able to manage continuous streaming data with low latency. Data received from sensors must be processed immediately and displayed on the user dashboard without significant delay.

g. Maintenance and Calibration Requirements

To keep the system operating properly, the system must also provide routine maintenance procedures such as checking the status of the device and notification of failure or performance degradation warnings. In addition, the system must provide a mechanism that makes it easy for users to perform sensor calibration periodically, including guidance or calibration automation features if possible.

B. Process Model Specification

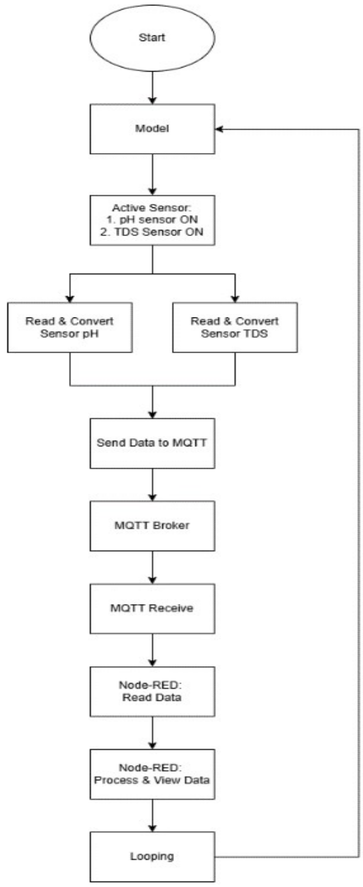

Fig 2 Process Model Specification

In Figure 2. The process starts from reading data by *pH* and *TDS* sensors, processed by *ESP32*, sent to the broker via the *MQTT protocol* (*Mosquitto*), and then sent to *Node-RED* to be displayed on the web dashboard. This process is cyclic and occurs periodically at set intervals.

C. Domain Model Specification

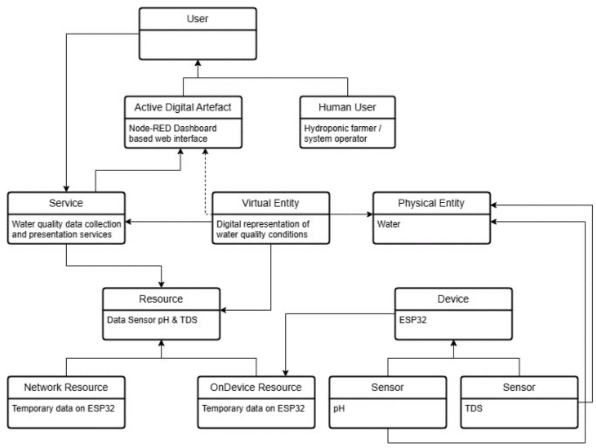

Fig 3 Domain Model Specification

In figure 3 shows the Domain Model, which shows the relationships between system entities. At this point,

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the important elements of the system are identified and classified based on the five main components of the Internet of Things (*IoT*) domain model: physical entities, virtual entities, devices, resources, and services. In the *Node-RED* dashboard, *pH* and *TDS* values are displayed as virtual entities. In contrast, *pH* and *TDS* sensors are depicted as input devices that measure water conditions (physical entities). *ESP32* processes the sensor data resources and sends them via the *MQTT* communication service. Furthermore, the data is visualized via *Node-RED* for end users to access. The structured flow of information from the physical environment to the digital display that can be monitored in real-time by the user is connected by the relationships between these entities.

1 Physical Entity
- Water

In hydroponic systems, water quality is the main physical entity monitored. To determine the acidity level and the amount of dissolved substances in the Water, *pH* and *TDS* sensors detect water conditions. An important factor for hydroponic plant growth is water quality.

2 Virtual Entity
- Digital Representation of Water Quality Conditions

The *pH* and *TDS* values of the sensors are processed by the *ESP32* and sent as digital representations. To make it easier for users to monitor water conditions in real-time, the data is visualized in the *Node-RED* dashboard. It is possible to monitor or analyze the actual water conditions through the digital representation of these virtual entities.

3 Device
- *ESP32*

Acting as a data processing and sending center, *ESP32* manages input from *pH* and *TDS* sensors and sends data to the *MQTT* broker to be forwarded to *Node-RED*. In addition, *ESP32* stores temporary data that can be accessed by the system.

