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Application of Fuzzy Logic for Android-Based Tempeh Fermentation Process Control and Monitoring

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ABSTRACT

Tempeh is a highly nutritious food source that is widely consumed by people every day. Tempeh artisans, such as those in Jatisari Village, produce quality tempeh through an optimal fermentation process. The ideal fermentation process takes place at a temperature of 30°C–35°C, a humidity of 65%–72%, and an ammonia gas content of 43–50 ppm, with a fermentation time of about 18 hours to produce cooked tempeh. To improve the efficiency and quality of the fermentation process, a tool that is able to control and monitor the condition of the fermentation chamber is needed automatically. This research develops a tempeh fermentation control and monitoring system using a NodeMCU microcontroller, relay, VNH2SP30, DHT11 sensor, and MQ-137 sensor, which are integrated with fuzzy logic. This system controls the incandescent lamp as a heater and the peltier as a cooler in the fermentation container compartment. Control and monitoring results are displayed in real-time via LCD and Android app, with the successful fermentation time shortened to 16 hours.

Introduction

Tempeh is one of the highly nutritious food sources that is widely consumed because of its affordable price. Tempeh is made from the main ingredient in the form of soybean seeds, equipped with ingredients to support the fermentation process, such as Rhizopus oligosporus mold, Rh. oryzae, Rh. stolonifer (bread mold), or Rh. Arrhizus (Djunaidi, Purwanto, Ningrum, Jatnika, & Kabidoyo, 2020)Tapai Ripeness Monitoring Application Using Fuzzy Tahani Method. The fermentation process is an important part of producing quality tempeh, and many tempeh artisans, including in Jatisari Village, strive to produce good products for consumption (Faqih & Miharja, 2024). The tempeh fermentation process is one of the important stages in tempeh making that determines the final quality of the product. This process requires careful control of temperature, humidity, and ammonia gas levels in order to produce high-quality tempeh. In general, fermentation of tempeh takes about 18 hours to reach a state ready for consumption. However, the success of fermentation is greatly influenced by the stability of these environmental parameters (Arifwidodo, Oktavian, & Ginting, 2022). The optimum temperature for fermentation of tempeh ranges from 30°C to 35°C, with an ideal humidity level between 65% to 72%. In addition, the level of ammonia gas produced during the fermentation process must be in the range of 43 to 50 ppm. Inaccuracies in controlling these parameters can cause fermentation to run suboptimally, thus affecting the quality, texture, taste, and nutritional value of tempeh (Mahali, 2016).

The need for equipment capable of automatically controlling and monitoring the fermentation process is very relevant. This kind of device not only helps to keep the fermentation environmental parameters within the ideal range, but also improves the efficiency of the tempeh production process. In this context, the use of fuzzy logic can be one of the innovative solutions (Said, Damanik, Yusri, Sofi, & Purnomo, 2024). Fuzzy logic is an intelligent control method that is able to handle variability and uncertainty in the system, so it is suitable for being applied to controlling temperature, humidity, and ammonia gas levels in the tempeh fermentation room (Purwanto et al., 2023). With fuzzy logic, the system can make automatic adjustments to changes in environmental conditions in real-time, ensuring that fermentation parameters remain stable and in accordance with requirements.

The implementation of fuzzy logic in controlling the tempeh fermentation process requires hardware consisting of a microcontroller and various supporting sensors. Microcontrollers, such as NodeMCUs, are used as the brains of the system that manages the data from the sensors and controls the actuators. Temperature and humidity sensors, such as DHT11 or DHT22, are used to monitor environmental conditions in fermentation chambers. Meanwhile, gas sensors, such as MQ-137, serve to detect the levels of ammonia gas produced during the fermentation process (Valencia, Purnama, Tjong, & Liman, 2022). The data obtained from these sensors will be processed by the microcontroller using fuzzy logic algorithms to determine the actions that need to be taken, such as turning the incandescent lamp on or off as a heater, as well as turning the peltier on or off as a cooler (Abidin, Supriyanto, Surtono, & Suciyati, 2024).

