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IOT-BASED HYDROPONIC WATER QUALITY CONTROL INTEGRATED WITH WEBSITE AND EARLY WARNING

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Abstract: The development of information and communication technology has driven digital transformation in various sectors, including agriculture. One of the technologies widely applied is the Internet of Things (IoT), which enables devices to be interconnected through the internet to perform monitoring and data exchange in real time. In hydroponic cultivation, water quality stability is a crucial factor that affects plant growth. The main parameters that need to be monitored include water acidity level (pH), water temperature, and dissolved nutrient concentration measured using Total Dissolved Solids (TDS). However, water quality monitoring is still commonly conducted manually, making it less efficient and potentially causing delays in detecting changes in water conditions. This study aims to design an IoT-based water quality monitoring system for hydroponic cultivation using an ESP32 microcontroller integrated with pH, temperature, and TDS sensors. The collected data are sent to a server and displayed on a web dashboard in real time, equipped with automatic notification features. The proposed system is expected to improve monitoring efficiency and increase the productivity of hydroponic cultivation

Keywords: esp32; hydroponics; internet of things; real-time monitoring; water quality.

Abstrak: Perkembangan teknologi informasi dan komunikasi mendorong transformasi digital dalam berbagai sektor, termasuk pertanian. Salah satu teknologi yang banyak diterapkan adalah Internet of Things (IoT) yang memungkinkan perangkat saling terhubung melalui jaringan internet untuk melakukan pemantauan dan pertukaran data secara real-time. Pada budidaya hidroponik, kestabilan kualitas air menjadi faktor penting yang mempengaruhi pertumbuhan tanaman. Parameter utama yang perlu diperhatikan meliputi tingkat keasaman air (pH), suhu air, serta konsentrasi nutrisi terlarut yang diukur menggunakan Total Dissolved Solids (TDS). Namun, pemantauan kualitas air masih banyak dilakukan secara manual sehingga kurang efisien dan berpotensi menimbulkan keterlambatan dalam mendeteksi perubahan kondisi air. Penelitian ini bertujuan merancang sistem pemantauan kualitas air hidroponik berbasis IoT menggunakan mikrokontroler ESP32 yang terintegrasi dengan sensor pH, suhu, dan TDS. Data dikirim ke server dan ditampilkan pada web dashboard secara real-time serta dilengkapi notifikasi otomatis. Sistem ini diharapkan meningkatkan efisiensi pemantauan dan produktivitas budidaya hidroponik.

Kata kunci: esp32; hidroponik; internet of things; kualitas air; monitoring real-time

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INTRODUCTION

The development of information and communication technology in the digital era is driving transformation in the agricultural sector. One emerging innovation is the Internet of Things (IoT). This technology enables devices connected via the internet to monitor and collect data in real time, thereby increasing efficiency, productivity, and the quality of agricultural produce compared to conventional manual methods. [1].

Hydroponic cultivation is a method of growing plants without soil, utilizing water containing a nutrient solution as a nutrient source. This method is more efficient in water use, requires less land, and produces higher-quality and more hygienic plants, making it widely used in modern agriculture and urban areas. [2] , [3].

The success of hydroponic cultivation is greatly influenced by the stability of water quality, which serves as a nutrient delivery medium for plants. Several important parameters to consider include water acidity (pH), water temperature, and dissolved nutrient concentration, measured by Total Dissolved Solids (TDS) or Electrical Conductivity (EC). The ideal pH for most hydroponic plants ranges from 5.5 to 6.5 to ensure optimal nutrient uptake by the roots. Furthermore, a stable nutrient balance and water temperature play a crucial role in supporting plant metabolism and healthy root growth. [4] , [5].

Water quality monitoring in hydroponic systems is still often done manually using conventional equipment. This method is time-consuming and labor-intensive and cannot continuously monitor water conditions. As a result, changes in water parameters are often detected too late, potentially disrupting the growth and productivity of hydroponic plants. [6],[7].

