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Research Article

A Low-Cost Hydroponic Monitoring System with Internet of Things and Fuzzy Logic

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Abstract: The need for urban communities to consume vegetables is increasing. This has caused people to start cultivating vegetables using hydroponic techniques. However, due to their busy activities, they do not have enough time to monitor and control hydroponics, which must always be in ideal conditions. This paper designs and implements an Internet of Things-based monitoring system to help hydroponic owners monitor their hydroponics anywhere and anytime. The built system requires a monitoring device assembled using a NodeMCU ESP8266 microcontroller, a pH detection detector sensor, and a DHT22 temperature and humidity sensor. This system uses the Mamdani Fuzzy Logic algorithm to determine warnings to be displayed on the application interface when the water pH, temperature, and humidity are in certain conditions. The Mamdani Fuzzy Logic algorithm can interpret environmental data into a warning that humans can easily understand, even if they lack technical expertise. In addition to being able to help monitor, this system also allows owners to find out what elements need to be added or changed for their hydroponic place. Our evaluation results show that the defuzzification stage in the application has high accuracy, which is 99.92%, compared to Matlab's results.

Keywords: Intelligent System; Mamdani Fuzzy Logic Algorithm; Microcontroller; Online Application; Real-time; Sensor; WhatsApp Notification.

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1. Introduction

The need for food in urban areas increases yearly, not only fast food but also healthy food containing vegetables. Hydroponics is the best solution for urban people who want to use their land to grow fresh and healthy vegetables. Hydroponics is cultivating growing vegetables using water as an alternative medium to replace soil for vegetable growth[1]. Hydroponics has also become a business opportunity for entrepreneurs who live in the city and want to run a vegetable business by utilizing the available space.

Hydroponics that utilize water as a planting medium, like soil media, must always pay attention to the water supply levels, oxygen, nutrients, acidity, and base levels or power of hydrogen (pH)[2]. In addition to all that, room temperature and humidity must also be maintained because they affect vegetable growth. Hydroponic vegetables require water conditions to be monitored at all times, because plants can absorb nutrients well if the water pH is at a certain threshold. Maintaining pH levels at their normal threshold can be achieved by regularly checking using a pH meter tool. Owners must also monitor and maintain the temperature and humidity of the room. The purpose of maintaining water pH, room temperature, and humidity at the tolerance threshold is to obtain healthy and good growth from the seedling phase to the harvest phase. These three elements make hydroponic owners have to frequently check the condition of the water and the room conditions. However, most urban communities are workers who have various other activities and cannot monitor their plants' condition at all times[3].

Technology in various fields is necessary to facilitate more effective and efficient work, especially in agriculture, using the Internet of Things (IoT) technology. IoT is a device that processes, provides, and transfers digital data from sensors embedded in physical objects [4], then sent via the Internet network. Digital data sent to a device has gone through data processing and storage so that humans can view and control it. IoT as a technology to facilitate work must also be supported by other devices, namely smartphones that use certain operating systems, such as Android[5], [6]. Fuzzy logic is a way to map an input space into an output space[7]–[9], by utilizing the area between 0 and 1, which is a grey area or fuzzy area. Thus, the fuzzy area can be utilized by stating two or more conditions at the same or different levels.

Based on the previously mentioned problems, we propose a solution to create a low-cost IoT-based monitoring system that can monitor the conditions of water pH, temperature, and room humidity in real-time. The data obtained is processed using the Mamdani Fuzzy Logic algorithm, and then the information that is successfully processed can be accessed by the hydroponic owner through an online application. In addition, a notification will be sent to the hydroponic owner via a WhatsApp message so that the water pH, temperature, and humidity levels can be adjusted back to their normal thresholds.

While previous IoT studies for hydroponics mainly focus on hardware implementation, our contribution is an IoT monitoring system with the Mamdani Fuzzy Logic algorithm that can interpret environmental data into a warning that humans can easily understand, even if they lack technical expertise. In addition, the system also send notifications to the user to ensure quick intervention to minimize potential damage to the crops.

2. Related Works

William Frederick Gericke pioneered the hydroponic system in the early 1930s in Berkeley, California. The hydroponic system is a cultivation system that uses water as its medium. The medium's water contains nutrients and minerals without soil[10]. Because it uses water as its medium, hydroponics is a solution for people who want to grow crops but do not have enough land for planting. Plant nutrients, temperature, and humidity determine the quality of plant growth. Nutrients can be absorbed well when the water pH is between 5.5 and 6.5. Temperature affects the growth and color of leaves, while high humidity will cause pests to appear on plants.

The Internet of Things (IoT) is a technology that uses devices that process, provide, and transfer digital data from sensors embedded in physical objects[4] and then send it via the Internet. Digital data sent to a device has gone through data processing and storage so that humans can see and control it. Thus, IoT is a concept that connects every technological object or object around us via the Internet, and each object can send data via the Internet so that it can be accessed from anywhere and anytime[11]. To create an IoT system, supporting devices are needed to collect data that will be processed in the application. The components used are microcontrollers and sensor modules. IoT is useful for solving real-world problems, including in the agricultural sector[12]–[14].

Several previous studies are similar to this research and serve as references. The study in [15] utilizes IoT technology to monitor hydroponic conditions remotely. The authors use a sensor device that consists of a NodeMCU ESP8266 microcontroller, a water temperature sensor, a pH level sensor, and a room humidity and temperature sensor. They utilize Node-Red as a tool for wiring hardware devices, APIs, and online services. The sensor readings from the microcontroller are sent to Node-Red, where the data will be analyzed, and the action will be taken based on that. The system has an IOS mobile application to help users monitor hydroponics and send notifications via emails and Telegram messages. This study does not implement any algorithm to analyze the sensor readings.

