Automatic Control and Monitoring for Hydroponic Lettuce with Blynk and ESP32

Anthony Jason Vito, Sandy Kosasi, David

STMIK Pontianak, Pontianak, Indonesia

Correspondence : *e-mail*: jasonvitonew@gmail.com

Abstrak

Selada (Lactuca sativa L.) merupakan tanaman hortikultura bernilai gizi tinggi dengan permintaan yang terus meningkat seiring kesadaran pola makan sehat. Hidroponik Nutrient Film Technique (NFT) menjadi solusi efisien dalam pemanfaatan lahan dan nutrisi, namun sering terkendala kompleksitas teknis. Untuk menjawab hal ini, penelitian mengembangkan sistem smart farming berbasis ESP32 yang mengatur pH dan nutrisi secara otomatis. Berbeda dari penelitian sebelumnya, sistem ini memadukan logika fuzzy Sugeno dengan kontrol pH dan pupuk yang terhubung ke aplikasi Blynk untuk pemantauan real-time. Logika fuzzy Sugeno digunakan untuk mengontrol pompa pH, sementara distribusi pupuk diatur berdasarkan sensor PPM. Integrasi dengan Blynk memungkinkan notifikasi dan pengendalian jarak jauh sehingga mengurangi intervensi manual. Hasil pengujian menunjukkan sistem mampu memberikan notifikasi akurat saat pH < 5,5 dan PPM < 560, serta menonaktifkan notifikasi ketika kondisi kembali normal. Selain itu, pompa pH Up, pompa A, pompa B, dan pompa Mix berfungsi sesuai skenario yang diberikan, menandakan sistem berjalan responsif dan andal dalam mendukung budidaya selada hidroponik NFT.

Kata kunci: *Selada Hidroponik, NFT, Blynk, ESP32, Fuzzy Sugeno*
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Abstract

Lettuce (Lactuca sativa L.) is a horticultural crop with high nutritional value, and its demand continues to increase along with the growing awareness of healthy eating. The Nutrient Film Technique (NFT) hydroponic system offers efficient use of land and nutrients but is often limited by technical complexity. To address this, this study developed a smart farming system based on ESP32 that automatically regulates pH and nutrient levels. Unlike previous studies, this system integrates Sugeno fuzzy logic with pH and fertilizer control connected to the Blynk application for real-time monitoring. Sugeno fuzzy logic is applied to control the pH pump, while fertilizer distribution is managed based on PPM sensor data. Integration with Blynk enables real-time notifications and remote adjustments, reducing manual intervention. The test results showed that the system successfully provided accurate notifications when pH < 5.5 and PPM < 560, and disabled notifications when conditions returned to normal. In addition, the pH Up pump, A pump, B pump, and Mix pump operated according to the given scenarios, indicating that the system functioned responsively and reliably to support lettuce cultivation in NFT hydroponics.

Keywords: *Hydroponic Lettuce, NFT, Blynk, ESP32, Fuzzy Sugeno*

1. Introduction

Lettuce (*Lactuca sativa* L.) is one of the horticultural commodities that holds significant value in maintaining a healthy diet, with its market demand continuing to increase in line with population growth and rising public awareness of nutrition [1][2]. The high demand for lettuce is also driven by its widespread use in restaurants and hotels as an ingredient in various dishes. Nevertheless, soil-based agricultural practices face several challenges, including inefficient use of chemical fertilizers, land degradation, and dependence on extreme weather conditions [3][4]. Hydroponic farming emerges as an alternative solution to address these challenges. This system eliminates the need for soil by utilizing a balanced nutrient solution to cultivate plants, thereby enabling efficient delivery of water and nutrients [5]. One of the most commonly applied hydroponic techniques is the Nutrient Film Technique (NFT), a system in which a thin and continuous flow of nutrient solution passes over the plant roots, thereby optimizing oxygen and nutrient supply [6].

