Intelligent System Design for Oyster Mushroom Cultivation Using Mamdani Fuzzy Inference with Internet of Things (IoT)

Sony Panca Budiarto
Department of Informatics Engineering, PGRI Banyuwangi College of Computer Science, Banyuwangi, Indonesia

Arif Hadi Sumitro
Department of Informatics Engineering, PGRI Banyuwangi College of Computer Science, Banyuwangi, Indonesia

M. Taufiq
Department of Informatics Management, PGRI Banyuwangi College of Computer Science, Banyuwangi, Indonesia

Abstract: Oyster mushroom (Pleurotus ostreatus) has great potential in agricultural development with increasing global market demand. This research develops an intelligent cultivation system based on Mamdani fuzzy and IoT to control air temperature, air humidity, and soil moisture automatically and in real-time, using DHT22 sensor, resistive soil moisture sensor, and ESP32 as microcontroller. The test results show a high level of accuracy, with an average sensor error of 1% for air temperature, 3.8% for air humidity, and 9.3% for soil moisture. The validation of watering, humidification, and fan prediction times compared to MATLAB calculations is excellent, with MAPE values of 1.52%, 1.43%, and 1.43%, respectively. This system offers a more accurate and responsive automated solution compared to conventional cultivation management. Further testing on actual oyster mushroom farms is required to determine whether the system can adapt to varying environmental conditions. The system relies heavily on a stable internet connection to optimally perform the real-time Mamdani fuzzy calculation function.

Keywords: Intelligent System, Internet of Things, Mamdani Fuzzy, MATLAB, Oyster Mushroom.

Introduction

Oyster mushroom (Pleurotus ostreatus) is a commodity that has great development potential and high nutritional value. Due to its high content of bioactive compounds, the mushroom has

Correspondents Author:
Sony Panca Budiarto, Department of Informatics Engineering, PGRI Banyuwangi College of Computer Science, Indonesia
Email : sonystikombanyuwangi@gmail.com

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different activities and properties such as antibacterial, antifungal, antimicrobial, antioxidant, anti-inflammatory, anticancer, and prebiotic activities (Sganzerla et al., 2022). The growing demand in the global market provides an opportunity to increase oyster mushroom production (Aditya et al., 2024) . However, there is a major challenge in oyster mushroom cultivation which is the management of environmental conditions that are highly influenced by factors such as temperature, air humidity, and soil moisture. In conventional oyster mushroom cultivation, to maintain temperature, air humidity and soil moisture, water is sprayed twice a day in the morning and evening (Setiawan et al., 2021). This is less effective because the temperature and humidity of the oyster mushroom cultivation environment is unstable and takes a lot of time and energy for oyster mushroom farmers. Seeing these challenges, this research focuses on increasing the efficiency of management and productivity of oyster mushroom cultivation by applying fuzzy Mamdani method based on the Internet of Things (IoT).

There is research that reveals that Internet of Things (IoT) technology has great potential to support smart and sustainable agriculture by enabling real-time monitoring and control of plant growth environments (Xu et al., 2022) . Smart farming, now part of agriculture 4.0, harnesses the power of digitisation to improve farm management (Karunathilake et al., 2023). The application of the Mamdani fuzzy inference system method for IoT-based rice growth prediction can be a strong foundation for the development of similar technologies in other agricultural fields (Yunan & Kurniadi, 2021). IoT can improve sensing, monitoring of production, agricultural resources, and crop growth (Abu et al., 2022) . Smart farming system for mushroom cultivation by introducing the use of information and communication technology (ICT) and Arduino IoT platform (Walter et al., 2017) and for sustainable agriculture, saving resources and increasing farming efficiency and yield through remote monitoring and management (Zhu & Shang, 2022). Development of temperature and humidity prototype in oyster mushroom using fuzzy logic controller (Najmurrokhman et al., 2019) . Designing a device to help mould development, the system works by using temperature and humidity sensors (Cruz-del Amen & Flores Villaverde, 2019) . The application of the fuzzy Mamdani method on the tool can control temperature in the range of 25 ° C to 28 ° C and air humidity in the range of 87% to 90% (Dani et al., 2022) .