In addition to hardware, software also plays an important role in this system. Fuzzy logic algorithms are designed to process data from sensors and generate the right decisions. For example, if the temperature in the fermentation chamber is too low, the system will increase the heating intensity by regulating the power of the incandescent lamp. Conversely, if the temperature is too high, the system will activate the peltier to cool the room. Likewise with humidity, if it is detected too low, the system can activate the humidifier to increase the humidity until it reaches the desired set-point. In the case of ammonia gas, if the gas level exceeds the specified threshold, the system can activate ventilation to reduce the concentration of gas in the fermentation chamber.

This control and monitoring system is designed to be integrated with an Android application to make it easier for users to monitor the fermentation process in real-time. Data from the sensor is transmitted to the application via a wireless connection, such as Wi-Fi, which is facilitated by the NodeMCU microcontroller. The Android app displays information about temperature, humidity, and ammonia gas levels in an easy-tounderstand graphical form, so users can monitor fermentation conditions remotely. In addition, the app can also provide notifications in case of abnormal conditions, such as excessive temperatures or ammonia gas levels that exceed safe limits, so users can immediately take the necessary action.

The advantage of this system lies not only in its ability to maintain the stability of fermentation parameters, but also in its efficiency in reducing fermentation time. Based on the results of the research, this fuzzy logic-based control system is able to cut the fermentation time from 18 hours to only 16 hours. This certainly provides significant benefits for tempeh artisans, especially in terms of productivity and production cost efficiency. With shorter fermentation times, artisans can increase production capacity without sacrificing product quality.

Method

System Planning

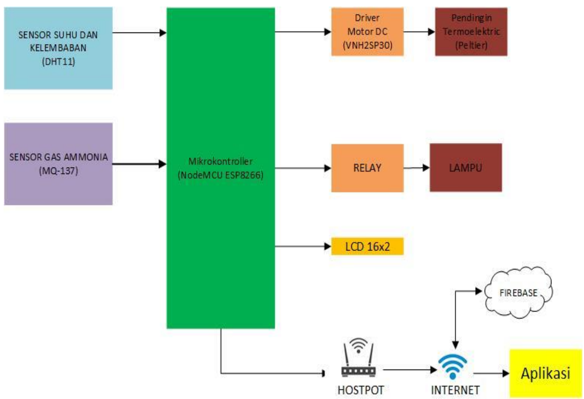

Figure 1
Block Diagram of the Whole System

Figure 1 illustrates the overall system diagram block. There is a DHT11 sensor that functions as a sensor for the temperature and humidity level of the room where the tempeh fermentation process takes place and an MQ-137 sensor as a detector for ammonia gas produced in the tempeh fermentation process. The readings from the two sensors will be processed in the microcontroller.

The microcontroller will control the DC Motor Driver VNH2SP30 and relay connected to the peltier thermoelectric cooler as well as the 5-watt lamp. The readings of temperature, humidity and ammonia gas are displayed on the LCD and the android app.

Formation of the Fuzzy Set

In the process there are 5 conditions based on fuzzy logic that are created. This fuzzy logic scheme has 3 types of member sets, namely 3 members of the input set (Temperature, Humidity, NH3 Gas Content) and 2 members of the output set (Lamp, Peltier).

Results and Discussion

1) Temperature Variable Membership Function

The first input of the temperature member set = {Cool, Normal, Hot} which has a speaker universe {0, 50} where the parameter i {0, 25, 50}. The temperature variable membership function for µCold {0, 5, 10, 15, 20, 25}, µNormal {20, 25, 30}, and for µHot {25, 30, 35, 40, 45, 50} is as shown in Figure 2.

