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IoT implementation for Adjustment Automatic pH and TDS/EC Parameters on the System Hydroponics Lettuce

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Abstract

Cultivation hydroponics becomes a solution for efficient modern agriculture, especially in the use of land and water. However, maintaining stability of pH and TDS/EC parameters remains become main challenge. Research: This developed system is based on the Internet of Things (IoT) using an ESP32 microcontroller for monitoring and adjusting automatic pH and TDS in cultivating lettuce. Integrated pH and TDS sensors with an actuator automatically in the form of a pump, micro and DC motors, which are controlled in real-time via the Flutter app and Firebase cloud storage. Test results show that the system succeeds in maintaining the pH in the range 6.0–7.0 for 96.44% of the time operations and TDS in the range 560–840 ppm for 96.79% of the time testing. The Paired Samples t-Test produced a p-value of 0.289 for pH and 0.595 for TDS. This value is more than 0.05, so there is no significant relationship in statistical relationship between the condition before and after automation. That is, the system automatically has no significant influence on parameter values, but is capable of guarding its stability consistently. Thus, the system is effective in managing hydroponic water quality in an automatic way.

Keywords: *Hydroponics, IoT, pH, TDS/EC, ESP32, Automation*

1. INTRODUCTION

Hydroponics is a method of cultivating plants without using land as a planting medium, but uses a solution that contains important nutrients [1]. This technique is very useful in the urban area of underprivileged land agriculture [2]. The stability of pH and TDS/EC parameters is very important in cultivation because it influences the absorption of nutrients by plants [3]. Plants will experience obstacle growth if the parameters are not guarded in the optimal range [4].

The main problem with conventional is that pH and TDS/EC settings are still done manually[5]. Approach This own shortcomings, such as delay adjustments and dependency on the operator. Therefore, is needed system automatic capable monitor and adjusting parameters in real-time [6].

Internet of Things (IoT) offers an innovative solution in automating the management system of hydroponics [7]. By combining sensors, ESP32 microcontrollers, actuators, and the Firebase cloud platform, the system can monitor and regulate pH and TDS automatically and distance [8]. Research This aims to develop and test an automated IoT system capable of maintaining water quality parameters in cultivation plant lettuce optimally [9].

2. RESEARCH METHODS

2.1. Objects study

Study This was performed on the system cultivation plant lettuce (Lactuca sativa) uses the Deep Flow Technique (DFT) method [10]. DFT is one of the techniques of hydroponics passive which uses water as a medium for nutrient solution nutrition, where the plant roots are submerged continuously in a continuous flow of nutrition with a certain depth. This method was chosen because own excess in guard circulation, consistent and stable nutrition, as well as the testing system automation of water parameters [11].

Plant lettuce was chosen because cycle its short growth cycle (around 30–40 days), and its sensitivity to high pH and TDS fluctuations, making it an ideal object in testing system arrangement Internet of Things-based water quality [12]. Ideal parameters for optimal growth of lettuce in system DFT hydroponics are a pH between 6.0 to 7.0 and TDS between 560 to 840 ppm [13]. The values This used as limitation logic system automatic in do adjustment to solution nutrition, using a pump and solution adjustment (pH up/down).

Besides plants and methods of cultivation, object study this also includes an environment closed (indoor) to minimize temperature and humidity from the environment outside. System tested in A rack hydroponics with long 1 meter and a capacity of 6 netpots, using solution AB Mix nutrients as a growing medium [14].

2.2. Research Flow

Stages study consists of from several step main, namely : (1) identification need system and parameters to be controlled, (2) design system device hardware and devices software, (3) development and integration component system, (4) sensor calibration and testing system in a way overall, and (5) collection and analysis of outcome data testing [15].

Figure 1. Research Flow IoT System

Figure 1 shows a channel study of the developed IoT system, which consists of stages: identification of needs, design, integration system, to analysis of results testing. Every stage is intended to ensure the system is capable of maintaining pH and TDS parameters within the optimal range in terms of automation.

2.3. System Design

The system consists of ESP32, pH sensor (PH4502C), TDS sensor, pump micro, DC motor, relay module, and Flutter application. Components equipped with a step-down power supply (LM2596) and connected with Firebase for storing and displaying data in real-time [16]. The workflow system is depicted in Figure 2.