Hydroponics is a cultivation method that utilizes water as the growing medium. Plants cultivated through hydroponic systems are generally able to grow with greater space efficiency, consistent quality, and higher yields compared to soil-based methods, as nutrient supply can be regulated to support optimal harvest outcomes [7]. Nevertheless, the application of this technique requires a reservoir containing precisely measured nutrient concentrations, which often poses a challenge for individuals interested in hydroponics due to the relatively complex adjustment process [8]. Smart farming represents the integration of technologies such as the Internet of Things (IoT), sensors, and automation systems, enabling farmers to monitor essential agricultural parameters in real time, including pH, humidity, and nutrient availability [9]. This system is designed to allow farmers to respond quickly based on the collected data, thereby supporting the success of precision cultivation.

This research aims to develop a smart farming system based on the ESP32 microcontroller to monitor and control pH levels and nutrient solution fertilization in lettuce cultivation. The system employs Sugeno fuzzy logic to regulate the pH of the solution automatically and to manage fertilizer distribution based on PPM values. Monitoring and control are conducted through the Blynk application, which provides convenient real-time access via mobile devices. Several previous studies have developed monitoring and control systems for nutrient solutions using fuzzy logic. For instance, Kaswar et al. utilized ESP32 to implement a Sugeno fuzzy logic–based control system for hydroponic lettuce cultivation. [10]. Wibowo et al. developed a monitoring system using Arduino Uno and ESP8266 to prevent rainwater from mixing into the NFT system [11]. Meanwhile, Fikar et al. built a monitoring system based on Arduino Mega 2560 and multiple sensors to accurately measure water level, humidity, temperature, and light intensity, applying the Sugeno fuzzy method [12].

This study differs from previous research, such as that conducted by Kaswar et al., which focused on adaptive nutrient control using Sugeno fuzzy logic with ESP32, but did not incorporate Blynk as an interface [10]. It also differs from the work of Wibowo et al., as this research applies fuzzy methods specifically for controlling water pH [11]. Furthermore, the study by Fiq et al. emphasized hydroponic plant monitoring systems with various parameters such as temperature, humidity, and light intensity, yet did not specifically implement Sugeno fuzzy logic for controlling pH and nutrient solutions. [12]. These distinctions are expected to provide new contributions to the development of smart farming systems for hydroponics, particularly in pH and nutrient solution control using Sugeno fuzzy logic integrated with real-time monitoring through ESP32 and Blynk, thereby supporting hydroponic lettuce cultivation with the NFT method.

2. Research Method

This research employs an experimental method to evaluate the prototype system under controlled conditions, thereby assessing its effectiveness, stability, and reliability in supporting the hydroponic cultivation process [13]. The experimental approach is utilized to develop an IoT-based smart farming system integrated with Sugeno fuzzy control. The study is conducted in four main stages: system construction, fuzzy logic design, interface development, and system testing. Data are collected through direct observation of hydroponic systems at farms, interviews with farmers or system operators regarding the application of technology, and experiments to evaluate the effectiveness of pH and nutrient control. A survey is also conducted to obtain user feedback on system performance [14]. Additional data are gathered from various literature sources and scientific journals concerning the use of AB Mix fertilizers and pH regulators, enriching the primary data with theoretical and historical insights.

The system development was carried out by designing an architectural scheme using Fritzing software. The hardware components included an ESP32 as the control unit, a pH meter and TDS meter for monitoring water quality, a 4-channel relay module for pump control, an I2C LCD for local display, and water pumps powered by an external power supply. All components were connected according to voltage and data line requirements, complemented by 0.1 μF ceramic capacitors to suppress interference and maintain signal stability. The development of Sugeno fuzzy logic utilized two input parameters, namely pH (Acidic, Ideal, Alkaline) and PPM (Low, Ideal, High) [8]. The membership functions were defined in linear and triangular forms, while the rule base regulated the operating percentage of the pH Up pump and the AB Mix pump. The inference process employed the minimum method, and defuzzification was conducted using the Weighted Average of All Rule Outputs to generate accurate control decisions. The interface was developed using the Blynk Mobile application and Blynk Desktop Dashboard. The interface features included pump control buttons, value displays for pH, PPM, and sensor voltage, virtual LEDs to indicate pump status, and an automatic notification system when parameters exceeded or fell below threshold values. Below the block diagram for this system.