The authors in [16] propose an IoT system for hydroponic monitoring using an air temperature and humidity sensor, a light intensity sensor, a water temperature sensor, a pH sensor, and a TDS sensor. An IoT gateway is implemented using a NodeMCU ESP8266. They also use Node-RED as a programming tool for wiring hardware devices, APIs, and online servers. Because this study does not implement any algorithm to analyze the sensor readings, users need to interact with the web interface via a mobile device to control the operation of the actuator (pumps and fans).

The purpose of the study in [1] is to control hydroponic nutrients using an IoT system focusing on monitoring water temperature, total dissolved solids (TDS), and water pH. An Arduino Leonardo as a microcontroller sends data from a pH sensor, a TDS sensor, and a

DS18B20 water temperature sensor via an ESP8266-01 to the ThingSpeak data storage service. The system applies the K-Nearest Neighbor algorithm to classify the water nutrient condition to order the pump actuator.

Fuzzy logic algorithm or fuzzy logic is a way to map an input space into an output space [8], [9], by utilizing the area between 0 and 1, a gray or fuzzy area. Thus, the fuzzy area can be utilized by stating two or more conditions at the same or different levels. Suppose the conditions "GOOD" and "BAD" are present at the same time, with a "GOOD" level of 20% and a "BAD" level of 80%. The fuzzy logic algorithm has the advantage of its flexibility by determining interdependent linguistic functions, and each linguistic function is determined into several linguistic variables with certain membership values[17]. For example, the linguistic function "TEMPERATURE" with specified linguistic variables such as "COLD", "COOL", and "HOT", then the value of each membership value is determined. For example, COLD has a value from 0 °C to 17 °C, COOL is from 15 °C to 20 °C, while 35 °C and above is the HOT linguistic variable.

The membership function is a graph that represents the degree of membership of each variable whose input interval is between 0 and 1. The symbol $\mu(x)$ is a symbol of the degree of membership of a variable x. When making inferences to conclude weight factors, the rule uses its membership function as a weight factor to determine its influence. The following is the membership function of the triangular curve used in this paper[18], [19]. The triangle curve membership graph combines two lines (linear) as shown in Fig. 1. It is used when there are three different parameters.

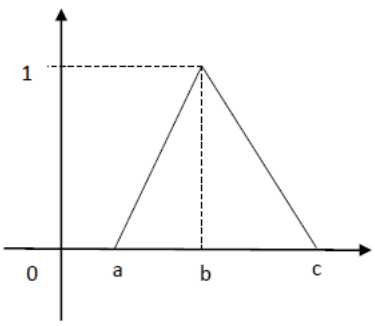

Figure 1. Triangle curve membership graph.

From the Fig. 1, the function values are:

$$\mu(x) = \begin{cases} 0; & x \leq a \\ \dfrac{x-a}{b-a}; & a \leq x \leq b \\ \dfrac{c-x}{c-b}; & b \leq x \leq c \\ 0; & x \geq c \end{cases} \tag{1}$$

Where a is the smallest domain value that has a membership degree of zero; b is the domain value that has a membership degree of one; c is the largest domain value that has a membership degree of zero; x is the input value that will be converted into a fuzzy logic number; μ are membership degree.

Fuzzy logic has several methods: Mamdani, Tsukamoto, Sugeno, and Adaptive Neuro Fuzzy Inference System (ANFIS). In this paper, the method chosen is the Mamdani method, commonly called the Max-Min method. This method was first introduced by Ebrahim Mamdani in 1975. The Mamdani method uses linguistic variables and mimics human reasoning, which makes it easier for users, which are hydroponic farmers, to understand, trust, and adjust the system based on their reasoning. While the Mamdani method is simple and flexible, the Sugeno method lacks the interpretability of Mamdani, and the Tsukamoto method is less intuitive for human operators[20], [21]. Mamdani's fuzzy rules are human-readable, so expert knowledge can be translated directly into the system without large datasets for training like ANFIS. The following are the four stages required to obtain the output from Fuzzy Mamdani[22].

2.1. Fuzzification

Input variables and output variables in the Mamdani method are divided into one or more fuzzy sets, and each fuzzy set has its membership function. The fuzzification stage aims to change the crisp value or firm value into a fuzzy or vague form by calculating the membership degree value in the membership function of each fuzzy set variable.

2.2. Implication Function

After obtaining the input and output variables, the next step is determining the implication function. The implication function used is Min. This function cuts the fuzzy set output. Fuzzy implications are based on the shrinkage strength and fuzzy sets determined for each output variable in the consequence section of each existing rule, which are then combined to obtain the fuzzy inference output results.

2.3. Rule Composition

After obtaining the results of the implication function, the next step is to determine the composition of each rule and the method used to perform fuzzy system inference, namely using the Max method. For the Max method, the fuzzy set solution is taken by taking the maximum value of the rule, after which it is used to modify the fuzzy region and then applied to the output using the OR operator. If all the prepositions have been evaluated, the output will contain a fuzzy set showing each preposition's contribution.

2.4. Defuzzification

The input of the defuzzification process is a fuzzy set obtained from the composition of fuzzy rules, while the output produced is a number in the domain of the fuzzy set. Defuzzification uses the centroid method, or Center of Area (COA) in the Mamdani method. Equation (2) is used for calculating COA.

$$z^* = \frac{\int_z \mu(z)z\,dz}{\int_z \mu(z)\,dz} \tag{2}$$

Where z^* is the exact value, which is the result of defuzzification; $\mu(z)$ is the membership value; $\int_z \mu(z)z\,dz$ I the moment for all regions resulting from the composition of rules; $\int_z \mu(z)\,dz$ is the area for all regions resulting from the composition of rules.