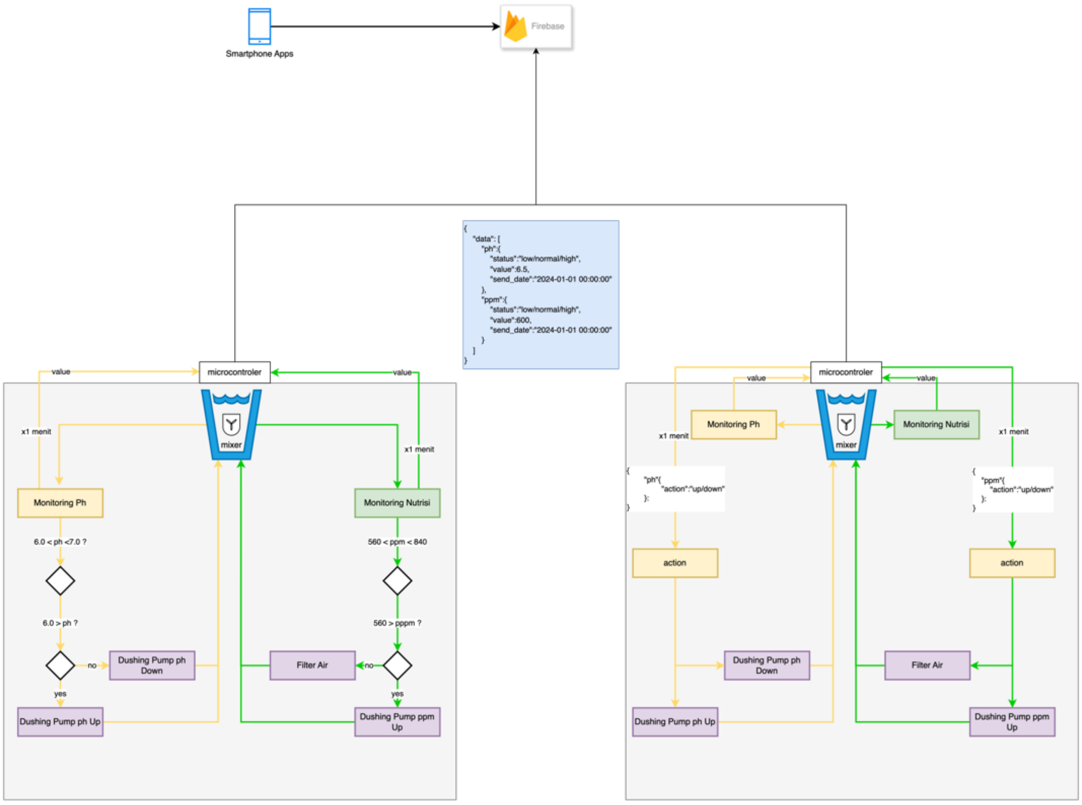

Figure 2. Workflow IoT System

Figure 2 shows the channel Work IoT system for monitoring and adjusting automatic pH and TDS parameters.

2.4. Tools and materials

Components used in the system include from ESP32 microcontroller as the center control, a pH sensor (PH4502C), a TDS sensor, a pump micro, a DC motor, and a relay module for actuation. The system is also equipped with a step-down power supply module (LM2596) for adapting voltage, and an application Flutter-based connected with Firebase for storing and displaying data. [17].

The election component considers market availability, compatibility with ESP32, and efficient power consumption. [18]. pH and TDS sensors are selected because they have sufficient accuracy for monitoring the hydroponic water environment.

Table 1. Tool Specifications

No	Tool Name	Type	Utility	Specification
1	ESP32	Microcontroller	As the central control for reading sensor data and controlling the actuator	Wi-Fi, Bluetooth, Dual Core

No	Tool Name	Type	Utility	Specification
2	pH Sensor	Sensor	Measure the pH value of the solution in the system	PH4502C, range 0–14, accuracy ±0.1
3	TDS Sensor	Sensor	Measure the amount of substance dissolved in the solution of nutrition	Range 0–1000 ppm, accuracy ±10 ppm
4	Micro Pump	Actuator	Add pH Up/Down liquid or solution nutrition	Power 3–12V, flow rate 1-3 L/m
5	DC Motor	Actuator	Mix the solution to ensure distribution evenly	12V Power
6	Relay	Control Components	Control the pump micro and DC motors safely	or 4 Channel Module, 5V Voltage
7	Breadboard and Cables	Equipment Electronic	Connect components electronic	General
8	Smartphone	Mobile Devices	Display monitoring data via the application	Display monitoring data via the application
9	12V Adapter	Resource	Provide Power For the pump, micro, and DC motors	12V Output
10	Step Down LM2596	Power Module	Lower the Input voltage from the adapter to the appropriate level for ESP32.	Input: 4V-35V, Output: 1.23V-30V, Current maximum: 3A
11	TXS0108E	Level Shifter (Bidirectional Logic Level Converter)	Stable communication between the ESP32 and the sensor or actuator that uses a voltage higher tall	VCCA: 1.65V – 3.6V VCCB: 2.3V – 5.5V
12	Water Filter (Cation, Anion, Carbon, Cotton)	Filtration	Reduces PPM of solution, filters excess ions	Material: Cation-anion & carbon resin active

Details technical information from the component system is presented in Table 1, which includes sensors, microcontrollers, actuators, and other devices. Other supporters of the IoT automation system include hydroponics.