Several studies have developed Internet of Things-based water quality monitoring systems utilizing pH, temperature, and TDS sensors connected to microcontrollers such as the ESP8266 or ESP32. Data is sent to an IoT platform so it can be monitored via a computer or smartphone. However, many systems still rely on third-party platforms like Blynk or Thingspeak, which have limited features, dependency on external services, and potential subscription fees. [8] , [9].

The research was conducted at Sigit Hydroponics, Kisaran, Asahan Regency. However, during the ongoing cultivation process, Sigit Hydroponics still faces several problems, including manual water quality monitoring, delays in detecting changes in important parameters such as pH, temperature, and TDS, and the lack of a monitoring system that can provide real-time information. This results in suboptimal nutrient management and potentially reduces plant growth and quality. Therefore, an IoT-based water quality monitoring system is expected to be a solution to improve the efficiency of hydroponic management as well as the productivity and quality of crop yields.

METHOD

Types of research

This research uses an engineering research method with an Internet of Things (IoT) system design and development approach for monitoring water quality in hydroponic plant cultivation.

Research Location

This research was conducted at Sigit Hydroponics, located at Jl. Kamboja No. 34, Kisaran City, East Kisaran City, Asahan Regency, North Sumatra.

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Research Stages

The block diagram in the image above illustrates the workflow of an Internet of Things (IoT)-based water quality monitoring system in hydroponic cultivation, starting from the process of data collection by sensors, data processing by the ESP32 microcontroller, to sending and presenting data via a server and web dashboard that can be accessed by users in real-time.

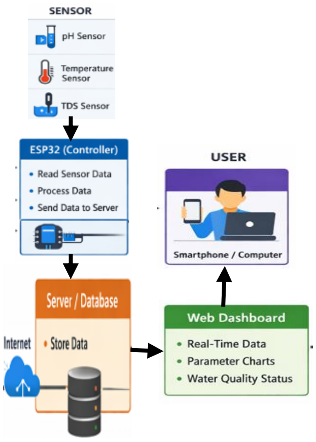

Image 1. System Block Diagram

System Requirements Analysis

System requirements are identified, including the hardware and software requirements used in the monitoring system. The water quality parameters monitored in this study include water pH, water temperature, and Total Dissolved Solids (TDS) as an indicator of nutrient concentration.

System Design

The system design stage is carried out by designing an IoT system architecture consisting of three main components, namely:

Sensor devices used to measure water quality parameters in hydroponic systems, namely pH sensors, water temperature sensors, TDS sensors. The system control device uses an ESP32 microcontroller as a data processing center whose task is to read data from sensors, process measurement data, and send data to the server. Monitoring system Data sent by ESP32 will be stored on the server database and displayed via a web dashboard that can be accessed by users via computer or smartphone devices.

Web Dashboard Design

Web dashboard developed independently to display sensor data in the form of, Real-time display of sensor values, Graph of changes in water parameters, Water condition status based on predetermined thresholds

System Implementation

The integration process between the designed hardware and software is carried out. A pH sensor, a temperature sensor, and a TDS sensor are installed in the hydroponic nutrient tank to continuously measure water quality. The resulting data is then sent by the ESP32 microcontroller to the server.

System Testing

System testing was conducted to determine the performance and accuracy of the developed monitoring system. This included: Sensor testing, which compared sensor readings with standard measuring instruments to determine the level of sensor accuracy; Data transmission testing, which tested the ESP32's ability to send sensor data to the server in real time; and Web dashboard testing, which tested the display of sensor data on the web dashboard.