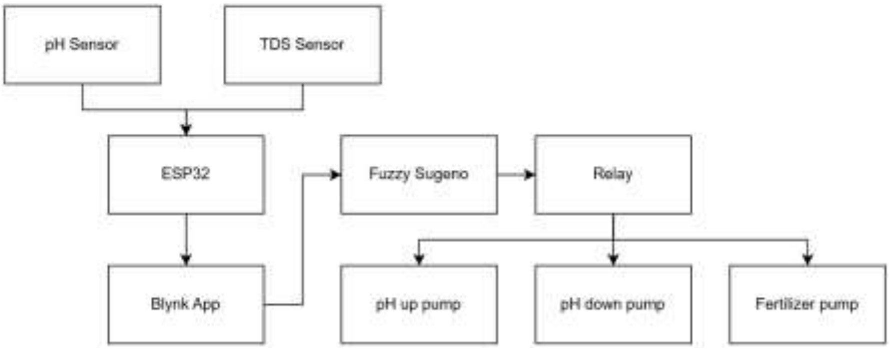

Figure 1. Control and monitoring block diagram.

System testing employed the Scenario-Based Test-Case Design method, referring to the activity diagram, sequence diagram, and class diagram [15]. Each scenario was tested using the Depth-First Search (DFS) technique to ensure all logical paths were verified. The three main scenarios tested included pH sensor calibration, water quality monitoring, and pH and nutrient control. Evaluation was performed using boundary-value analysis to measure the conformity of the system's response to various input conditions.

3. Result and Discussion

The results of the smart farming system in this study began with the design of a component architecture scheme. The prototype was constructed using Fritzing software with key components including a half breadboard, power supply, 4-channel relay, I2C LCD, ESP32, TDS meter, pH meter, water pumps, and ceramic capacitors. The ESP32 functioned as the central controller and the power source for all components except the pumps, which required 12V from an external power supply. The breadboard was utilized to extend power distribution, while the I2C LCD displayed pH and TDS values directly on the device. The TDS meter was connected to GPIO33 and the pH meter to GPIO32, both through 0.1 µF capacitors to ensure stable readings. The water pumps were controlled via the relay module connected to GPIO27, GPIO25, GPIO14, and GPIO15, with additional capacitors installed to suppress electrical interference.

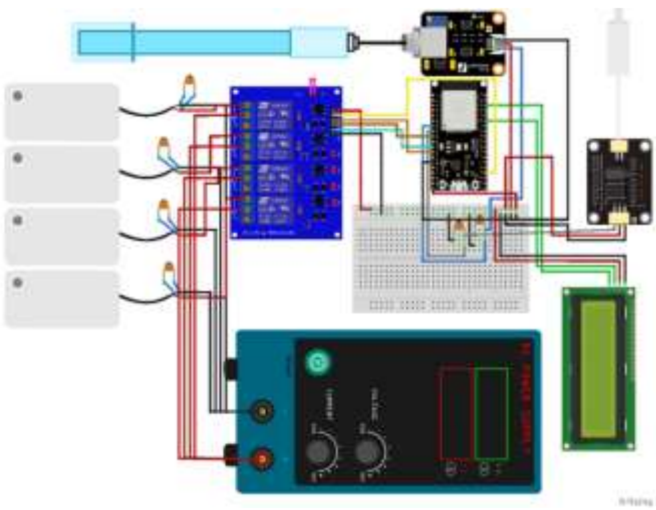

Figure 2. Component architecture scheme.

Subsequently, the system was equipped with a Sugeno fuzzy algorithm as the automatic control logic [15]. The pH value was classified into three categories: Acidic (0–6.0), Ideal (5.5–6.5), and Alkaline (6.5–8), while PPM was divided into Low (0–560), Ideal (560–840), and High (840–1200) [16][17]. Linear and triangular membership functions were employed for each category. The rule base combined pH and PPM conditions to determine the operating percentage of the pH Up pump and the AB Mix pump. The computation process was carried out through fuzzification, inference using the minimum method, and defuzzification with the Weighted Average technique to produce a precise output that defined when the pumps should be activated or deactivated, thereby preparing the system for implementation.

