Fuzzy Logic Controller Design for pH Automation in Hydroponic Farming

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Abstract: The present research suggests utilizing a fuzzy logic controller to regulate the pH of the nutrient solution in hydroponic farming. The proposed control mechanism employs sensor to measure the pH of solution, and to adjusts the operation time of the solution pump via the fuzzy controller. The main goal is to maintain specific values for the pH of the nutrient solution. To achieve this objective, an esp32 board is utilized in the control system. The fuzzy controller takes inputs from pH sensor and generates an output for the operating time of the pump. Based on the experimental results, the proposed control system can significantly alleviate the measurement burden and complicated calculations for producers by efficiently regulating nutrient solutions.

Keywords: pH, Esp32, Fuzzy logic, Hydroponic.

I. INTRODUCTION

Hydroponics is a popular method for cultivation, but the traditional method of preparing nutrient solutions requires manual measurement of pH, which is time consuming and prone to errors. The pH of a hydroponic nutrient solution is a measure of its acidity or alkalinity and can affect the availability of nutrients plants. For lettuce plants, the recommended pH range is typically between the 5.5 to 6.5 [4]. When the pH of the growing medium is outside of this optimal range, the availability of nutrients to the plant can be affected, which can impact growth and yield. For example, if pH is too low(acidic), the availability of certain essential nutrients such as calcium, phosphorous, and magnesium may be reduced. On the other hand, if the pH is too high(alkaline), the availability of micronutrients such as iron, zinc, and manganese may be reduced. The balance of the nutrient solution is crucial for plant growth, and the pH need to be controlled effectively. Fuzzy logic controllers have been shown to be effective in hydroponic systems.

The aim of this study was to create a hydroponic system that utilizes fuzzy logic control, which can detect the pH levels of nutrient solution through sensor at any given time. By utilizing fuzzy control, the system can automatically adjust the nutrient solution pump to raise or lower the pH levels, thus promoting plant growth. The system significantly reduced the manual effort and time required for pH measurement and calculation, offering better accuracy and control.

Overall, the study demonstrated the effectiveness of fuzzy logic controllers in hydroponic systems, improving plant growth and yield by maintaining the pH of the nutrient solutions.

II. SYSTEM ARCHITECTURE AND METHODOLOGY

A. *Research Framework*

The system architecture flowchart is depicted in figure 1. The fuzzy controller proposed in this study consists of fuzzifier, inference engine, rule base and defuzzifier, is integrated into the esp32 board. The esp32 hardware receives inputs, which is pH sensing value, and produces 2 relays that can be utilized to regulate pH up solution and pH down Solution. The resulting mixture fluid is then pumped into the nutrient's solution adjustment tank.

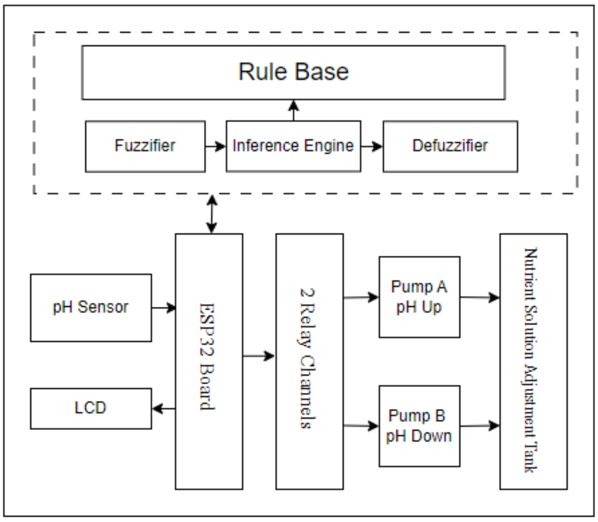

Fig. 1: System Architecture

B. *Methodology*

Fuzzy control technology has found widespread application in agriculture such as in district irrigation intelligent systems [1], electro-hydraulic suspension systems and autonomous navigation of wolfberry picking robots [2]. In this study, the fuzzy control technology was also employed to automate the regulation of pH in hydroponic farming system.

This section provides a description of the hardware utilized in the study, which includes the esp32 development board, pH sensors, dosing pumps, relays, LCD and other components. This fuzzy control program is written in C language.

Hydroponic fuzzy controller design: The diagram in figure 2 illustrate the basic operation of a hydroponic system, including the movement of pumps, sensors, and two conditioning fluids. The design process and steps are as follows [3].

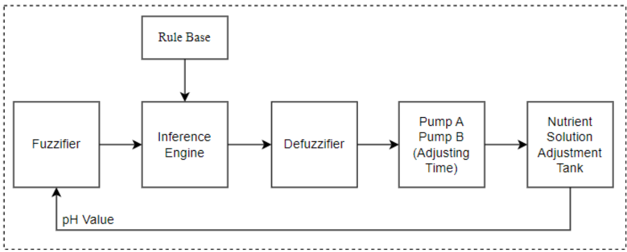

Fig. 2: Hydroponic Fuzzy Controller Architecture

Step 1: Figure 2 confirms the input and output relationships of the hydroponic system. The input is pH sensor, while the outputs are Pump A (for pH up), Pump B (for pH down). Additionally, figure 2 shows the structure of the hydroponic fuzzy controller.