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RESULTS AND DISCUSSION

pH Sensor (pH-4502C)

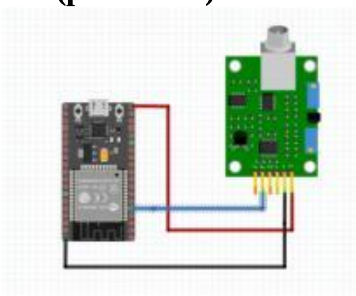

Image 2. Ph Sensor Circuit

The pH sensor (pH-4502C) has three main pins, namely VCC, GND, and AO (Analog Output), where in the implementation of the PH sensor VCC pin system design is connected to the ESP32 5V pin, the PH sensor GND pin to the ESP32 GND pin, while the AO pin is connected to the ESP32 GPIO34 pin. The main function of this AO pin is to read the analog pH value..

A pH sensor is used to measure the acidity of nutrient solutions in hydroponic systems. Before use, the sensor is calibrated using standard buffer solutions of pH 7 and pH 4 to improve reading accuracy.

Test results show that the calibration process significantly improves sensor accuracy. Prior to calibration, the sensor readings differed significantly from the reference values. However, after calibration, the sensor readings became closer to the standard values.

In a pH 7 buffer solution, the sensor reading before calibration was 6.20, while after calibration it increased to 7.02, very close to the reference value. In a pH 4 buffer solution, the sensor reading before calibration was 5.10 and after calibration it was 4.05. These results indicate that the calibration process can improve the stability and accuracy of the sensor in making measurements.

Hydroponic nutrient solution and PDAM water. The measurement results showed that the pH readings were within the range appropriate for the conditions of the tested solution. This demonstrates that the pH sensor can be used for real-time monitoring of hydroponic water quality.

TDS Sensor

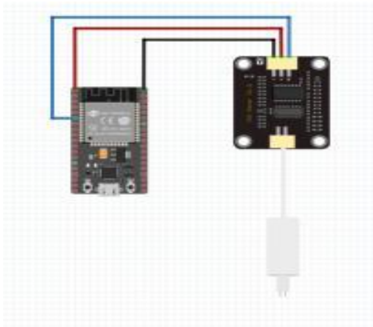

Image 3. TDS Sensor Circuit

The TDS sensor is used to measure the amount of dissolved solids (Total Dissolved Solids) in a hydroponic nutrient solution. The TDS module generally consists of a probe and a signal processing board with three main pins: VCC, GND, and AOUT (Analog Output), where VCC is connected to 5V on the ESP32, GND is connected to the ESP32 GND, AOUT (Analog Output) is connected to GPIO35 on the ESP32dihubungkan ke GND ESP32,

The TDS sensor is used to measure the concentration of dissolved substances in hydroponic nutrient solutions, expressed in parts per million (ppm). This parameter is crucial because it directly affects the amount of nutrients available to plants.

Sensor testing was conducted using a standard solution with a value of 1382 ppm as a calibration reference. After calibration, the sensor was able to detect changes in solution concentration quite

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well. The values displayed by the sensor were close to the reference values used in the testing process.

These results indicate that the TDS sensor used in this study is capable of providing fairly accurate readings and can be used to monitor nutrient concentrations in hydroponic systems in real time. This monitoring allows the system to automatically activate the nutrient pump when nutrient concentrations exceed predetermined limits.

Rain Sensor

Image 4. Rain Sensor Circuit

The rain sensor has three main pins: VCC, GND, and DO (Digital Output), where VCC is connected to the 3.3V or 5V pin on the ESP32, GND is connected to the GND pin of the ESP32, 3. DO is connected to GPIO14 on the ESP32 to read the rain status (HIGH = not raining, LOW = raining).

A rain sensor is used to detect the presence of water droplets on the sensor surface. In practice, this sensor functions as a support for automation systems, particularly to anticipate environmental conditions during rain. The rain sensor is connected to a microcontroller, and the results are displayed as "Raining" or "Not Raining" on a web dashboard. Testing is carried out under dry, humid, and wet conditions to determine the sensor's response.

The rain sensor successfully outputs the rain status. When the sensor detects water, the system displays the message "Rain detected! Pump turned off." This means the pump automatically stops working to prevent waste and system damage during rain. Conversely, when the sensor is dry, the system displays the message "No rain. Pump on," indicating that the pump is active again to flow water.