In the previous 3 studies, there were 2 input parameters monitored, namely air temperature and air humidity, in this study we used 3 monitored parameters, namely stable air temperature in the temperature range of 20-26° C (Abbasi et al., 2022; Sharma et al., 2018) , air humidity in the range of 60-95% (Elewi et al., 2024) and soil moisture of 50-65% is in the medium category (25% to 70%) which is suitable for various stages of oyster mushroom development (Irwanto et al., 2024). The purpose of monitoring soil moisture is to keep the soil moisture consistent, not too dry or too wet. Humid and wet soil conditions will grow oyster mushrooms faster (Hanson et al., 2000; Kencanawati et al., 2016; Safitri & Munthe, 2022). Good soil moisture supports mycelial growth and provides the necessary water for the metabolic processes of the fungus.

The superiority of problem solving offered in this research is the use of the Fuzzy Inference System (FIS) Mamdani Method based on the Internet of Things which is adapted to the oyster mushroom cultivation environment. The system made can make the right control decisions, based on the conditions of air temperature, air humidity and soil moisture to activate watering, humidification and fans in order to get the ideal oyster mushroom growth cultivation environment conditions. The fuzzy Mamdani method was chosen because in research with the title "Comparative Analysis of Fuzzy Inference Tsukamoto Mamdani and Sugeno in the Horticulture Export Selling Price" revealed the Mamdani method has a greater level of accuracy compared to the Tsukamoto method and the Sugeno method (Napitupulu et al., 2020). With the above background, this research aims to design an intelligent oyster mushroom cultivation system using Mamdani fuzzy inference with the internet of things (IoT) that can perform automatic control to activate watering, humidification and fans. Oyster mushroom farmers can monitor and manage oyster mushroom environmental conditions remotely using a smartphone.

Research Method

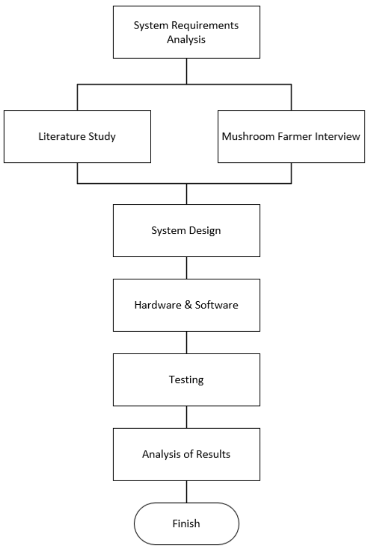

Figure 1 Block Diagram of Research Flow

Steps in carrying out research on Intelligent System Design for Oyster Mushroom Cultivation Using Mamdani Fuzzy Inference with Internet of Things (IoT).

1. System Requirement Analysis

Conduct observations and interviews with oyster mushroom farmers and study matters related to the theory that is relevant and supports the planning and design of the system. Books or journals related to fuzzy Mamdani method, DHT22 sensor module, soil moisture sensor, ESP32, temperature data control system, air humidity and soil moisture using android.

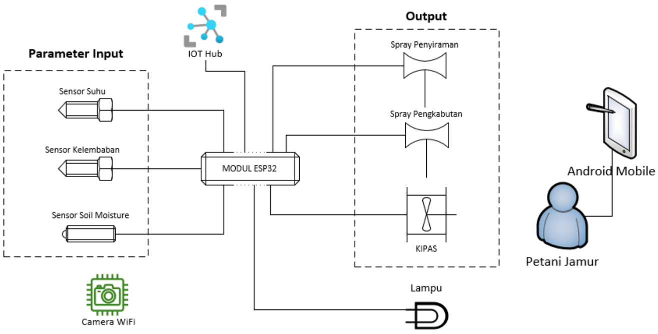

Figure 2 System Design

Figure 2 explains the intelligent system design of oyster mushroom cultivation using Mamdani fuzzy inference with the internet of things (IoT), how data acquisition from air temperature, air humidity and soil moisture sensors. Input values from air temperature, air humidity and soil moisture sensors are then processed using Mamdani fuzzy inference on the ESP32 microcontroller. The DHT22 sensor input device is useful for detecting air temperature and humidity (Yulizar et al., 2023) Meanwhile, the soil moisture sensor is useful for detecting soil moisture in the oyster mushroom growth environment (Chowdhury et al., 2022).