3. Methodology, Design, and Implementation

3.1. Methodology

The Mamdani Fuzzy Logic process in the hydroponic monitoring system is shown in Fig. 2. This diagram explains the contents of the input and output of the system. The input data are water pH, temperature, and air humidity. The data will be processed using the Mamdani Fuzzy Logic algorithm. The application will provide output based on the input, i.e., a warning.

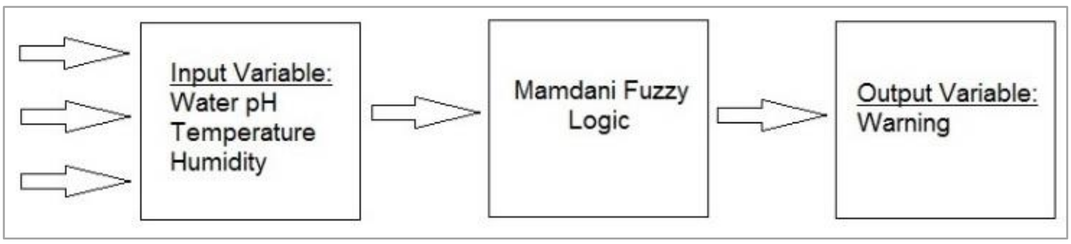

Figure 2. Input and output of the system.

In making an IoT-based hydroponic monitoring system using fuzzy logic, three input variables are sent from the sensor and microcontroller. These three linguistic functions are essential factors in hydroponic growth that affect the growth and development of plants. These linguistic functions are:

3.1.1. Water pH

The linguistic function of water pH has three membership functions: acid, neutral, and alkaline[23].

1. Acid: the pH of water that has a level between 0 and 5.6 has a high acidity level, which will cause the roots in hydroponic plants to be unable to absorb the nutrient solution needed by the plants.
2. Neutral: hydroponic plants require neutral water pH at levels of 5.5 to 6.5. Neutral water pH is needed so that the plant's roots can properly absorb the nutrients they need.
3. Alkaline: at levels of 6.4 and above, hydroponic plants can no longer absorb nutrients properly because the water pH is fundamental.

3.1.2. Temperature

The linguistic function of temperature has three membership functions: cold, normal, and hot[24].

1. Cold: room temperatures below 0 to 22 Celsius can cause plants to lose their physiological abilities, such as respiration, photosynthesis, transpiration, nutrient absorption, and water absorption.
2. Normal: room temperatures ranging from 20 to 30 Celsius are optimal for plant growth, especially salad vegetables.
3. Hot: A room temperature of 28 to above 50 Celsius affects the oxygen in the room. The hotter the room, the less oxygen there is in it.

3.1.3. Humidity

The linguistic function of humidity has two membership functions: humid and very humid. High humidity above 80% triggers the development of pathogenic fungi that will attack plants[23].

The output variable has only one linguistic function, namely warning. There are two membership functions whose results are warnings: normal condition and beyond the limits. Based on the input and output of the system, the variables and membership sets are determined, as can be seen in Table 1.

Table 1. Variables and membership sets.

Variable Types	Membership	Domain
Input	Water pH	Acid (0 – 5.6)
		Neutral (5.5 – 6.5)
		Alkaline (6.4 – 14)
	Temperature	Cold (<0 – 22 ^{o}C)
		Normal (20 – 30 ^{o}C)
		Hot (28 – >50 ^{o}C)
	Humidity	Humid (1% – 85%)
		Very humid (80% - 100%)
Output	Warning	Normal condition
		Beyond the limits

3.2. Mamdani Fuzzy Logic

The Mamdani fuzzy inference process consists of four main stages: fuzzification, implication, rule composition, and defuzzification.

3.2.1. Fuzzification

This step transforms crisp values from sensor readings (water pH, temperature, and humidity) into fuzzy values based on the membership functions defined in Section 3.1.

3.2.2. Implication Using Min Function

The implication stage applies the Min function to determine the membership degree of each fuzzy rule. The Min function ensures that the rule activation strength is based on the lowest membership value among the input variables. This is formulated as Equation (3).

$$\alpha_{Ri} = \min\left(\mu_{pH}(x), \mu_{Temperature}(x), \mu_{Humidity}(x)\right) \quad (3)$$

Where Ri represents the fuzzy rule applied in the system. The rules used are based on combining three input variables, as shown in Table 2.

3.2.3. Rule Composition

The Max function is applied to combine the results of all active fuzzy rules. This generates the overall fuzzy output by selecting the highest degree of membership among the triggered rules.

3.2.4. Defuzzification

The centroid method (Center of Area - COA) is applied to convert the fuzzy output into a crisp value.

Table 2. Rules formation.