Telegram Real-Time Notifications

The implementation of real-time notifications using the Telegram Bot application was successfully carried out. The system is able to automatically send notification messages whenever there are changes in sensor readings or pump status. These messages are received quickly, with an average delay of approximately 1–2 seconds, allowing users to obtain timely information. This feature makes monitoring more efficient because users do not need to continuously access the web dashboard. Through these notifications, users can immediately be informed about rainfall conditions, circulation and nutrient pump status, as well as any changes in the system's operating mode in real time.

Web Dashboard

The results of the Hydroponic Web Dashboard implementation indicate that the system is capable of displaying sensor data and actuator status in real time through an interactive and user-friendly interface. The main dashboard page presents monitoring cards that are clearly organized into several sections, including rain sensor status, TDS values, and pH values. In addition, the system also displays the operational status of the circulation pump and nutrient pump. This structured and visual presentation helps users

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easily understand system conditions, monitor changes effectively, and make quick decisions based on accurate and up-to-date information provided by the dashboard.

Image 5. Dashboard view

The rain sensor displays a "No Rain" status, followed by a statement that the circulation pump is active. The TDS value is read at 1520 ppm with the status "TDS normal - Nutrient pump off," indicating that the system has successfully adjusted the logic according to the nutrient threshold. Furthermore, the pH sensor displays a value of 5.67, which is categorized as a normal condition, so no nutrient pump is active. Meanwhile, the status of the circulation pump, nutrient pump A, and nutrient pump B is also clearly displayed, each accompanied by a function description such as "for alkaline pH > 7.5" or "for acidic pH < 5.5."

In addition to information in the form of cards, the dashboard also provides a graph of sensor data to monitor historical trends in nutrient conditions. At the bottom of the dashboard, a graph of TDS values and water temperature recorded over time is displayed. This makes it easier for users to analyze the development of water quality in the hydroponic system, so that decisions regarding nutrient additions and pH adjustments can be made more precisely. Overall, the implementation results show that the web dashboard can run well and according to design. Sensor data can be displayed in real-time, pump status can be monitored directly, and other supporting information such as pH and rainfall conditions can be displayed with clear visual indicators. With this dashboard, users no longer need to monitor the system manually in the field, but can simply use the web display that has been integrated with the microcontroller.

CONCLUSION

The hardware design of this system was successfully realized by utilizing the ESP32 microcontroller as the main control center. The selection of ESP32 is based on its ability to support WiFi communication, thus facilitating the integration process with the server for Internet of Things (IoT)-based monitoring purposes. This system is equipped with several sensors, namely a pH sensor that functions to measure the acidity level of water, a TDS sensor that is used to determine the content of dissolved substances in the nutrient solution expressed in ppm units, and a rain sensor that functions to detect the condition of the surrounding environment.

In addition, the system is also equipped with actuators in the form of three pumps, each of which has a different function, namely Pump A to add nutrients, Pump B to reduce nutrient levels, and a circulation pump which functions to maintain water movement in the hydroponic system so that nutrients can be distributed evenly..

The software implementation on the ESP32 microcontroller has also been successful, implementing integrated system control logic. The developed program allows the ESP32 to read data from all installed sensors, perform data processing, and automatically control actuators according to predetermined conditions.

The system operates based on the nutrient concentration values detected by the TDS sensor and the time schedule obtained from the DS3231 Real Time Clock (RTC) module. Pump A will be activated when the TDS value is below 700 ppm as an indication that the nutrient concentration is too low, while Pump B will be activated when the TDS value exceeds 1200 ppm to reduce excessively high nutrient levels. Meanwhile, the circulation pump operates between 6:00 AM and 6:00 PM provided that the environmental conditions are not rainy. This control mechanism is designed to maintain stable water quality in the hydroponic system so that the plant's nutritional needs can be optimally met.

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