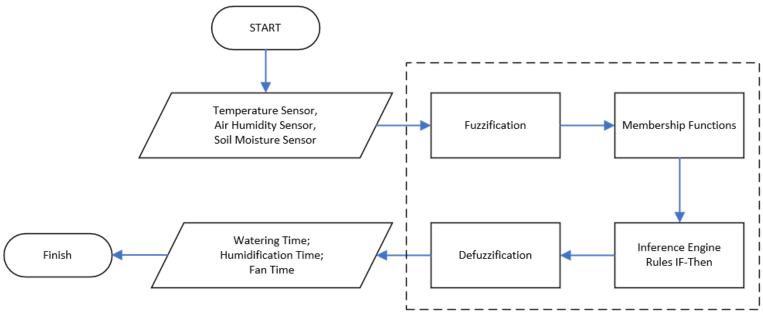

Figure 3 Software Design of Fuzzy Logic Flow

A fuzzy logic control system is developed with the help of four blocks. The first block is fuzzification, which converts crisp input values into fuzzy values by assigning membership degrees to the inputs. Then, the second block is the inference engine that infers the fuzzy result from the fuzzified input based on the if-then rule block. An if-then rule is a rule base that contains all relevant input and output combinations designed by the user to show the mathematical relationship between them (Espitia et al., 2019; Li & Gong, 2019; Singh et al., 2022). Based on the membership function, the fuzzified input and output are distributed into different sets. The controller provides a crisp output derived from the fuzzy output generated by the inference engine. To activate watering, humidification and fans is determined from the defuzzification calculation results. Figure 3 shows a general fuzzy logic-based control system in block diagram form. Fuzzy belongs to the category of intelligent control systems (Arafat & Weiwei, 2023) . The process flow of the fuzzy logic software system design as shown in Figure 3 is carried out on the ESP32, the input and output data of the system is sent in real time to google spreadsheets.

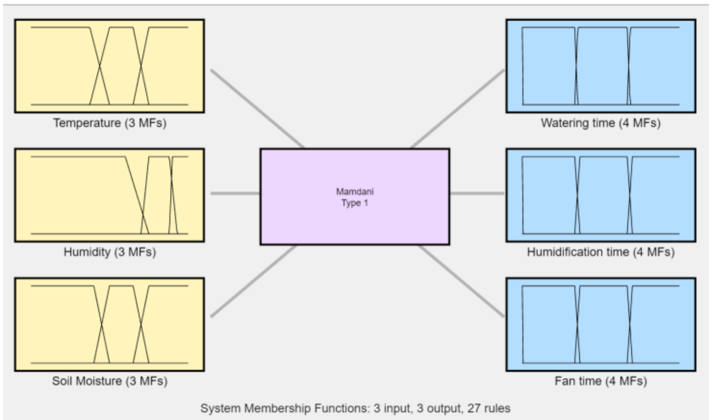

Figure 4 System Inference Fuzzy

In this study MATLAB was used to design the membership function of the Mamdani method of oyster mushroom FIS, as shown in Figure 4 fuzzy inference system developed with MATLAB. In this study we used 3 input variables namely air temperature, air humidity, soil moisture. The output of watering time, humidification time, fan time is controlled based on fuzzy rules defined in MATLAB fuzzy rule base there are 27 fuzzy rule rules.

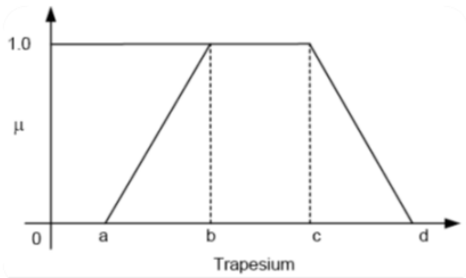

Figure 5 Trapezoidal Curve Representation

Each of the input and output variables is defined with the help of a trapezoidal membership function. The trapezoidal fuzzy membership function was chosen because there are some points that have a membership value of 1 (Wirawan, 2017) As shown in Figure 5, the representation of a trapezoidal curve.

Membership function as in (1)

$$\text{Trapezoid (x, a, b, c, d)} = \begin{Bmatrix} 0; \ x \leq a \\ \frac{x-a}{b-a}; \ a \leq x \leq b \\ 1; \ b \leq x \leq c \\ \frac{d-x}{d-c}; c \leq x \leq d \\ 0; \ x \geq d \end{Bmatrix} \quad (1)$$

The input membership functions of air temperature, air humidity, and soil moisture are obtained based on data from observations and interviews and combined with references from books and research journals. In this research, the ideal conditions of the planned oyster mushroom barn are air temperature 20-26° C (Abbasi et al., 2022; Sharma et al., 2018), air humidity 75-88% (Elewi et al., 2024) and soil moisture 50-65% (Irwanto et al., 2024).