The implementation phase was realized through the integration of the Blynk interface and hardware components. The Blynk interface provided pump and sensor controls, pH calibration input, as well as displays for pH, PPM, pH voltage, and pump status. Automatic notifications were triggered when values fell below the standard threshold. The hardware assembly consisted of an ESP32, an I2C LCD, a pH meter, a TDS meter, a relay, water pumps, and a 12V power supply, with all connections organized through a breadboard and protected against voltage surges.

Figure 3. Interface display on the Blynk application.

Finally, the system was tested using a Scenario-Based Test-Case Design to ensure that all functions operated as expected. The initial testing stage focused on the preparation process of the smart farming system, such as powering on the device, preparing buffer solutions for calibration, and verifying connectivity with the Blynk application. The sensors were tested to confirm that voltage, pH, and PPM data could be accurately displayed. Subsequently, control scenarios were tested, including the delivery of automatic notifications and pump activation when pH and PPM values fell below threshold levels. This method demonstrated that the system was capable of operating automatically based on fuzzy logic and generating appropriate responses to real conditions. The scenario-based testing approach is particularly relevant in embedded systems and Internet of Things (IoT) applications, as it ensures that all logical paths and device functions are thoroughly and contextually evaluated [15].

Table 1. Testing of notification and pump control

Test Scenario	Test Case		Expected Result	Result
	Input value pH	Input Value TDS		
Notification when pH value is below 5.5	5		Notification of acidic pH appears on Email and Smartphone	Passed
Notification when PPM value is below 560		340	Notification of low nutrient level appears on Email and Smartphone	Passed
No notification when pH value is above 5.5	7,2		No acidic pH notification on Email and Smartphone	Passed
No notification when PPM value is above 560		781	No low nutrient notification on Email and Smartphone	Passed
Activate pH Up pump when pH value is below 5.5	5,1		pH Up pump is activated	Passed
Activate Pump A and B when PPM value is below 560		472	Pump A and B are activated	Passed

Deactivate pH Up pump when pH value is above 5.5	6,8		pH Up pump is deactivated	Passed
Deactivate Pump A and B when PPM value is above 560		883	Pump A and B are deactivated	Passed
Mix pump is activated when pH Up pump is active	5		Mix pump is activated	Passed
Mix pump is activated when Pump A and B are active		340	Mix pump is activated	Passed
Mix pump is activated when both pH Up pump and Pump A/B are active	4,2	488	Mix pump is activated	Passed
Mix pump is deactivated when both pH Up pump and Pump A/B are inactive	7,2	781	Mix pump is deactivated	Passed

The testing was conducted by providing various input values in each scenario to ensure that the system functioned reliably. When the pH value dropped below 5.5, the system automatically sent a “pH acidic” notification to both email and smartphone. Similarly, when the PPM value fell below 600, a “low nutrient” notification was successfully delivered. The pump control system was also tested to verify that the pH Up pump, Pump A and B, as well as the Mix pump, could be activated and deactivated according to the given input conditions. The results showed that all scenarios operated as expected, both in activating the pumps when values fell below the threshold and deactivating them once the conditions returned to normal. This testing confirmed that the system was capable of delivering accurate notifications and effectively controlling the pumps under various conditions. The following figure illustrates the final outcome of this research.

Figure 4. Final results of the hydroponic lettuce control and monitoring system.

This research successfully developed a smart farming system based on ESP32 and Blynk, capable of automatically monitoring and controlling the pH and nutrient solution fertilization using Sugeno fuzzy logic. The system provides a novel contribution compared to previous studies by integrating pH and nutrient control with real-time monitoring through a mobile application [10][11][12].

4. Conclusion

This research successfully developed an IoT-based smart farming system using ESP32 and Blynk for monitoring and controlling pH and nutrient distribution in NFT hydroponics. The implementation of Sugeno fuzzy logic enabled automatic adjustment of pH and PPM, accompanied by real-time monitoring and notifications when parameters exceeded optimal thresholds. This approach reduces manual intervention while supporting efficient system management. However, the study has not yet implemented pumps with variable speed control nor directly evaluated lettuce growth under the smart farming application. For future development, the system is expected to be enhanced through the integration of additional sensors, the adoption of adaptive pumps, and experimental testing to assess the impact of this technology on the growth and quality of hydroponic lettuce.

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