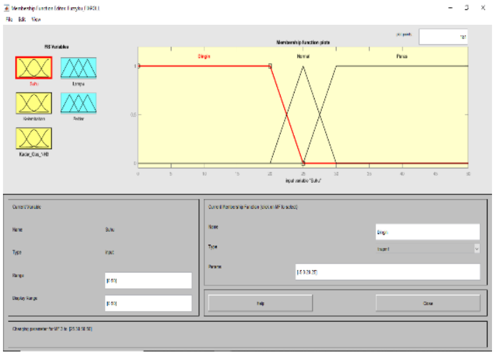

Figure 2
Temperature Variable Membership Function

Then for the interval range classification table for each set of temperature members that has been made, it is shown in table 1.

TABLE 1
CLASSIFICATION OF TEMPERATURE MEMBER SET INTERVALS

Classification	Interval
Cold	0°C – 20°C
Usual	21°C - 30°C
Hot	>30°C

2) Fungi Membership Variable Humidity

The second input of the moisture member set = {Too Dry, Ideal, Too Humid} which has a speaker universe {0 100} where the parameter i {0 50 100}. The humidity variable membership function for µ Terlalu_Kering {0, 10, 20, 30, 40, 50, 55}, µIdeal {45, 55, 65}, and µ Terlalu_Lembab {55, 60, 70, 80, 90, 100} corresponds to Figure 3.

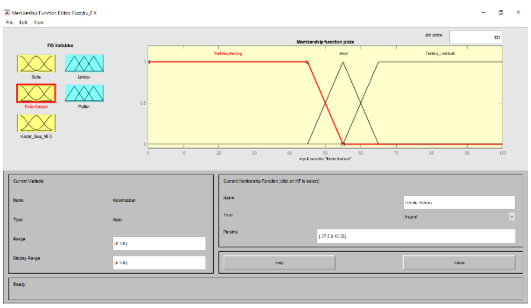

Figure 3
Humidity Variable Membership Function

Then for the interval range classification table for each set of moisture members that has been made, it is shown in table 2.

TABLE 2
CLASSIFICATION OF MOISTURE MEMBER SET INTERVAL

Classification	Interval
Too Dry	<45%
Ideal	45% - 65%
Too Moist	>65%

3) Ammonia Gas Variable Membership Function

The third input of the member set Kadar_Gas_NH3 = {Belum_Matang, Mature, Overmature} which has a speaker universe {0 100} where the parameter i {0 50 100}. The humidity variable membership function for μ Belum_Matang {0, 10, 20, 30, 40, 43}, μRipe {45, 47.5, 50}, and μ Terlalu_Matang {51, 60, 70, 80, 90, 100} corresponds to Figure 4.

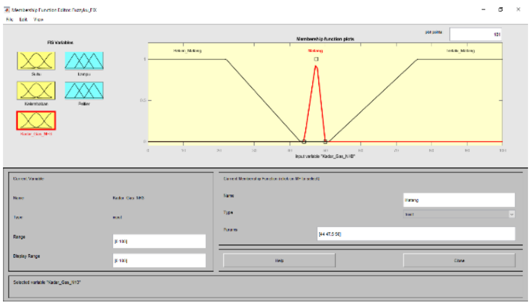

Figure 4
Ammonia Gas Variable Membership Function

Then for the interval range classification table for each member set of NH3 gas levels that have been made, it is shown in table 3.

TABLE 3
MEMBER SET INTERVAL CLASSIFICATION GAS AMMONIA

Classification	Interval
Immature	<43 ppm
Ripe	44 ppm – 50 ppm
Overripe	>51 ppm

4) Lamp Output Membership Function

After determining the membership function of each input variable, then determine the membership function of the output that functions to run the actuator, namely a 5-watt lamp and a peltier thermoelectric cooler (Guo, Li, & Li, 2019). For the first output member function, i.e. the lamp shown in figure 5.