1. Air Temperature

   The input variable air temperature is defined with the help of three linguistic variables namely low, normal and hot, as shown in figure 6. The value range is 0-40°C to indicate the air temperature in degrees Celsius. The membership function parameters are as follows:

   - Low trapezoidal membership function with parameters [0 0 15 20]
   - Normal trapezoidal membership function with parameters [15 20 26 30]
   - Hot trapezoidal membership function with parameters [26 30 40 40]

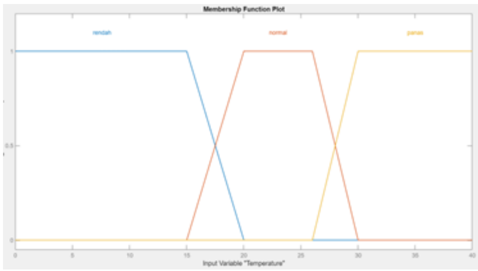

Figure 6 Variable Temperature (20-26^{0}C)

2. Air Humidity

   The input variable air humidity is defined with the help of three linguistic variables namely dry, normal and humid, as shown in figure 7. The value range is 0-100 to indicate the percentage of moisture content in the air. The membership function parameters are as follows:

   - Dry trapezoidal membership function with parameters [0 0 60 75]
   - Normal trapezoidal membership function with parameters [15 20 26 30]
   - Humid trapezoidal membership function with parameters [70 75 88 93]

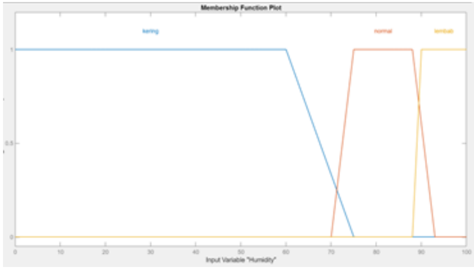

Figure 7 Air Humidity Variable (75-88%)

3. Soil Moisture

   The input variable soil moisture is defined with the help of three linguistic variables namely dry, normal and moist, as shown in figure 8. The value range is 0-100 to indicate the percentage of moisture content in the soil. The membership function parameters are as follows:

   - Dry trapezoidal membership function with parameters [0 0 40 50]
   - Normal trapezoidal membership function with parameters [40 50 65 75]
   - Moist trapezoidal membership function with parameters [65 75 100 100]

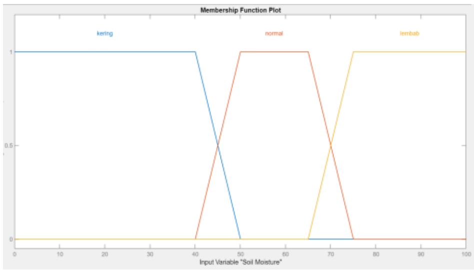

Figure 8 Planned soil moisture (50-65%)

Output membership functions of watering time, dabbing time and fan time

4. Watering Time

   The output variable watering time is defined with the help of four linguistic variables namely short, medium, long and stop, as shown in figure 9. The value range is 0-156 to indicate the length of time in seconds. The membership function parameters are as follows:

   - Short trapezoidal membership function with parameters [0 0 52 55]
   - Medium trapezoidal membership function with parameters [52 55 104 107]
   - Old trapezoidal membership function with parameters [104 107 156]
   - Stopped trapezoidal membership function with parameters [0 0 0 0]

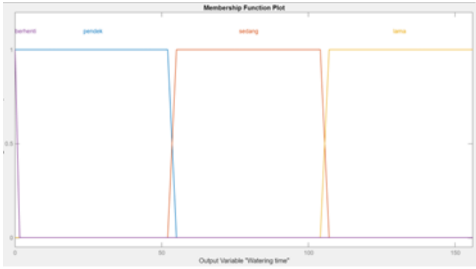

Figure 9 Variable Watering Time (156 seconds)

5. Humidification Time

The humidification time output variable is defined with the help of four linguistic variables namely short, medium, long and stop, as shown in figure 10. The value range is 0-150 to indicate the length of time in seconds. The membership function parameters are as follows:

- Short trapezoidal membership function with parameters [0 0 50 55]
- Medium trapezoidal membership function with parameters [50 55 100 105]
- Old trapezoidal membership function with parameters [100 105 150 150]
- Stopped trapezoidal membership function with parameters [0 0 0 0]