- *pH* Sensor and *TDS* Sensor

pH & *TDS* Sensor Are input devices used to capture water quality conditions. The *pH* sensor detects the acidity level of water, and the *TDS* sensor measures the amount of total dissolved substances.

4 Resource
- Data *pH* and *TDS* Sensor

This is the main resource of the system to generate monitoring information. For analysis and display, the data is collected and sent via *ESP32*.

- On Device Resource

Before the data is sent to the visualization platform, temporary data stored on the *ESP32* is used.

- Network Resource

Shows how the local network is used to send data from the *ESP32* to the *MQTT* broker and then to *Node-RED*.

5 Service
- Water Quality Data Collection and Presentation Services

The service includes collecting data from *pH* and *TDS* sensors, sending data via *MQTT*, and presenting information on the *Node-RED* dashboard. The service allows users to monitor water conditions visually and in real-time via a browser.

6 Active Digital Artefact
- *Node-RED* Dashboard based web interface

a web-based digital interface that displays monitoring data. To make it easy for users to understand, *Node-RED* presents *pH* and *TDS* information in the form of graphs and color indicators.

7 Human User
- Hydroponic Farmers / System Operators

To monitor water quality, people using the system can interact with the dashboard, view data in real-time, and then take action based on the information the system provides.

8 User
- User

A generic entity that interacts with an Active Digital Artifact. In the context of this system, a user can access information through a browser and rely on the system to make decisions about hydroponic water management.

D. Information Model Specification

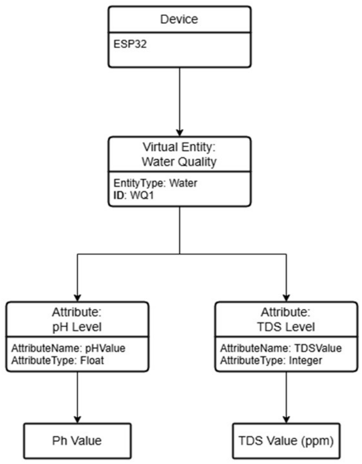

Fig 4 Information Model Specification

In Figure 4 shows an information model that describes the data structure and main attributes of a hydroponic water quality monitoring system. This model shows how data is generated, classified, and displayed as virtual entities in an *IoT*-based system.

The Device entity is an *ESP32* microcontroller unit, which functions as a data processing and sending center. *ESP32* receives data from *pH* and *TDS* sensors connected to it, and then forms a digital representation in the form of a Virtual Entity.

Water Quality is a virtual entity with ID = WQ1, EntityType is Water, and functions as a digital representation of the actual water conditions monitored in the hydroponic system.

This virtual entity has two main characteristics:

1. *pH* Level
   - AttributeName: pHValue
   - AttributeType: Float

   The acidity value of the water determined by the *pH* meter usually represents this attribute, which

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usually ranges between 0 and 14. The ideal hydroponic value is around 5.5 to 6.5.

2. *TDS* Level
   - AttributeName: TDSValue
   - AttributeType: Integer

   This attribute indicates the amount of total dissolved solids (*TDS*) in the water in ppm, or parts per million. The value indicated by the *TDS* sensor is the level of nutrient density in the hydroponic solution.

The *ESP32* sends the values of these two attributes periodically to a visualization platform, such as *Node-RED*. Thus, users can see the values in real-time and make adjustments if the values are outside the optimal limits.

E. Service Specification

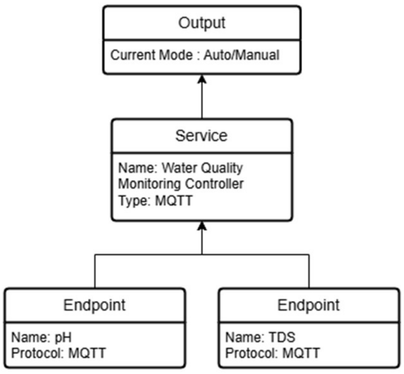

Fig 5 Service Specification

Figure 5 shows the System Service Specification that illustrates how the system uses the *MQTT* protocol to help sensors communicate with a central monitoring controller. In this configuration, *MQTT* endpoints labeled *pH* and *TDS* send *pH* and *TDS* sensor readings to the endpoint, which sends real-time data to a service called the Water Quality Monitoring Controller via a lightweight protocol.