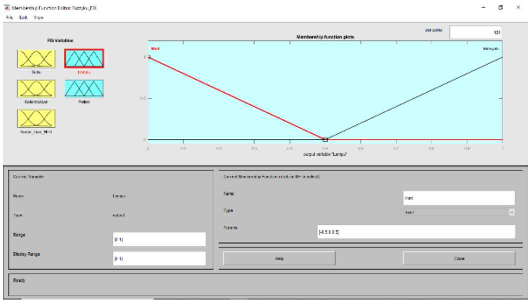

Figure 5. *Fuzzy Logic* Output Lamp Actuator

To achieve 2 output conditions as shown in Figure 5 must meet the following conditions:

1. Output Off, the light turns off when the temperature is above the set-point, which is 36°C.
2. Output On, the light turns on when the temperature is below the set-point which is <35°C.

5) Peltier Thermoelectric Cooler Output Membership Function

For the first output member function, i.e. the lamp shown in figure 6.

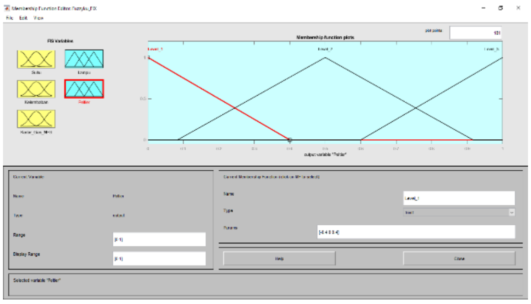

Figure 6 *Fuzzy Logic Output* Peltier Actuator

To achieve the 3 output conditions as shown in Figure 3.9 must meet the following conditions:

1. Level 1 output, Driver VNH2SP30 generates a PWM signal of 0 PWM indicating the peltier is in the off position.
2. Level 2 output, Driver VNH2SP30 generates a PWM signal of 128 PWM signaling a live peltier with a Vout of 6V.
3. Level 3 Output, Driver VNH2SP30 generates a PWM signal of 255 PWM indicating the peltier is in the live position with a Vout VNH2SP30 of 12V.

6) Rule Base

After the membership function is formed, each input and output variable then creates a rule base. There are 18 rules that apply to decision-making in this system according to Figure 7.

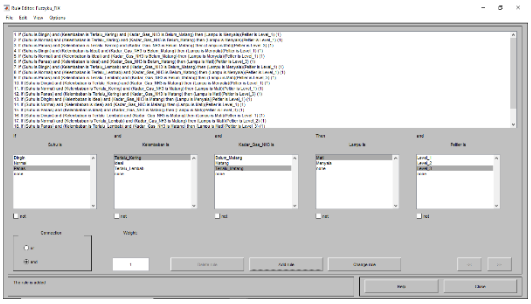

Figure 7 Rule Fuzzy Logic

The last one is a rule viewer where we can enter the input value and see the output produced.

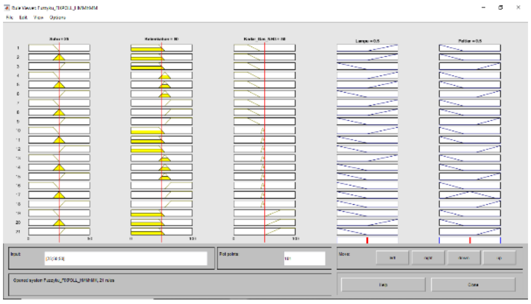

Figure 8 *Rule Fuzzy Logic*

Sensor Node Assembly

All existing components will be connected to the NodeMCU as a microcontroller. It will be assembled according to Figure 9. on the sensor *node*.

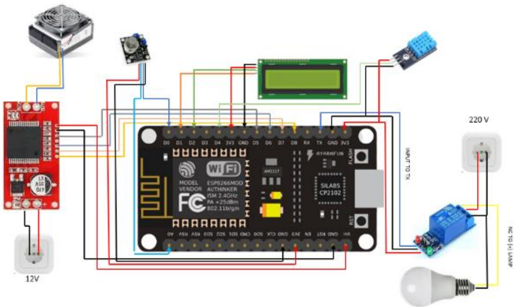

Figure 9 *Overall Tool Sensor* Node

Hardware Manufacturing Results

Figure 10 is the final result of the pre-designed hardware assembly.