Rules	Water pH	Room Temperature	Room Humidity	Result
R1	Acid	Cold	Humid	Beyond the limits
R2	Acid	Cold	Very humid	Beyond the limits
R3	Acid	Normal	Humid	Beyond the limits
R4	Acid	Normal	Very humid	Beyond the limits
R5	Acid	Hot	Humid	Beyond the limits
R6	Acid	Hot	Very humid	Beyond the limits
R7	Neutral	Cold	Humid	Beyond the limits
R8	Neutral	Cold	Very humid	Beyond the limits
R9	Neutral	Normal	Humid	Normal
R10	Neutral	Normal	Very humid	Beyond the limits
R11	Neutral	Hot	Humid	Beyond the limits
R12	Neutral	Hot	Very humid	Beyond the limits
R13	Alkaline	Cold	Humid	Beyond the limits
R14	Alkaline	Cold	Very humid	Beyond the limits
R15	Alkaline	Normal	Humid	Beyond the limits
R16	Alkaline	Normal	Very humid	Beyond the limits
R17	Alkaline	Hot	Humid	Beyond the limits
R18	Alkaline	Hot	Very humid	Beyond the limits

3.3. The System

The hydroponic monitoring system is visualized in Fig. 3. Sensing data are collected through sensors and then on the NodeMCU ESP8266 microcontroller. The collected data are sent via the Internet to Firebase – a real-time cloud-hosted NoSQL database. The communication technology used by ESP8266 to send data to Firebase is Wi-Fi, and the communication protocol used is HTTPS (Hypertext Transfer Protocol Secure), which is implemented in the FirebaseESP8266 library. With HTTPS, the data is encrypted using SSL/TLS to ensure secure communication and to prevent unauthorized access during transmission. The FirebaseESP8266 library uses standard REST API methods (GET, POST, and PUT) to send and receive data. The data that have been stored will be processed into meaningful information that users can access. Users can access and view data using a laptop or smartphone via an online application's user interface.

3.4. The Hardware

The sensor device consists of only two sensors, i.e., a pH Detection Detector (Pride and Module) sensor[25] and a DHT22 digital temperature and humidity sensor[26]. Both sensors are connected to NodeMCU ESP8266[27]. NodeMCU ESP8266, which a power supply has powered, collects data from the two sensors to be sent via the Internet to the server. The sensors are connected to NodeMCU via several NodeMCU pins, as summarized in Table 3.

Table 3. Pin configuration.

NodeMCU	DHT22	pH Meter	Power Supply
D3 pin	AOUT	-	-
Analog pin	-	AOUT	-
3.3V	3.3V	-	-
Vin	-	5V	VCC
GND	GND	GND	GND

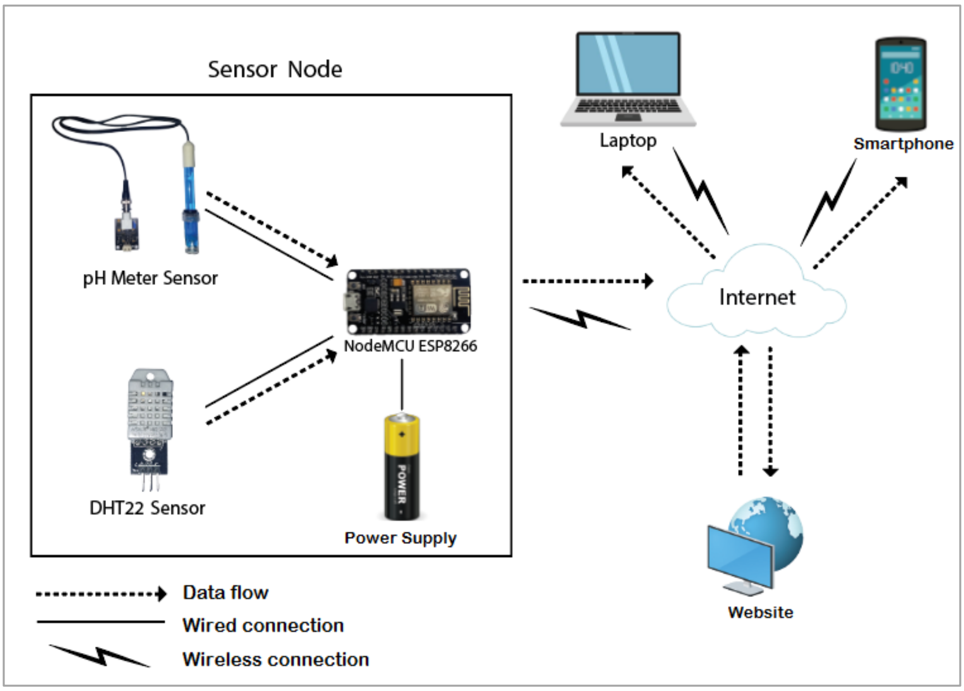

Figure 3. Hydroponic monitoring system diagram

3.5. The Software

The application workflow is divided into the client side (sensor device) and the server. On the client side, after the initialization process, the program will detect whether the system is connected to the Internet or not. If it is connected, the sensors will retrieve data in the form of water pH, voltage, temperature, and humidity. The data received are sent directly to the server, and all processes will continue to repeat. The processes on the server also occur repeatedly. When the server is connected to the Internet, the server will receive data sent by the sensor device. The received data are stored in the server in JSON format on Firebase. The data that have been stored will be processed by the server using the Mamdani Fuzzy Logic algorithm, for example, to produce information for users whether the pH value of the water is acid, neutral, or alkaline. The Mamdani Fuzzy Logic algorithm results will be displayed on an online application that users can access. This application can also send a notification message to users via WhatsApp.

Fig. 4 shows one of the processes that occurs in the server, namely at the data processing stage of the Mamdani Fuzzy Logic algorithm. Sensor data stored in the database will be read, including the water pH, temperature, and humidity, which are crisp values or firm values. The three variables will be processed at the fuzzification stage by finding their membership functions and then the membership degree values. After getting the membership degree values, the implication function will be searched using the Min method. The next stage after getting the rules that will be used according to the implication function of the Min method is the rule composition stage using the Max method. After obtaining the rule composition, the value will be changed into a firm or crisp form at the defuzzification stage. The results that have been obtained will be sent to be stored in the database and displayed on the application's user interface.