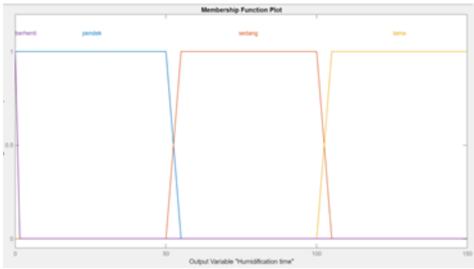

Figure 10 Variable humidification time (150 seconds)

6. Fan Time

The fan time output variable is defined with the help of four linguistic variables namely short, medium, long and stop, as shown in figure 11. The value range is 0-150 to indicate the length of time in seconds. The membership function parameters are as follows:

- Short trapezoidal membership function with parameters [0 0 50 55]
- Medium trapezoidal membership function with parameters [50 55 100 105]
- Old trapezoidal membership function with parameters [100 105 150 150]
- Stopped trapezoidal membership function with parameters [0 0 0 0]

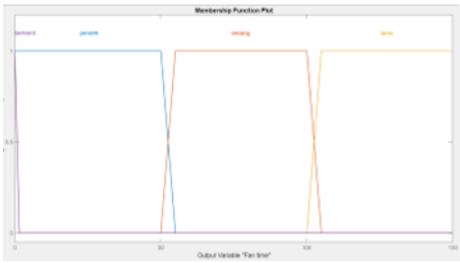

Figure 11 Variable Fan Time (150 seconds)

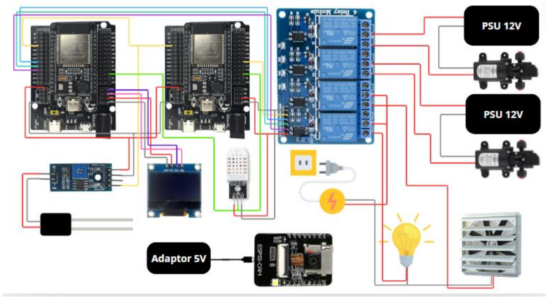

Figure 12 Hardware design intelligent oyster mushroom cultivation system using Mamdani fuzzy inference with internet of things (IoT)

The system is designed using 2 ESP32s that are assembled in parallel. The first ESP32 is used as data communication from the sensor to the blynk application and for the process of monitoring data on air temperature, air humidity and soil moisture as well as for ON/OFF lights. The second ESP32 is used to perform the fuzzification process, the output of which activates the relay to turn on the watering pump, humidification pump and fan. ESP 32 WiFi Camera is useful to control and supervise the oyster mushroom barn. The air temperature and humidity sensor uses DHT22 because it has a high level of accuracy with a relatively small error rate (Irwanto et al., 2024). The soil moisture sensor uses a resistive soil moisture type because it is proven to fulfil a fairly high accuracy to a certain extent (Kandwal et al., 2021) .

In this study, testing was carried out on a limited scale to determine the level of time accuracy generated by the system. Testing is done by comparing the time value generated by the Oyster Mushroom Cultivation Smart System tool using Mamdani Fuzzy Inference and Internet of Things (IoT) with the calculation results from MATLAB. Data is validated using Mean Absolute Percentage Error (MAPE). MAPE is one of the most popular measures of prediction accuracy (Kim & Kim, 2016). MAPE shows the prediction accuracy in percentage, with the following formula 2:

$$MAPE = \frac{\sum_{i}^{n} \frac{|Xi - Fi|}{Xi} x\ 100\%}{n} \quad (2)$$

With: Xi = actual value of period i, Fi = forecast value for period i, n = Number of periods

Table 1 Classification of MAPE Calculation Results

MAPE Value	Category
MAPE < 10%	Very Good
MAPE 10-20%	Good
MAPE 20-50%	Feasible
MAPE > 50%	Bad

Result and Discussion

In this research, the tests carried out are tool testing and system testing. Tool testing is done to test whether all components can function normally. System testing is carried out to test the accuracy of the calculation of fuzzy Mamdani time for watering, humidification time and fan time. Testing of tools and systems is carried out in a prototype oyster mushroom barn, as shown in Figure 13.

Figure 13 Oyster Mushroom Barn Prototype

1. Tool testing

Testing the data communication from the sensor to the blynk application in the process of monitoring data on air temperature, air humidity and soil moisture as well as for ON/OFF lights.

a. DHT22 sensor testing

The test was carried out by placing the DHT22 sensor and HCT hygrometer measuring instrument on the oyster mushroom barn prototype. This test aims to see the accuracy of the sensor in reading the air temperature and humidity values.