As a central *MQTT* subscriber, this service collects and monitors all incoming data from the two sensor channels. This data is then processed and translated into system outputs such as the Current Mode status, which indicates whether the system is operating in manual or automatic mode. This structure allows for efficient, real-time communication with low bandwidth, allowing users or automated modules to make timely decisions about the water quality status.

F. *IoT* Level Specification

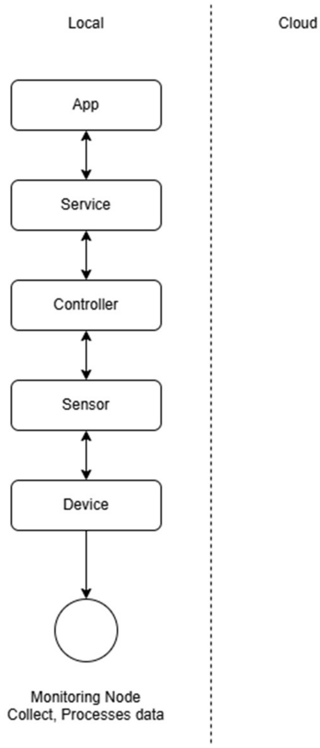

Fig 6 IoT Level Specification

Figure 6 shows that the system consists of a single local monitoring node consisting of various integrated components. The microcontroller device (*ESP32*), which acts as the main controller, is where the process begins. This device directly indicates the water quality by reading the *pH* and *TDS* sensor values in the hydroponic system.

The internal control uses *ESP32* to handle the data after the sensor values are read. It validates and converts the data into a digital format that can be sent. Next, the data is sent to the service section via the *MQTT* communication protocol. The service section delivers the data to the application interface, which is a web-based *Node-RED* dashboard.

The entire process is done locally without cloud involvement, so the dashboard can display the *pH* and *TDS* values in real-time in the form of graphs and label status. In addition, the system can show the current system mode (Auto/Manual) as additional information displayed to the user. This allows the system to collect and process data entirely within the local network, making it suitable for use in places where there is no cloud.

G. Functional View Specification

Application	
Web Application Node-RED Dashboard	**Application Server** Node-RED Engine
Management Application Management Device Management	**Service** Web Service **Communication** MQTT (MQTT Broker, Node-RED Logic)
Device Sensor (pH Sensor, TDS Sensor), Microcontroller (ESP32)	

Fig 7 Functional View Specification

Figure 7 shows the structure of an Internet of Things (IoT)-based system divided into three main layers: applications, services, and devices. Each layer shows the role and function of each system component in a modular

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and hierarchical manner. The physical components in the device layer, or device layer, include pH and TDS sensors. They are used to measure the quality of the nutrient solution in a hydroponic system. The ESP32 microcontroller is connected to both sensors, which functions as the main controller to read sensor data, perform initial processing, and transmit data wirelessly using the MQTT protocol, which is very lightweight and supports real-time communication. The service layer includes management components and interaction systems. In the Management sector, there are Application Management and Device Management functions that are operated through the logic flow on Node-RED. Meanwhile, in the Service section, the system implements a Web Service based on Node-RED Logic and the MQTT protocol managed by the MQTT Broker as a liaison to transfer data from the device to the application. This architecture allows the system to provide a real-time and cloud-independent hydroponic water quality monitoring solution, making it particularly suitable for deployment in urban environments that have limited internet access but still require a reliable monitoring system.

H. Operational View Specification

Table 1 Operational View Specification

Application	Application Server: *Node-RED* Engine
Service	*Web Service*
Communication	*MQTT (MQTT Broker, Node-RED Logic)*
Devices	Controller: *ESP32* Sensor: *pH Sensor*, *TDS Sensor*

Table 1 shows various operational options that can be used to implement and operate an Internet of Things system that combines hydroponic water quality. To ensure that all hardware and software components can work in an integrated and mutually supportive manner, this stage is very important.