Step 2: The inputs and outputs of the hydroponic fuzzy controller are defined through fuzzy sets. The control conditions are described using vague language. The fuzzy membership function for pH, such as “strong acid” (StrongA), “Medium Acid” (MediumA), “Weak acid” (WeakA), “zero” (z), “Weak base” (WeakB), “Medium Base” (MediumB) and “Strong base” (StrongB). Range of pH is set within 0 to 14 as in figure 3. Similarly, the fuzzy membership function for the two output pumps flow rate, one for pH up tank and the other for pH down tank, like “slow”, “very medium”, “medium”, “fast”, “very fast”. Range of output pump is 0 to 1.

Step 3: The hydroponic fuzzy controller’s membership functions are designed to determine the degree of membership of input variables. Each input and output variable has its own membership function, with errors classified as large, appropriate, or small. A fuzzy membership function is established for pH (acidity and alkalinity), and the pump. Theses membership functions are subjected to numerous tests, as shown in figure 3, figure 4, figure 5 and figure 6, to ensure their effectiveness. Triangular and trapezoidal mixed membership functions are used in this study, despite different form expert opinions, and are successful in providing an accurate reconstruction of the global signal characteristic.

Step 4: The design of the hydroponic fuzzy controller’s fuzzy rules base involves creating a table that outlines the rules. The fuzzy rule is base in this study is presented in Table 1. The design process must adhere to the steps outlined in definitions 2 to 5. The membership functions and fuzzy rules together establish the fuzzy rule base.

Step 5: To convert fuzzy sets into a crips value, a defuzzification process is employed, which utilizes the center of area method. This involves using a formula to calculate the precise value in seconds, where y_{PUMP} represents the pump’s adjustment output (in seconds), μpump(x) represents the membership value, and x represents the corresponding number of seconds of the pump’s membership value. Equation (1) shows this formula.

$$y_{PUMP} = \frac{\int_x \mu_{PUMP}(x)xdx}{\int_x \mu_{PUMP}(x)dx} \quad \text{-----------(1)}$$

TABLE I: HYDROPONICS FUZZY RULE BASE

Target / Sensed	StrongA	MediumA	WeakA	Z	WeakB	MediumB	StrongB
StrongA	Slow both	Very medium up	Medium up	Medium up	Medium up	Fast up	Very fast up
		Slow down	Slow down	Slow down	Slow down	Slow down	Slow down
MediumA	Slow up	Slow	Very medium up	Medium up	Medium up	Fast up	Fast up
	Very medium down		Slow down	Slow down	Slow down	Slow down	Slow down
WeakA	Slow up	Slow up	Slow	Very medium up	Medium up	Fast up	Fast up
	Mediun down	Very medium down		Slow down	Slow down	Slow down	Slow down
Z	Slow up	Slow up	Slow up	Slow	Very medium up	Medium up	Medium up
	Medium down	Medium down	Very medium down		Slow down	Slow down	Slow down
WeakB	Slow up	Slow up	Slow up	Slow up	Slow	Very medium up	Very medium up
	Fast down	Fast down	Mediumm down	Very medium down		Slow down	Slow down
MediumB	Slow up	Slow up	Slow up	Slow up	Slow up	Slow both	Very medium up
	Very fast down	Fast down	Medium down	Meium down	Very medium down		Slow down
StrongB	Slow up	Slow up	Slow up	Slow up	Slow up	Slow up	Slow both
	Very fast down	Fast down	Medium down	Medium down	Medium down	Very medium down	