Table 2 Air Temperature Testing

No	Temperature		Delta	Error
	DHT22	Hygrometer HTC		
1	30	30	0	0,0
2	29,6	29,7	0,1	0,3
3	27,9	28,1	0,2	0,7
4	26,5	26,6	0,1	0,4
5	25,4	25,7	0,3	1,2
6	24,2	24,2	0	0,0
7	23,4	23,8	0,4	1,7
8	22,1	22,1	0	0,0

9	20,2	20,6	0,4	1,9
10	19,3	20	0,7	3,5
Mean Error				1,0

Table 3 Air Humidity Testing

No	Humidity		Delta	Error
	DHT22	Hygrometer HTC		
1	92,6	89	3,6	4,0
2	88,2	84	4,2	5,0
3	70,6	66	4,6	7,0
4	70,1	66	4,1	6,2
5	82,6	80	2,6	3,2
6	89,8	87	2,8	3,2
7	97,5	95	2,5	2,6
8	99	96	3	3,1
9	99	97	2	2,1
10	99,9	98	1,9	1,9
Mean Error				3,8%

Based on the results of testing the air temperature sensor with a HTC hygrometer, the average error is 1%, which is relatively small as reported in (Liu, n.d.; Rahman et al., 2023). The error can be caused by the sensitivity of the sensor and is still within the DHT22 error tolerance limit (±5° C). (Liu, n.d). The test results of the air humidity sensor obtained an average error of 3.8%. The highest error value obtained is 2%. According to the sensor datasheet, the humidity value is still within the DHT22 error tolerance limit (MAX ± 5%RH). So, the sensor still works well to be implemented into the system.

b. Soil Moisture Sensor Testing

The sensor is plugged into the soil which was originally dry then given water little by little in the prototype oyster mushroom barn.

Table 4 Soil Moisture Testing

No	Soil Moisture		Delta	Error
	Resistive soil Moisture sensor	3 in 1 Soil Moisture Meter		
1	54	50	4	8,0
2	52	49	3	6,1
3	50	47	3	6,4
4	47	42	5	11,9
5	46	40	6	15,0
6	44	41	3	7,3
7	38	33	5	15,2
8	38	34	4	11,8

9	20	18	2	11,1
10	12	12	0	0,0
Mean Error				9,3%

The test results of the soil moisture sensor compared to the 3 in 1 soil meter have an average error value of 9.3%. This sensor is proven to be able to fulfil a fairly high accuracy to a certain extent (Kandwal et al., 2021).

2. System Testing

Testing to determine the performance of fuzzy Mamdani inference with internet of things (IoT) in predicting watering time, humidification time and fan time. Testing is done by comparing the data in table 5sensor input data and fuzzy Mamdani output from google spreadsheets with the calculated data from MATLAB. with the calculation result data from MATLAB.

Table 5 Display of Mamdani fuzzy data on google spreadsheets

No	Time	Temperature (°C)	Humidity (%)	Soil Moisture (%)	Watering (Second)	Humidification (Second)	Fan (Second)
1	11:38:38	27.10	83.60	56.00	75.81	73.87	73.87
2	11:40:04	27.00	83.90	58.00	75.33	73.40	73.40
3	11:41:28	26.80	84.40	56.00	74.05	72.16	72.16
4	11:42:52	27.90	84.20	58.00	77.89	75.91	75.91
5	11:44:19	29.00	80.40	57.00	79.00	77.00	77.00
6	11:45:47	29.30	76.80	57.00	79.18	77.18	77.18
7	11:47:16	28.80	74.00	58.00	83.11	80.74	80.74
8	11:48:48	27.70	77.10	58.00	77.55	75.57	75.57
9	11:50:15	27.00	78.70	57.00	75.33	73.40	73.40
10	11:51:41	26.20	82.60	55.00	59.05	57.53	57.53
11	11:52:49	25.80	83.80	58.00	0.00	0.00	0.00
12	11:52:59	25.60	84.40	58.00	0.00	0.00	0.00
13	11:53:09	25.70	85.10	57.00	0.00	0.00	0.00
14	11:53:18	25.70	85.20	58.00	0.00	0.00	0.00
15	11:53:28	25.60	86.10	58.00	0.00	0.00	0.00
16	11:53:37	25.40	86.30	58.00	0.00	0.00	0.00
17	11:53:47	25.50	86.20	58.00	0.00	0.00	0.00
18	11:53:56	25.40	86.10	58.00	0.00	0.00	0.00
19	11:54:06	25.40	86.90	58.00	0.00	0.00	0.00
20	11:54:15	25.40	87.70	58.00	0.00	0.00	0.00

The test results of fuzzy Mamdani calculations by the system show that the system performs fuzzy Mamdani calculations every 10 seconds when the watering, humidification and fan conditions are inactive then uploads the data to google spreadsheets, as shown in table 5.