ESP32 serves as the main controller in this system, connecting *pH* and *TDS* sensors to measure water quality parameters. The data obtained is then sent in real-time via the *MQTT* communication protocol, which is lightweight and ideal for Internet of Things-based applications.

This system uses *Node-RED* Engine and *MQTT* Broker (Mosquitto) as an application server. *Node-RED* not only receives and processes data from the broker but also provides an interactive web dashboard interface that directly displays *pH*, *TDS*, and system status. This system is ideal for use in areas with limited internet because it operates locally without relying on the cloud.

I. Device and Component Integration

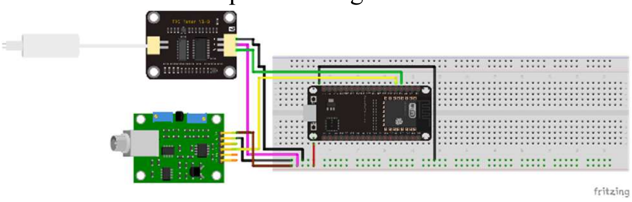

Fig 8 Device and Component Integration

The process of integrating all software and hardware in the system into one functional unit is depicted in Figure 8 Device and Component Integration. In order for the system to monitor hydroponic water quality in real-time, the integration of these components is very important.

The two main components of the system are the physical components (hardware) and the logical components (software). The *ESP32* microcontroller is directly connected to the hardware with two sensors: a *pH* sensor and a *TDS* sensor. The *pH* sensor measures the acidity or alkalinity of the nutrient solution, and the *TDS* sensor measures the amount of dissolved substances present in the water concerning nutrient levels.

The *ESP32* acts as a control center that calculates the values of both sensors. After the reading is complete, the data is formatted and packed in JSON format using firmware developed in the Arduino IDE. Next, the data is sent to a locally running broker, *Mosquitto*, via the *MQTT* protocol.

On the software side, *Node-RED* is a workflow-based visual platform used to process and display sensor data. *Node-RED* subscribes to topics sent by the *ESP32* and displays *pH* and *TDS* values on a web-based dashboard in real-time.

Using a browser that is on the same network as the *Node-RED* server, you can access this dashboard without being connected to the internet. Through the use of value indicators and graphs, users can track changes in water quality and use this data to make decisions.

Ensuring that sensor data can be read, sent, received, and visualized efficiently, this process runs automatically and synchronously. In order for this monitoring system to run well, good hardware and software integration is essential.

J. Application Development

In the application implementation stage, the author carried out several stages to realize an *IoT*-based hydroponic water quality monitoring system. The first stage uses the *Node-RED* platform to produce real-time graphic visualization of *pH* and *TDS* sensor data. Next, the author sets up data communication using the *MQTT* protocol, which functions as an information exchange path between the application platform and the microcontroller. To ensure that data reading runs smoothly, the next stage is to configure the controller (*ESP32*) and connect it to the *pH* and *TDS* sensors. After the configuration is complete, the author installs the sensors and hardware on the hydroponic system. This includes testing the stability of the readings and network connections. Data visualization and analysis are the final steps in this implementation. In the *Node-RED* web dashboard, data sent by the *ESP32* via *MQTT* is displayed. This allows users to see changes in *pH* and *TDS* values in real-time and make decisions based on the information they see.

1. Application Development

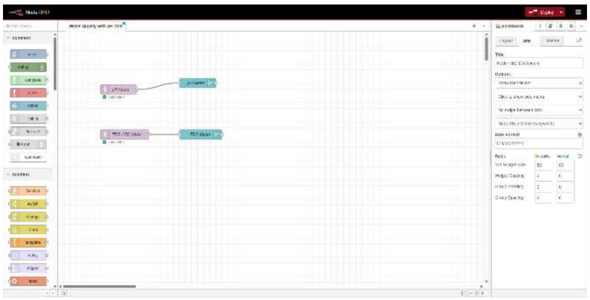

Fig 9 Node-RED Flow

Figure 9 shows the *Node-RED* flow configuration to receive *pH* sensor and *TDS* sensor data from the *MQTT* Broker and then display it in the form of a bar graph.

Fig 10 Node-RED Dashboard Output

Figure 10 is a *Node-RED* dashboard displaying the *pH* sensor and *TDS* sensor data previously received from the *MQTT* Broker.