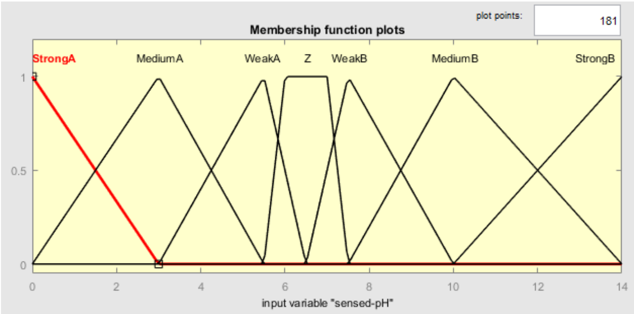

Fig. 3: Sensed pH membership function

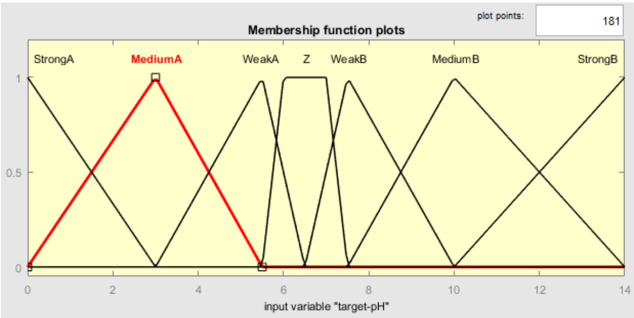

Fig. 4: Target pH membership function

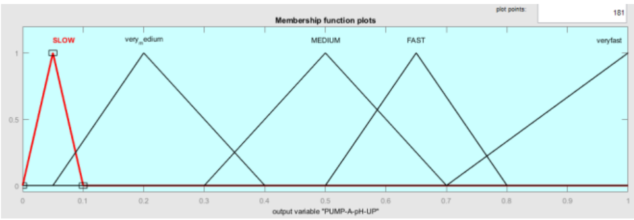

Fig. 5: Pump A pH up membership function

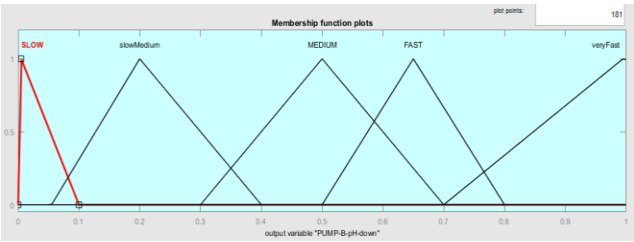

Fig. 6: Pump B pH down membership function

III. Data Analysis and Results

A. *Data Analysis Tools and Techniques*

For controlling the pH, fuzzy logic is design using the MATLAB Simulink, we design the 49 rules for controlling the pH sensor sensed value, and according to rule the output pump A and pump B are rum for specific time. To increase the pH of a hydroponic farming solution, we add the potassium hydroxide (KOH) or sodium hydroxide (NaOH). Similarly, to decrease the pH of a hydroponic farming solution, we add the nitric acid (HNO3) or phosphoric acid(H3PO4). The equation (2) can be used to calculate the amount of KOH or HNO3 needed to increase or decrease the pH of hydroponic solution by a specific number of units. This equation is a useful tool for growers to determine the appropriate amount of acid needed to adjust the pH of the solution, and the dosing pump was used to control the amount of acid added. The dosing pump which was used to adjust the pH have the flow rate of 80ml per minute.

Amt of Acid (in mL) = (X * volume of solution (in liters) x 1000) / (normality of acid x 1000) -------- (2)

B. *Analysis Results*

From the simulation using MATLAB, it is found that if target pH value is high and sensed pH value is low then the pump-A i.e., pH up motor will run for certain time as shown in figure 7. Similarly, if target pH value and sensed pH value is same then both pumps will “off”, as show in figure 8 and if the target pH value is low and the sensed pH value is high then the pump-B will run for certain time as shown in figure 9. From the simulation we find the accuracy of 98% for pH up and 95 % for pH down.

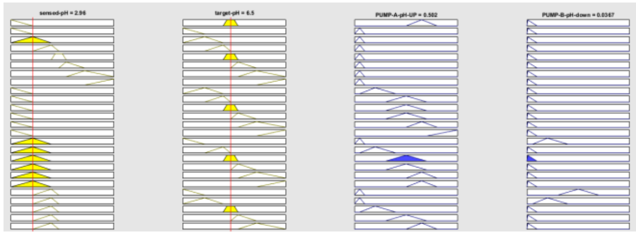

Fig. 7: Simulation of sensed pH value low and target pH value high

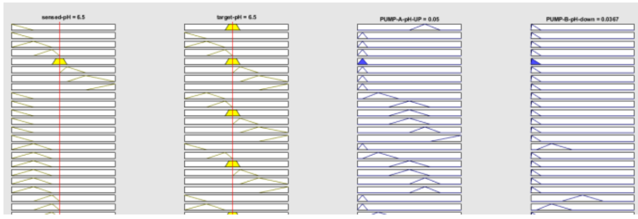

Fig. 8: Simulation of sensed pH and target pH value same

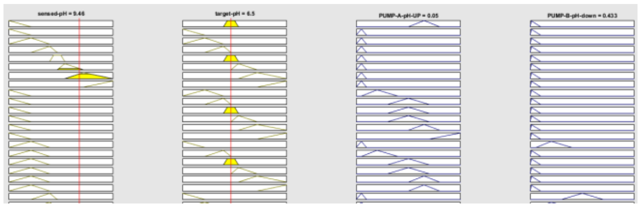

Fig. 9: Simulation of sensed pH high and target pH is low

IV. Conclusion and Future Works

This study aimed to develop a hydroponic system that utilizes a fuzzy logic controller to regulate the pH levels of the nutrient solution for optimal plant growth. By detecting the pH levels through sensor, the system can simplify the measurement process for producers and reduce the need for complex calculations. This system can provide effective control and reduce labor requirements for producers. The study found that the system achieved a 98% accuracy for the pH up pump and 95% accuracy for the pH down pump, resulting in an overall accuracy of 96%. The result suggest that the system is suitable for hydroponic cultivation. In addition, futures research could also explore the use of machine learning algorithms to improve the accuracy and efficiency of the control system.

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