Table 6 Fuzzy Mamdani Testing of Watering Time.

No	Sensor Input			Watering Time (seconds)		
	Temperature (°C)	Humidity (%)	Soil Moisture (%)	Watering (Seconds)	MATLAB	Error (%)
1	27.10	83,6	56	75,81	74	2,45
2	27	83,9	58	75,33	73,3	2,77
3	26,8	84,4	56	74,05	71,4	3,71
4	27,9	84,2	58	77,89	77	1,16
5	29	80,4	57	79	78	1,28
6	29,3	76,8	57	79,18	79	0,23
7	28,8	74	58	83,11	82,9	0,25
8	27,7	77,1	58	77,55	76,5	1,37
9	27	78,7	57	75,33	73,3	2,77
10	26,2	82,6	55	59,05	51,6	14,44
11	25,8	83,8	58	0	0	0
12	25,6	84,4	58	0	0	0
13	25,7	85,1	57	0	0	0
14	25,7	85,2	58	0	0	0
15	25,6	86,1	58	0	0	0
16	25,4	86,3	58	0	0	0
17	25,5	86,2	58	0	0	0
18	25,4	86,1	58	0	0	0
19	25,4	86,9	58	0	0	0
20	25,4	87,7	58	0	0	0
Mean Error (%)						1,52%

Table 7 Fuzzy Mamdani Testing of Humidification Time.

No	Sensor Input			Humidification Time (Seconds)		
	Temperature (°C)	Humidity (%)	Soil Moisture (%)	Humidification (Seconds)	MATLAB	Error (%)
1	27.10	83,6	56	73,87	72,2	2,31
2	27	83,9	58	73,4	71,4	2,80
3	26,8	84,4	56	72,16	69,5	3,83
4	27,9	84,2	58	75,91	75	1,21
5	29	80,4	57	77	77	0,00
6	29,3	76,8	57	77,18	77	0,23
7	28,8	74	58	80,74	80,5	0,30
8	27,7	77,1	58	75,57	74,5	1,44
9	27	78,7	57	73,4	71,4	2,80
10	26,2	82,6	55	57,53	50,6	13,70
11	25,8	83,8	58	0	0	0
12	25,6	84,4	58	0	0	0
13	25,7	85,1	57	0	0	0
14	25,7	85,2	58	0	0	0
15	25,6	86,1	58	0	0	0
16	25,4	86,3	58	0	0	0

17	25,5	86,2	58	0	0	0
18	25,4	86,1	58	0	0	0
19	25,4	86,9	58	0	0	0
20	25,4	87,7	58	0	0	0
Mean Error (%)						1,43%

Table 8 Fuzzy Mamdani Testing of Fan Time.

No	Sensor Input			Fan Time (Seconds)		
	Temperature (°C)	Humidity (%)	Soil Moisture (%)	Fan (Seconds)	MATLAB	Error (%)
1	27.10	83,6	56	73,87	72,2	2,31
2	27	83,9	58	73,4	71,4	2,80
3	26,8	84,4	56	72,16	69,5	3,83
4	27,9	84,2	58	75,91	75	1,21
5	29	80,4	57	77	77	0,00
6	29,3	76,8	57	77,18	77	0,23
7	28,8	74	58	80,74	80,5	0,30
8	27,7	77,1	58	75,57	74,5	1,44
9	27	78,7	57	73,4	71,4	2,80
10	26,2	82,6	55	57,53	50,6	13,70
11	25,8	83,8	58	0	0	0
12	25,6	84,4	58	0	0	0
13	25,7	85,1	57	0	0	0
14	25,7	85,2	58	0	0	0
15	25,6	86,1	58	0	0	0
16	25,4	86,3	58	0	0	0
17	25,5	86,2	58	0	0	0
18	25,4	86,1	58	0	0	0
19	25,4	86,9	58	0	0	0
20	25,4	87,7	58	0	0	0
Mean Error (%)						1,43%