2. Hardware assembly and integration

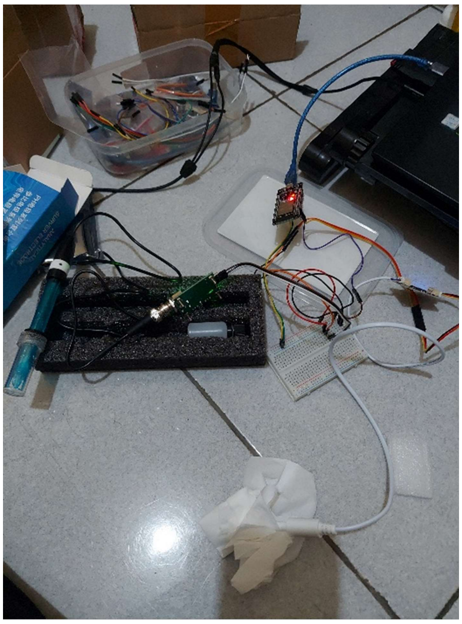

Fig 11 Controller Assembly

In Figure 11 the hardware is assembled, the *ESP32* microcontroller is connected to the *pH* sensor and *TDS* sensor.

3. *ESP32* Programming

The *ESP32* is programmed using the C++ programming language through the Arduino IDE platform. This microcontroller is configured to read data from the *pH* sensor and *TDS* sensor, then process it before sending it via the *MQTT* protocol. Figure 12, Figure 13, and Figure 14 show the complete scripts used to read sensor data and send it to the *MQTT* broker periodically.

Fig 12 Script ESP32 (a)

Fig 13 Script ESP32 (b)

Fig 14 Script ESP32 (c)

K. Application Testing

This stage is carried out after the application has been successfully developed; System testing is carried out using *black-box testing* to ensure that the application functions properly as expected. Table 2 shows some of the tests carried out.

Table 2 Black-box Testing

No	Description	Expected Results	Results
1	The *pH* sensor reads the value of the hydroponic solution	The *pH* value is displayed on the dashboard according to the actual value.	Success
2	*TDS* sensor reads dissolved substance levels	*TDS* values are displayed on the dashboard according to actual values.	Success
3	*ESP32* sends sensor data to *MQTT* broker	Data successfully sent to *MQTT* topic and received by *Node-RED*	Success
4	*Node-RED* receives and displays sensor data	Data appears on the dashboard in real-time	Success
5	Users access the dashboard from a browser	The dashboard opens and displays the *pH* and *TDS* graphs.	Success
6	The system continues to run while the sensor is given repeated input.	No crashes, values stay updated in real-time	Success

The black-box testing results showed that the system operated as expected in all scenarios. Both the *pH* and *TDS* sensors were able to accurately detect and transmit the actual hydroponic solution values, which were then displayed correctly on the *Node-RED* dashboard. The *ESP32* microcontroller consistently sent data from the sensors to the *MQTT* broker, and the *Node-RED* interface received and visualized this data in real-time. Furthermore, the dashboard remained accessible through the browser interface, and the displayed graphs were continuously updated in response to new data input. The system remained active and responsive without any delays or crashes even when multiple sensors interacted. These results demonstrate that the system can reliably and

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continuously monitor hydroponic water quality. These results make the system feasible for use in real-world situations.

IV. Conclusion

This research has created and implemented a hydroponic water quality monitoring system based on the Internet of Things (*IoT*) that uses *pH* and *TDS* sensors connected to the *ESP32* microcontroller. By using the *MQTT* communication protocol, this system can read water quality data periodically and send it in real-time to the *Node-RED* platform. This data is then presented in a web dashboard that can be accessed through the *Node-RED* platform.

Acidity levels (*pH*) and dissolved solids levels (*TDS*) are two main hydroponic parameters that can be monitored stably by the system. The implementation stage includes hardware and software integration. The results of the *black-box* method test show that all system features, including sensor readings, data transmission, and information visualization, have run according to expectations and planned specifications.

This system is included in the *IoT* Level 2 category, which means that they can perform real-time monitoring but do not have automatic control functions. However, this system is built modularly and allows for further development, including storing historical data into a database and automatic actuator control.