2.5. Data *Collection and Analysis Techniques*

After the calibration process finished, the system read data from the pH and TDS sensors automatically every 30 minutes. Data read is sent to Firebase via Wi-Fi connection on ESP32 and visualized in a Flutter application. The system also provides notifications such as “NORMAL”, “STABLE”, or “FAIL” [19].

Data collected over three tens of days and exported to CSV format for analysis using Python. Analysis statistics using the Paired Samples t-Test was carried out to evaluate the stability of system automation [20].

Statistical analysis was done with the Independent Samples t-Test to evaluate the effectiveness of system automation in guard stability of pH and TDS parameters. This test was done using the scipy.stats library in Python.

3. RESULTS AND DISCUSSION

3.1. Flutter Application

Flutter apps play a role as the main interface user For monitor the condition system in real-time. The application displays sensor reading data in the form line graph and system status. In addition to the features that monitor automatically, users are also given the option to enable manual control mode as an action corrective addition if needed.

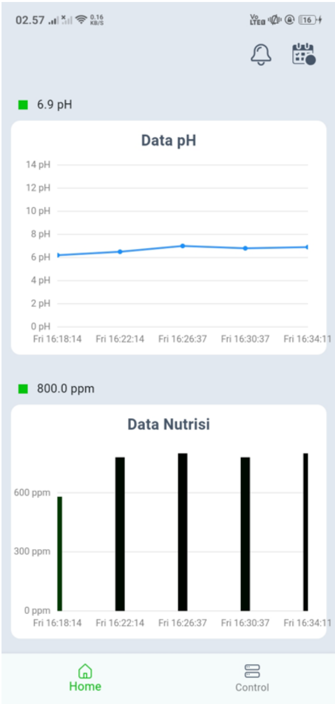

Figure 3. Application Dashboard View

Figure 3 displays the application dashboard. Show two charts, the main things that can be obtained from pH sensor data and TDS sensor data.

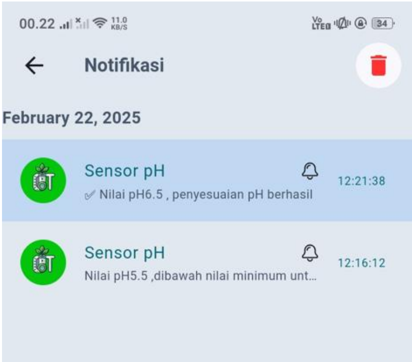

Figure 4. Display Notifications

Figure 4 shows that the application successfully accepts notifications sent by the IoT system to give the latest information related to sensor data. At 12:16 AM, the system detects a decline in pH value up to 5.5, which is below the minimum limit that has been determined. As a response, a system, in a way, automatically does pH adjustment by adding an appropriate solution. Then, at 12:21 AM, the system succeeded do adjusting so that the pH value was back to 6.5, which is in an optimal range. Information success. This is sent return to the user through notifications on mobile applications, ensuring that the user still gets Updates in real-time regarding the condition system they

3.2. Sensor Calibration

Calibration of the pH sensor is performed using standard buffer solutions, pH 4.01 and 6.86. The TDS sensor is calibrated with a solution standard of 1382 ppm. The calibration process is done to ensure accurate sensor readings under the conditions. Actually.

3.3. Monitoring and Adjustment Automatic

During testing, the system is capable of maintaining pH and TDS in an optimal range. If the pH value exceeds the optimal limit, the system will activate the actuator (pump) micro) for add solution sour phosphate (H_3PO_4) to lower the pH or potassium hydroxide (KOH) to raise the pH. If TDS more lower than the minimum limit (560 ppm), the system will add solution nutrition through the pump micro. If more high than the maximum limit (840 ppm), the system will filter water to balance the concentration.