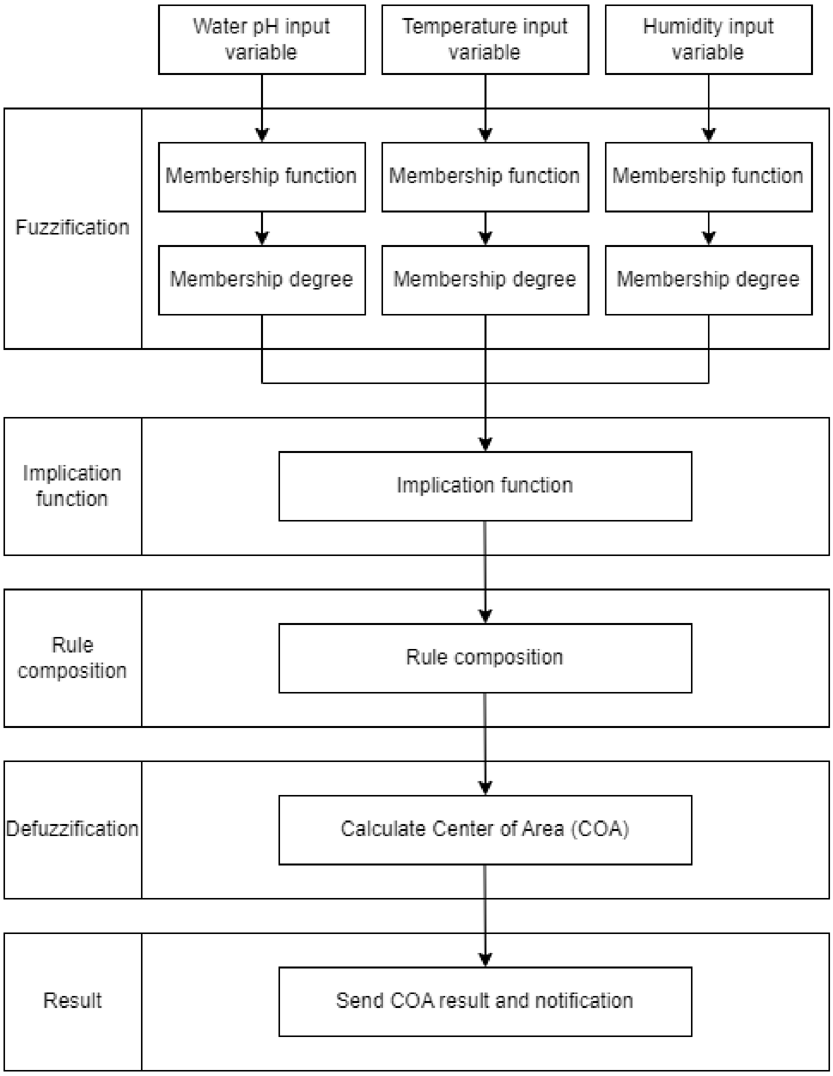

Figure 4. Proposed Mamdani fuzzy logic algorithm.

4. Results

The hydroponic monitoring system is evaluated by first checking each sensor's reading accuracy. Secondly, we compare the application output with the results from manual calculation. Thirdly, we compare the application output with the results from Matlab. Then, we experimented 18 times according to the rules that were created in the Mamdani Fuzzy Logic algorithm to see whether all the rules produced the correct results.

4.1. Sensor Accuracy Evaluation

Sensor accuracy evaluation tests whether the application and monitoring device function properly according to the design. Thus, the application and device are ready to carry out experiments in the hydroponic field.

The first sensor tested was the pH Detection Detector (Pride and Module), which measures water pH. We dissolve 4.01, 6.86, and 9.18 pH solution powder into three glasses with 250 ml of water. We compare the pH Detection Detector sensor reading with a pH meter as the manual measuring tool to find the offset of each value and calculate the average value. Fig. 5 shows the three tests that have been carried out and Table 4 shows the results of the water pH accuracy test.

The second sensor tested was the DHT22 Temperature and Humidity sensor, which measures room temperature and humidity. We compare the DHT22 Temperature and Humidity sensor reading with a digital hygrometer temperature meter as the manual measuring tool to find the offset of each value and calculate the average value. The test was carried out

10 times with an interval of every 5 minutes to see the difference between the manual measuring tool and the DHT22 sensor. Fig. 6 shows three out of ten tests carried out. Table 5 and Table 6 show the results of the temperature and humidity accuracy tests, respectively.

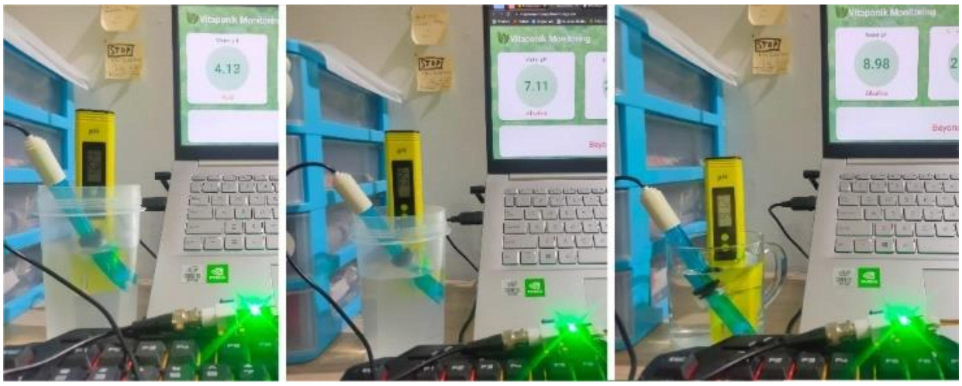

Figure 5. pH sensor accuracy evaluation using three glasses of water with different pH.