It is hoped that this system will be a simple yet successful solution to help hydroponic farmers maintain nutrient stability and increase crop yields by monitoring water quality more efficiently, practically, and accurately.

References

[1] D. Descartes, H. Harianto, and F. Falatehan, "Penyuluhan Pertanian dan Pengaruhnya terhadap Pendapatan Usahatani di Gapoktan Rorotan Jaya, Rorotan, Cilincing, Provinsi Dki Jakarta," *Jurnal Ekonomi Pertanian dan Agribisnis*, vol. 5, no. 2, pp. 390–403, Apr. 2021, doi: 10.21776/ub.jepa.2021.005.02.10.

[2] T. S. Yulia, "Strategi Pemanfaatan Media Air (Hidroponik) Pada Budidaya Tanaman Kangkung, Pakcoy, Dan Sawi Sebagai Alternatif Urban Farming," *Journal on Education*, vol. 06, no. 01, pp. 5835–5848, Dec. 2023.

[3] L. Pamungkas, P. Rahardjo, and I. G. A. P. Raka Agung, "RANCANG BANGUN SISTEM MONITORING PADA HIDROPONIK NFT (NURTIENT FILM TEHCNIQUE) BERBASIS IOT," *Jurnal SPEKTRUM*, vol. 8, no. 2, p. 9, 2021, doi: 10.24843/spektrum.2021.v08.i02.p2.

[4] F. Nurrizky, H. Budiyono, and Ismarani, "ANALISIS PENGEMBANGAN USAHA HIDROPONIK PADA DHIEFFI FARM HIDROPONIK KOTA BEKASI," *CEFARS : JURNAL AGRIBISNIS DAN PENGEMBANGAN WILAYAH*, vol. 8, no. 1, pp. 74–85, Apr. 2025, doi: 10.33558/cefars.v8i1.10895.

[5] M. P. Manek, M. S. Pareira, and M. A. Tuas, "Optimalisasi Pemberian Pupuk Organik Cair untuk Pertumbuhan Tanaman Kangkung (Ipomea sp.) dengan Sistem Hidroponik," *Hidroponik : Jurnal Ilmu Pertanian Dan Teknologi Dalam Ilmu Tanaman*, vol. 2, no. 1, pp. 213–227, Feb. 2025, doi: 10.62951/hidroponik.v2i1.269.

[6] A. Hermanto, T. Ahmad, H. Al Mubarok, and A. Kridoyono, "PEMBUATAN SISTEM PEMANTAUAN PH DAN PPM AIR PADA HIDROPONIK BERBASIS *IoT*," *Jurnal Sistem Informasi dan Informatika (Simika) P-ISSN*, vol. 8, no. 1, pp. 2622–6901, 2025.

[7] N. Heriyani and S. Ernawati, "PEMANFAATAN TEKNOLOGI IOT BERBASIS MOBILE DALAM UPAYA MONITORING KUALITAS AIR PADA TANAMAN HIDROPONIK," Jun. 2024.

[8] S. Tansa, N. Latekeng, R. Yunginger, and I. Z. Nasibu, "Monitoring Kualitas Air Sungai (Kekeruhan, Suhu, *TDS*,*pH*) Menggunakan Mikrokontroler Atmega328," *Jambura Journal of Electrical and Electronics Engineering*, vol. 6, no. 1, pp. 70–75, 2024, doi: 10.37905/jjeee.v6i1.23315.

[9] N. L. Luqyana, F. Arinie, and A. Muzzakhim, "Telemonitoring Padatan Terlarut pada Filtrasi Air Limbah Laundry Menggunakan Sensor *TDS* dan Sensor *pH* untuk Media Budidaya Tanaman Hidroponik Berbasis Mikrokontroler," *Jurnal Jartel: Jurnal Jaringan Telekomunikasi*, vol. 11, no. 2, pp. 67–73, 2021, doi: 10.33795/jartel.v11i2.55.

[10] I. Z. J. M. Fahd, M. F. Hasan, A. F. Andoko, and A. Sumarahinsih, "Rancang Bangun Alat Ukur Kualitas Air pada Penampungan Air Hujan dengan Sensor *TDS* Berbasis Mikrokontroller ESP8266," *JASIEK (Jurnal Aplikasi Sains, Informasi, Elektronika dan Komputer)*, vol. 5, no. 1, pp. 1–8, 2023, doi: 10.26905/jasiek.v5i1.10015.