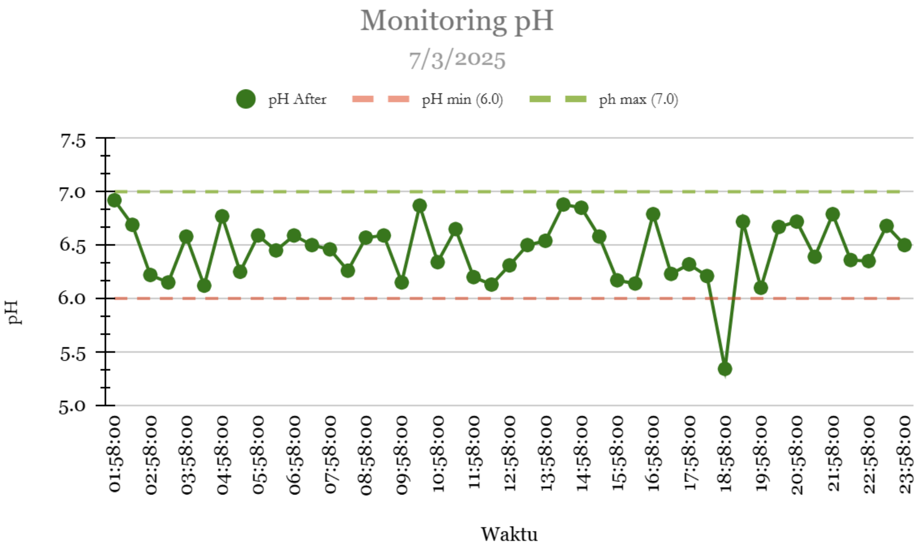

Figure 5. pH Monitoring Graph for 1 Day (March 7, 2025)

Based on Figure 5, the system is capable of guarding pH value in the optimal range (6.0–7.0) almost throughout time. Dots monitoring shows consistent stability, with A little fluctuations that still exist are within a reasonable limit. The red and green horizontal lines on the graph show the minimum and maximum pH limits for lettuce.

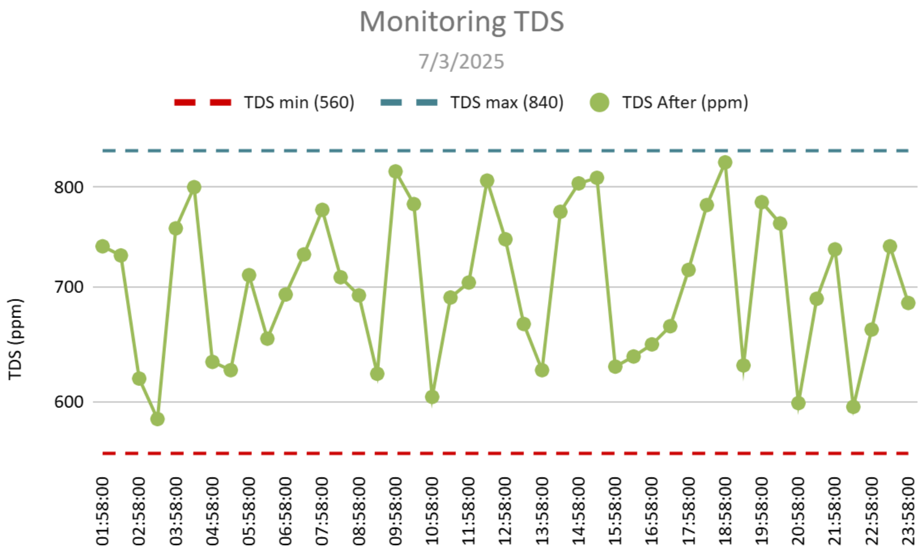

Figure 6. Daily TDS Graph

Figure 6 shows the TDS value over the same period. Graph This shows that the TDS value remains constant is at in the optimal range (560–840 ppm) during almost all time observation. System automation works in a way responsive to adapt nutrition solutions, which is indicated by fluctuations fixed TDS value within ideal limits.

Visualization of data distribution in a boxplot shape is displayed to clarify the distribution mark as well as the stability of parameters during the testing period.

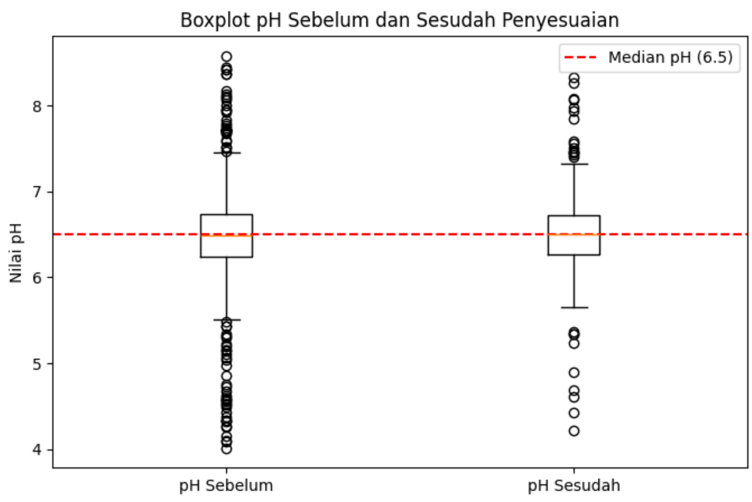

Figure 7. pH boxplot

Figure 7. Boxplot of pH values before and after adjustment, with red line as the median (6.5).