Table 4. Results of pH accuracy evaluation.

pH Detection Detector	pH Meter	Offset
4.13	4.04	0.09
7.11	7.04	0.07
8.98	9.12	0.14
average		0.1

Table 5. Results of room temperature accuracy evaluation.

DHT22 Temperature and Humidity	Digital Hygrometer Temperature Meter	Offset
29.4	28.9	0.5
30.1	29.6	0.5
30	29.7	0.3
26.8	28.3	1.5
27.1	28.8	1.7
27.2	29	1.8
27.2	29	1.8
27.3	28.4	1.1
27.5	28.3	0.8
27.4	28.3	0.9
average		1.09

Table 6. Results of room humidity accuracy evaluation.

DHT22 Temperature and Humidity	Digital Hygrometer Temperature Meter	Offset
79	80	1
77	77	0
76	69	7
83	75	8
83	72	11
82	71	11
82	70	12
81	70	11
81	71	10
82	71	11
average		8.2

Figure 6. Three examples of temperature and humidity sensor accuracy evaluation.

4.2. Comparison with Manual Calculation

Implementing the Mamdani Fuzzy Logic algorithm must produce the same results as the manual calculation. Therefore, we compare the application output with the results from manual calculation, which are summarized in Table 7. This evaluation uses the following values: pH = 3, temperature = 25, and humidity = 60. Fig. 7 shows the result of the Mamdani Fuzzy Logic algorithm on the application. The page directly displays the stages of how the application processes the Mamdani Fuzzy Logic algorithm.

Table 7. Comparison of the results from application and manual calculation.

Stages	Application	Manual Calculation	Offset
Fuzzification			
pH = 3	Acid (0.93)	Acid (0.96)	0.03
Temperature = 25	Normal (1)	Normal (1)	0
Humidity = 60	Humid (0.59)	Humid (0.59)	0
Implication function	[R3] IF (Water pH = Acid (0.9285714285714285)) AND (Temperature = Normal (1)) AND (Humidity = (Humid (0.5952380952380952)) THEN (Result = Beyond the Limits (0.5952380952380952)	[R3] IF (Water pH = Acid (0.96)) AND (Temperature = Normal (1)) AND (Humidity = (Humid (0.59)) THEN (Result = Beyond the Limits (0.59)	
Rule composition	0.59	0.59	0
Defuzzification	3.255582459	3.26	0.004

4.3. Comparison with Matlab

A comparison with Matlab aims to see the accuracy of the final value or defuzzification of the application. We use Mamdani version 2.0 from Matlab's fuzzy inference system with the Min function in the implication method, the Max function in the aggregation method, and the Centroid function in the defuzzification method. The Matlab simulation is executed 10 times. The first simulation uses the previously mentioned manual calculation values, i.e. pH = 3, temperature = 25, and humidity = 60. Then, the remaining nine simulations use random values. Table 8 summarizes the results of the application and Matlab. Fig. 8 shows the result using Matlab where pH = 3, temperature = 25, and humidity = 60.

This evaluation shows that the Mamdani Fuzzy Logic algorithm in the application has run well and following the stages of the algorithm and the rules that have been made. The final results of the defuzzification stage in the application show that the accuracy is 99.92%, which is calculated from 100% - 0.07625 (average offset with Matlab's results). The small differences occur as the application, which is built using JavaScript, experiences rounding issues with floating-point numbers.

Figure 7. Result of the Mamdani fuzzy logic algorithm on application.

Table 8. Comparison of the results from application and Matlab.

Values (pH; Temperature; Humidity)	Matlab	Application	Offset
3; 25; 60	3.26	3.255582459	0.00442
6; 25; 43	1.66	1.555555556	0.10444
6; 3; 90	3.33	3.322424242	0.00758
10.2; 35; 70	3.16	3.149058149	0.01094
6.3; 27.7; 50	1.81	1.211111111	0.59889
13; 45 ; 80	3.07	3.058268033	0.01173
7; 44; 90	3.08	3.076691729	0.00331
13; 10; 43	3.13	3.124933546	0.00507
10; 20; 30	3.05	3.044733045	0.00527
6.45; 24.5; 89.5	3.06	3.049122807	0.01088
average			0.07625

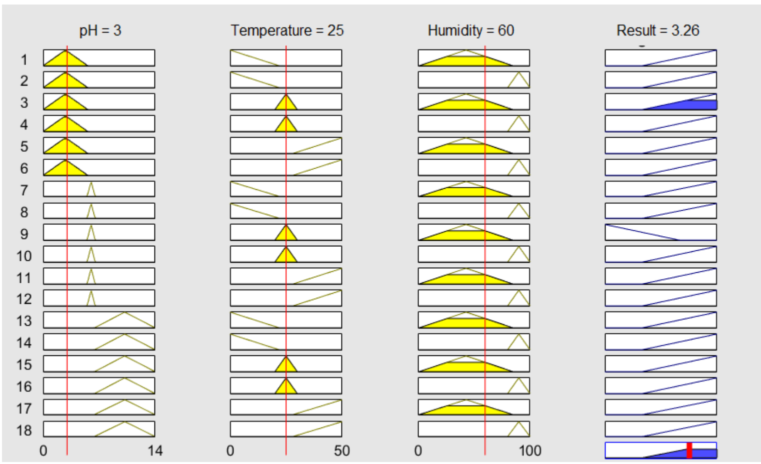

Figure 8. Result of the Mamdani fuzzy logic algorithm using Matlab (water pH = 3, temperature = 25, and humidity = 60).