[11] U. Umar, "RANCANG BANGUN SISTEM KONTROL DAN MONITORING PH, SUHU AIR DAN *TDS* PADA SISTEM AKUAPONIK BERBASIS INTERNET OF THINGS (IOT)," *JTT (Jurnal Teknologi Terapan)*, vol. 10, no. 1, p. 19, Mar. 2024, doi: 10.31884/jtt.v10i1.557.

[12] D. Wijayanto, E. P. Silmina, and A. A. Aditiya, "PROTOTYPE IOT UNTUK PEMANTAUAN NUTRISI DAN PH PADA HIDROPONIK MENGGUNAKAN *ESP32* DI KEBUN HIDROPINIK VEFAR YOGYAKARTA," *HOAQ (High Education of Organization Archive Quality): Jurnal Teknologi Informasi*, vol. 15, no. 2, pp. 100–106, 2024.

[13] F. Hakim, I. W. Supardi, and N. N. Ratini, "Perancangan dan Pembuatan Sistem Kontrol Penyiraman Tanaman Hidroponik Otomatis Menggunakan Sensor *TDS* Berbasis Mikrokontroler ATMEGA328," *BULETIN FISIKA*, vol. 25, no. 1, p. 1, 2024, doi: 10.24843/bf.2024.v25.i01.p01.

[14] A. N. Sholihah, T. Tohir, and A. R. Al Tahtawi, "Kendali *TDS* nutrisi hidroponik deep flow technique berbasis *IoT* menggunakan fuzzy logic," *JITEL (Jurnal Ilmiah Telekomunikasi, Elektronika,*

dan Listrik Tenaga), vol. 1, no. 2, pp. 89–98, 2021, doi: 10.35313/jitel.v1.i2..89-98.

[15] M. W. Hamdani, A. Stefanie, and Saragih Yuliarman, "Perancangan dan Implementasi Metode Kontrol Fuzzy Logic Mamdani pada Sistem Kontrol *TDS* dan *pH* Hidroponik," *JTT (Jurnal Teknologi Terpadu)*, vol. 10, no. 2, pp. 171–183, 2022, doi: 10.32487/jtt.v10i2.1555.

[16] Rouhillah, R. Faulianur, and F. Fazila, "Alat Monitoring Kualitas Air Minum Menggunakan Sensor *TDS* Berbasis Internet of Things," *J-Innovation*, vol. 12, no. 2, pp. 43–47, Dec. 2024, doi: 10.55600/jipa.v12i2.212.

[17] M. C. A. Prabowo, A. A. Janitra, and N. M. Wibowo, "Sistem Monitoring Hidroponik Berbasis *IoT* dengan Sensor Suhu, *pH*, dan Ketinggian Air Menggunakan ESP8266," *JURNAL TECNOSCIENZA*, vol. 7, no. 2, pp. 312–323, 2023, doi: 10.51158/tecnoscienza.v7i2.894.

[18] G. N. De Side, G. M. D. Putra, and D. A. Setiawati, "*IoT* (internet of things) microclimate monitoring system using node-red platform at plant factory," *IOP Conf Ser Earth Environ Sci*, vol. 1441, no. 1, p. 012012, Jan. 2025, doi: 10.1088/1755-1315/1441/1/012012.

[19] A. Rifa'i, "SISTEM PEMANTAUAN DAN KONTROL OTOMATIS KUALITAS AIR BERBASIS INTERNET OF THINGS (IOT) MENGGUNAKAN PLATFORM NODE-RED UNTUK BUDIDAYA UDANG," *JTT (Jurnal Teknologi Terapan)*, vol. 7, no. 1, p. 19, 2021, doi: 10.31884/jtt.v7i1.317.

[20] A. Bahga and Madisetti Vijay, *Internet of Things: A Hands-On Approach*. 2014. Accessed: May 15, 2025. [Online]. Available: https://books.google.co.id/books?id=JPKGBAAAQBAJ&printsec=frontcover#v=onepage&q&f=false