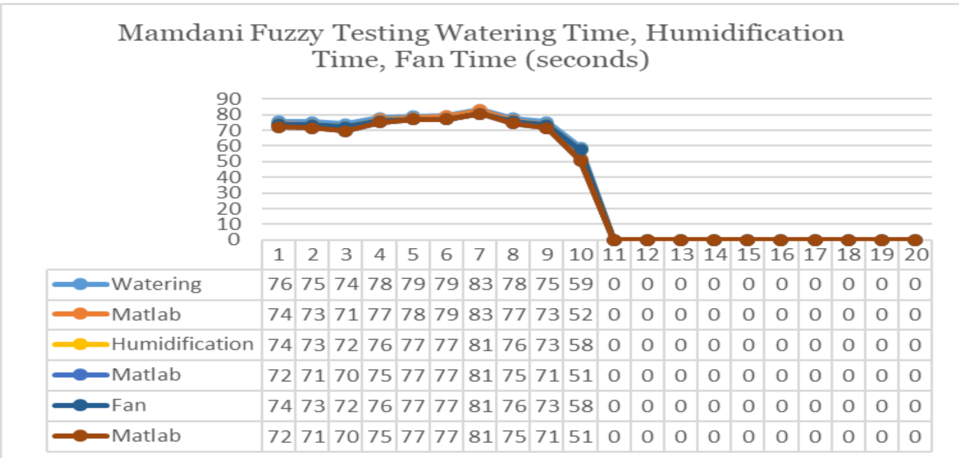

Figure 14 Graph of Fuzzy Mamdani Output Testing Results Watering Time, Humidification Time and Fan Time on the tool compared to the output value of MATLAB

From 20 times testing the input data of air temperature, air humidity and soil moisture sensors, the results of the accuracy of the system watering time compared to MATLAB with an average error of 1.52% are shown in Table 6. The results of testing the accuracy of the system humidification time compared to MATLAB obtained an average error of 1.43% shown in Table 7. The results of testing the accuracy of the system fan time compared to MATLAB obtained an average error of 1.43% shown in Table 8.

Calculation of Validation and Accuracy with MAPE:

Watering
MAPE:=((2,45%+2,77%+3,71%+1,16%+1,28%+0,23%+0,25%+1,37%+2,77%+14,44%+0%+0%+0%+0%+0%+0%+0%+0%+0%+0%)/20) x100% = 1.52%

MAPE of Humidification:

=((2,31%+2,8%+3,83%+1,21%+0%+0,23%+0,30%+1,44%+2,80%+13,70%+0%+0%+0%+0%+0%+0%+0%+0%+0%+0%)/20) x100% = 1.43%

MAPE of Fan:

=((2,31%+2,8%+3,83%+1,21%+0%+0,23%+0,30%+1,44%+2,80%+13,70%+0%+0%+0%+0%+0%+0%+0%+0%+0%+0%)/20) x100% = 1.43%

MAPE validation and accuracy results for watering time 1.52%, humidification time 1.43% and fan 1.43%. Based on Table 1 - the classification of the MAPE calculation results is included in the Very Good category.

Conclusions

The intelligent oyster mushroom cultivation system using Mamdani fuzzy inference with internet of things (IoT) designed was successfully realised and showed great potential in improving the efficiency of environmental control of oyster mushroom cultivation. The results of testing the accuracy of air temperature and air humidity sensors obtained an average air temperature error of 1%, an average air humidity error of 3.8%. The soil moisture sensor test results have an average error value of 9.3%. This sensor is proven to be able to fulfil high accuracy to a certain extent. With real-time measurements, the system offers a more accurate and responsive automated solution compared to conventional cultivation management. The results of MAPE validation testing the accuracy of predicting watering time, humidification time and fan time from the system compared to the results of MATLAB calculations are included in the Very Good category. The use of IoT technology combined with fuzzy logic can be an important foundation for the development of automation systems in the oyster mushroom farming sector. The limitation of this research is that testing is carried out on a limited scale within the scope of the oyster mushroom farm prototype. This system relies heavily on a stable internet connection to optimally perform the real-time Mamdani fuzzy calculation function. Suggestions for future research include testing on actual oyster mushroom barns to determine whether the system can adapt to varying environmental conditions. If you do not need real-time data from Mamdani fuzzy results to be analysed centrally, the use of internet connections on ESP32 spreadsheets can be eliminated, this allows the system to continue to run effectively in controlling environmental conditions without dependence on internet connections.

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