4.4. All Conditions Evaluation based on Rules

This evaluation is carried out 18 times according to the rules created in the Mamdani Fuzzy Logic algorithm to check if all the rules produce the correct results. Table 9 summarizes the results of all 18 evaluations that have been carried out.

Table 9. All conditions evaluation.

Rules	Water pH	Room Temperature	Room Humidity	Result	Valid
R1	Acid (2.8)	Cold (10)	Humid (43)	Beyond the limits	Yes
R2	Acid (2.8)	Cold (10)	Very humid (85)	Beyond the limits	Yes
R3	Acid (2.8)	Normal (25)	Humid (43)	Beyond the limits	Yes
R4	Acid (2.8)	Normal (25)	Very humid (85)	Beyond the limits	Yes
R5	Acid (2.8)	Hot (35)	Humid (43)	Beyond the limits	Yes
R6	Acid (2.8)	Hot (35)	Very humid (85)	Beyond the limits	Yes
R7	Neutral (6)	Cold (10)	Humid (43)	Beyond the limits	Yes
R8	Neutral (6)	Cold (10)	Very humid (85)	Beyond the limits	Yes
R9	Neutral (6)	Normal (25)	Humid (43)	Normal	Yes
R10	Neutral (6)	Normal (25)	Very humid (85)	Beyond the limits	Yes
R11	Neutral (6)	Hot (35)	Humid (43)	Beyond the limits	Yes
R12	Neutral (6)	Hot (35)	Very humid (85)	Beyond the limits	Yes
R13	Alkaline (10.2)	Cold (10)	Humid (43)	Beyond the limits	Yes
R14	Alkaline (10.2)	Cold (10)	Very humid (85)	Beyond the limits	Yes
R15	Alkaline (10.2)	Normal (25)	Humid (43)	Beyond the limits	Yes
R16	Alkaline (10.2)	Normal (25)	Very humid (85)	Beyond the limits	Yes
R17	Alkaline (10.2)	Hot (35)	Humid (43)	Beyond the limits	Yes
R18	Alkaline (10.2)	Hot (35)	Very humid (85)	Beyond the limits	Yes

5. Discussion

The system is tested in one of the hydroponic field called Vitaponik in Manado, North Sulawesi. Fig. 9 shows the evaluation field that uses a semi-indoor place. The type of hydroponics tested is the Deep Water Culture (DWC) type which contains 1000 liters of water.

Figure 9. The Deep-Water culture (DWC) hydroponic field.

The field evaluation tests whether the application and monitoring device run well in real time. The system monitors the hydroponic field from 8 AM to 8 PM for two days. Fig. 10, Fig. 11, and Fig. 12 show the graphs of water pH, temperature, and humidity, respectively for the two-day monitoring. The two-day monitoring dataset is available at https://l1nk.dev/hydroponic.

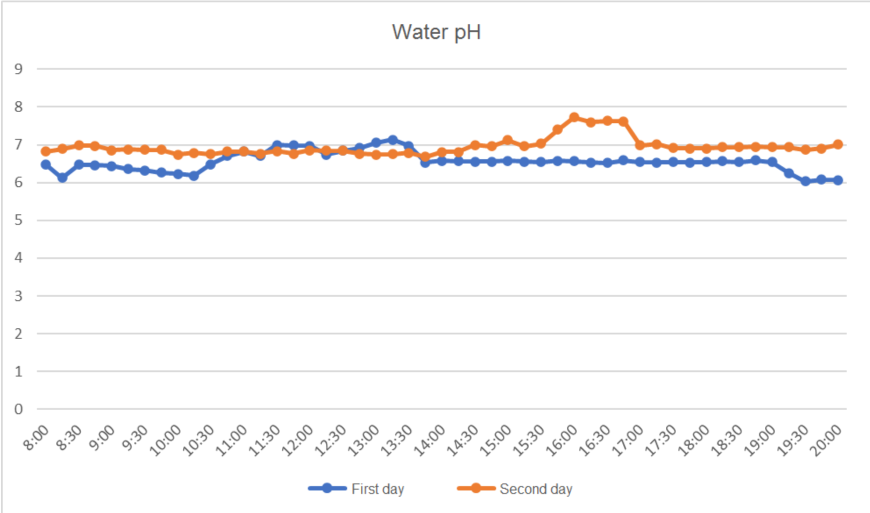

Figure 10. Two-day water pH monitoring.