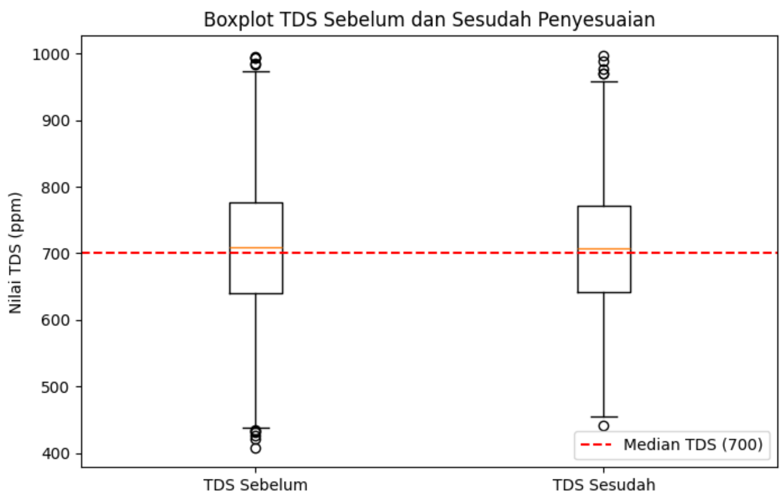

Figure 8. TDS boxplot

Figure 8. Boxplot of TDS values before and after adjustment, with red line as the median (700 ppm).

The monitoring results show that the system succeeds in guarding pH value in the range 6.0–7.0 for 96.44% of the time operations and TDS values in the range 560–840 ppm for 96.79% of the time testing. Fluctuation of the value that occurs is still within the limit tolerance system and can respond to in a way automatically by adjusting the adjuster that has been programmed.

3.4. Analysis Statistics

Analysis was done using the Independent Samples t-Test on the data measurement results before and after the implementation of system automation. Testing objectives: This is to know whether there is a significant difference in stability pH and TDS values after the automation system is applied.

A Paired Samples t-test was conducted against the before and after data automation. Table 2 shows statistical test results.

Table 2. t-Test Results

Parameter	**T-Statistic**	**P-Value**	**Significant (α): 0.05**
pH	-1.059	0.289	Not significant
TDS	-0.532	0.595	Not Significant

pH: p-value = 0.289
TDS:p-value = 0.595

Table 2 shows results t-test testing using Python produced a p-value of 0.289 for pH and 0.595 for TDS. A higher p-value greater than 0.05 indicates that there is no significant difference between the before and after data automation. Thus, the system successfully maintained guard stability of pH and TDS parameters consistent during the testing period.

4. CONCLUSION

Based on results research and analysis that have been done, it can be concluded that :

1. An ESP32-based IoT system has been successfully developed to monitor and adjust pH and TDS parameters regularly, automatically in the system's hydroponics with the Deep Flow Technique (DFT) method.
2. During testing for three days, the system was capable guard stability pH value in the range 6.0–7.0 for 96.44% of the total testing time, and maintaining TDS value in the range 560–840 ppm for 96.79%.
3. Integrated Flutter app with Firebase working effectively, for displaying sensor data in real-time, as well as giving system status notifications in a direct way.
4. Statistical test results using the Independent Samples t-Test show that there is no significant difference between the conditions before and after automation is applied (p-value > 0.05), so the system is rated as effective and working stably.

SUGGESTION

Study. This can be developed more, carry on with some suggestions as follows:

1. Integrate method control based on fuzzy logic or a learning machine to increase the precision adjustment solution.
2. Adding additional sensors like temperature, humidity, air, and intensity light, for supervision environment grow more comprehensive.
3. Develop a system to support giving notifications based on critical conditions via SMS or push notification on the mobile application.
4. Optimizing the use of energy with the implementation source Power renewable, such as solar panels, for sustainability systems in remote areas.

With improvement and development more next, the system This own potential for applying to scale urban farming and home ladder in a wide way.

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