Figure 10

Tempeh Fermentation Box Seen from the Inside

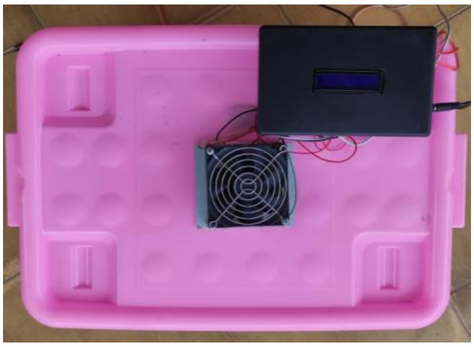

Figure 11

Tempeh Fermentation Box Top View

Software Creation Results

In this section, we explain the parts in the design of the application display on an android smartphone for the tempeh fermentation control system. The design of this android application is carried out using the 7.0 software framework.

Figure 11

App Main View

DHT11 Sensor Testing

The test of the DHTll sensor aims to find out how accurate the data results read by the DHTl1 sensor against the Hygrometer measuring instrument. Later, the output value of DHTll will affect the condition of the tempeh fermentation container box.

Figure 12
DHT11 Sensor Value Accuracy Testing

Based on the testing of the DHT11 sensor, the data that has been obtained is presented in a table as shown in the following table IV:

TABLE 4
DHT11 SENSOR ACCURACY DATA

Testing	Sensor Value (%)	Higrometer Value (%)	Error (%)
1	49%	47%	4.2
2	48%	47%	2.1
3	48%	47%	2.1
4	48%	47%	2.1
5	48%	47%	2.1
6	48%	47%	2.1
7	48%	47%	2.1
8	49%	47%	4.2
9	49%	47%	4.2
10	49%	47%	4.2
	Average		2.94

MQ-137 Sensor Testing

The MQ137 sensor test aims to find out how accurate the data results read by the MQ137 sensor against the ammonia meter measuring device. Later, the output value of MQ-137 will affect the condition of the tempeh fermentation container box.

Figure 13
MQ-137 Sensor Accuracy Testing

The data generated from the MQ-137 sensor accuracy test are presented in the form of a table as follows:

TABLE 5
MQ-137 SENSOR ACCURACY DATA

Testing To-	Test Results: Ammonia Meter (ppm)	MQ-137 (ppm)	Error (%)
1	55.9	55.7	0.44
2	56.4	55.2	0.22
3	55.5	55.3	0.44
4	55.8	55.7	0.22
5	57.2	57.3	0.21
6	55.2	55.4	0.44
7	56.2	56.1	0.22
8	61.5	61.7	0.45
9	60.6	60.5	0.2
10	56.7	56.8	0.21
	Average		0.31

Comparison of Tempeh Fermentation Test Results with Tools and Without Tools

Then after the test data was taken. Furthermore, the duration of tempeh fermentation is compared between testing with equipment with conventional or traditional tempeh fermentation. The results of the comparison are shown in table 6 as follows:

TABLE VI
COMPARATIVE DATA ON THE FERMENTATION PROCESS OF TEMPEH WITH AND WITHOUT TOOLS

NO	With Tools		No Tools	
	Hour	Information	Hour	Information
1	06.00 until 10.00 a.m.	Raw	06.00 to 06.00 10.00	Raw
2	11.00 until 20.00	Partially Grow Mold	11.00 until 10:00 p.m.	Partially Grow Mold
3	21.00 until 10:00 p.m.	Ripe	10:00 p.m. 00.00	Ripe

In table 6, the difference between fermentation results with equipment with fermentation without using equipment or traditionally. The tempeh fermentation process uses tools from 06.00 WIB to 22.00 WIB while the fermentation process without using tools is from 06.00 WIB to 00.00 WIB. So from research, the tempeh fermentation process using tools is 2 hours faster than without using tools.