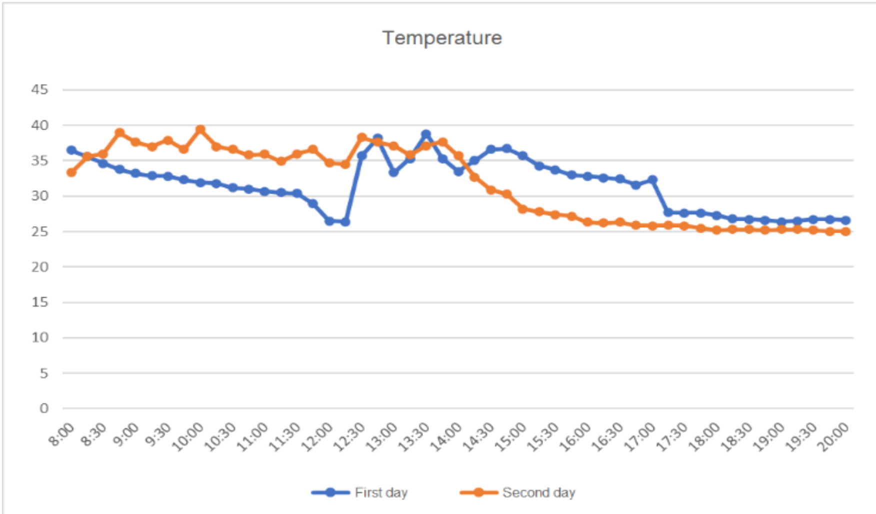

Figure 11. Two-day room temperature monitoring.

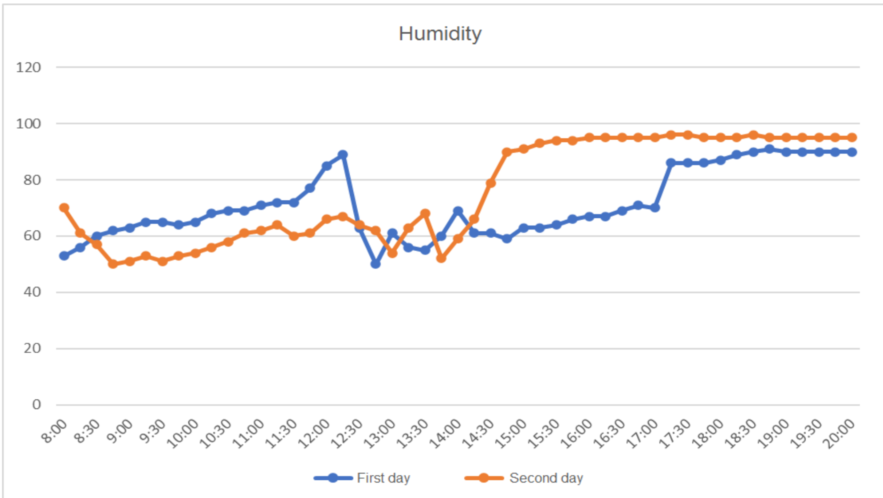

Figure 12. Two-day room humidity monitoring.

The two-day field evaluation shows that the monitoring system functions well. Unfortunately, we are not permitted by the Vitaponik owner to change the conditions in the hydroponic field. Even so, this system can help users or hydroponic owners monitor their hydroponic field and be aware of what needs to be changed to normalize the condition based on the real-time warning from the application. Figure 13 shows the WhatsApp notification that matches the information in the online application. The WhatsApp notification is set to be sent every 15 minutes.

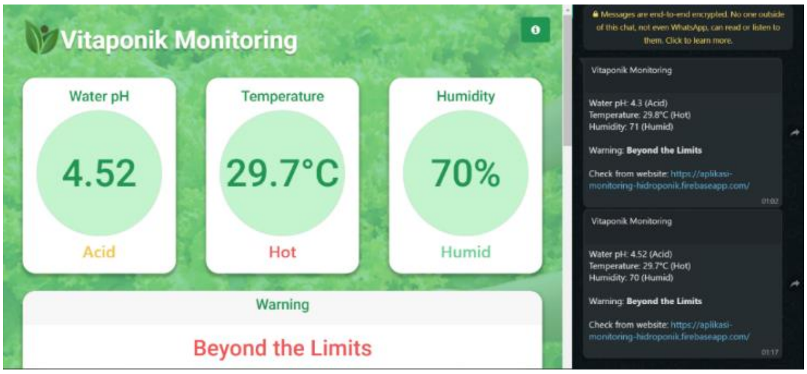

Figure 13. WhatsApp message notification content and online application.

6. Conclusions

This paper designs and implements a low-cost IoT-based hydroponic monitoring system that can help users determine the pH level of water, temperature, and humidity of the hydroponic field. This system can minimize users' work to check the conditions directly and repeatedly by allowing users to monitor the conditions via an online application in real-time and receive WhatsApp notification messages. The system consists of a sensor device built using only a pH Detection Detector (Pride and Module) sensor, a DHT22 Temperature and Humidity sensor, and NodeMCU ESP8266. The online application processes the gathered sensor data using the Mamdani Fuzzy Logic algorithm to produce output regarding the conditions of the hydroponic field, i.e., normal or beyond the limits.

Before the system is tested in a real hydroponic field, several evaluations have been carried out to validate the performance of the system, including sensor accuracy evaluation with manual measuring tools, comparison with results from the manual calculation, comparison with results from Matlab, and all conditions evaluation based on the 18 rules. The system can provide information about water pH levels, room temperature, and humidity in the two-day field evaluation. The system can also display warning results in real-time via an online application and send notifications in the form of messages via WhatsApp. The system can help hydroponic owners minimize repetitive checking and help them to be aware of things that need to be added or changed to their hydroponic fields.

The following are some suggestions for future works. Firstly, one can deploy more than one sensor device to compare sensor readings in several different places in the same hydroponic field. Secondly, one can use this monitoring system on different types of hydroponics, such as the wick system or the Nutrient Film Technique (NFT) system. Thirdly, this system can be developed into an automatic system that can neutralize conditions in the field by changing the measured parameter values. For example, by using pH up and down fluids to stabilize the pH value of water and using air conditioning to lower the room temperature.

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