Conclusion

The Mamdani fuzzy logic-based tempeh fermentation control and monitoring system integrated with the application has succeeded in increasing the efficiency of the tempeh fermentation process. With a temperature and humidity sensor reading accuracy of 97.06%, as well as an ammonia gas sensor of 99.31%, the system is able to maintain fermentation parameters according to the specified set-point. Temperature, humidity, and ammonia gas levels are regulated to produce a fermentation process that is two hours faster than conventional methods. This system not only increases the fermentation speed, but also maintains the quality of the resulting tempeh. Real-time monitoring of fermentation conditions through the application provides convenience for users. With this tool, the productivity of tempeh MSMEs can increase significantly. This technology proves the potential of fuzzy logic in the control of complex processes. In addition, the use of accurate sensors ensures the stability of the fermentation environment. This innovation opens up opportunities for the adoption of similar technologies in various other fermentation industries. This research makes a real contribution in supporting MSMEs to improve their production efficiency and quality.

Bibliography

Abidin, Ramadhani, Supriyanto, Amir, Surtono, Arif, & Suciyati, Sri Wahyu. (2024). LPG Safety Monitoring System Using Artificial Neural Network with Back Propagation Method Based on The Internet of Things (IoT). *Journal of Energy, Material, and Instrumentation Technology*, *5*(3), 100–108.

Arifwidodo, Bongga, Oktavian, Donny Arief, & Ginting, Jafaruddin Gusti Amri. (2022). The Performance Analysis of Hybrid SDN–IP Reactive Routing on ONOS Controller in Tree Topologies. *2022 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT)*, 118–122. IEEE.

Djunaidi, Karina, Purwanto, Yudhy Setyo, Ningrum, Rahma Farah, Jatnika, Hendra, & Kabidoyo, Wali Syahputro Cahoyo. (2020). Tapai Ripeness Monitoring Application Using Fuzzy Tahani Method. *Journal of Physics: Conference Series*, *1477*(5), 52019. IOP Publishing.

Faqih, Abu Rizal, & Miharja, Rediawan. (2024). Quality Management Analysis Using Seven Tools Case Study of Tinumpuk Tempe Factory. *ProBisnis: Jurnal Manajemen*, *15*(5), 831–840.

Guo, Jian, Li, Zhaojun, & Li, Meiyan. (2019). A review on prognostics methods for engineering systems. *IEEE Transactions on Reliability*, *69*(3), 1110–1129.

Mahali, Muhammad Izzuddin. (2016). Smart door locks based on internet of things concept with mobile backend as a service. *Elinvo (Electronics, Informatics, and Vocational Education)*, *1*(3), 171–181.

Purwanto, Heri, Nugraha, Rikky Wisnu, Ferdiansyah, Fahmi Reza, Dewi, Deshinta Arrova, Sofian, Rudy, & Rizaldy, Muhammad Faridh. (2023). Sustainable Smart Home IoT to Open and Close the House Fence using a Scanning Method. *International Journal of Advanced Computer Science and Applications*, *14*(10).

Said, Ade Irawan, Damanik, Tania Sephia Azzahra, Yusri, Ardhini Ramadhani, Sofi, Nurdiyana, & Purnomo, Hari. (2024). Design of an Iot Based Automatic Lawn Vacuum & Leaf Bag Using Usability and Work Posture Method. *SHS Web of Conferences*, *189*, 1003. EDP Sciences.

Valencia, Venna, Purnama, Louis Putra, Tjong, Chandra, & Liman, Johansah. (2022). Rancang Bangun Alat Pendeteksi Kebocoran Gas LPG Berbasis Internet of Things Dengan Katup Regulator Otomatis. *Techné: Jurnal Ilmiah Elektroteknika*, *21*(2), 225–242.