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Temperature and Humidity Control System for Tempeh's Fermentation Room Using Fuzzy Logic

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ABSTRACT

Tempeh is a traditional Indonesian food that requires precise temperature and humidity control during the fermentation process to produce the best quality. This research aims to design and implement an Internet of Things (IoT)-based automatic control system with the Mamdani fuzzy logic method to maintain the stability of the temperature and humidity of the tempeh's fermentation room. The system utilizes a DHT22 sensor to read temperature and humidity in real-time, with data processing on an ESP32 microcontroller to control the fan, incandescent lamp, and mist maker. Monitoring data is sent to the Firebase Realtime Database so that it can be accessed online through the MIT App Inventor application. Testing for 22–24 hours showed that the system was able to maintain a temperature of 30–32°C and humidity of 68–75% as targeted, working stably according to the designed fuzzy logic. These results prove that the system is able to function well and support the efficiency of the tempeh fermentation process

INTRODUCTION

Tempeh is one of Indonesia's traditional foods with high nutritional value. Most Indonesians consume it as part of their daily diet. Tempeh consumption is not limited to the lower classes; it is also popular among the middle and upper classes. Due to high demand, many people are taking advantage of this opportunity to produce and sell tempeh.(Andoko et al., 2020).

Indonesia is the largest soybean market in Asia and the world's largest producer of tempeh. Tempeh accounts for 50% of Indonesia's soybean consumption, 40% for tofu, and 10% for other products such as soy sauce, tauco, and others. According to 2014 National Soybean Survey (SUSENAS) data published by the Central Statistics Agency (BPS), the average Indonesian consumes approximately 6.45 kg of tempeh annually.(Alvina et al., 2019).

Tempeh is a food made from soybeans and tempeh yeast (Rhizopus Oligosporus), which undergo a fermentation process. This yeast is crucial because it is the main factor in the success of tempeh production. For optimal tempeh results, a balance between the amount of yeast and the amount of soybeans to be fermented must be maintained.(Surbakti et al., 2020).

The traditional fermentation process at one of the tempeh factories in Padang City requires 36 to 48 hours to produce optimal tempeh. Therefore, precise timing is crucial to determine when the tempeh is properly cooked. Furthermore, during the tempeh fermentation process, artisans predict the tempeh's maturity by counting the days from the start of the process.

This final project is designed to control the temperature and humidity of the fermentation chamber to keep it stable at a temperature of 27-35°C and a humidity of 60-80%RH. This range is chosen so that the device can better adapt to changes in the fermentation chamber conditions. By determining the initial setpoint value of the temperature from the range of 27-35°C and humidity in the range of 60-80%RH, it is expected that the system after testing will obtain the ideal temperature and humidity values to be used as the appropriate setpoint values for tempeh fermentation. The control system was developed by utilizing Internet of Things (IoT) technology and implementing the Mamdani fuzzy logic method to regulate the fan and light speeds. With this development, the system can make adjustments automatically and efficiently, in order to maintain the stability of the fermentation chamber process.

LITERATURE REVIEW

Tempeh

Tempeh contains various important nutrients such as protein, fiber, and vitamins, so it can be used as a source of nutrition as well as a functional food that supports body health. According to Tarwatjo (1998), every 100 g of tempeh contains 10-20 g of protein, 4 g of fat, vitamin B12, and 129 mg of calcium, but no fiber.(Supratiwi et al., 2023).

DHT-22 Sensor

DHT22 is a digital temperature and humidity sensor. The DHT22 sensor uses a capacitor and measures the surrounding air and outputs a signal on the data pin. DHT22 is claimed to have good reading quality, seen from the fast response of the data collection process and its minimal size, as well as a cheap price compared. Several studies on the implementation of temperature and humidity sensors include temperature and humidity measurements using the DHT22 sensor. Judging from its responsiveness, One of the best sensors, this sensor reads data quickly and is anti-interference. Widely used in temperature and humidity measurement applications due to its small size and the ability to transmit signals up to 20 meters(Irfandi et al., 2023).

ESP 32

The ESP 32 is a microcontroller developed by Espressif Systems. It is an extension of the ESP8266 and offers more features and capabilities. The ESP 32 has two CPU cores (dual-core), more memory, support for a variety of wireless communication protocols, and various additional peripherals that allow for a variety of applications. In this tool design, the ESP32 acts as a microcontroller and also as a liaison between monitoring and using applications. The ESP 32 has quite complete features because it supports analog and digital input/output, PWM, SPI, I2C, and more. In this system, the ESP32 is used to process DHT22 sensor data.

L298N Motor Driver

The L298N motor driver is the most widely used DC motor driver module in the electronics world, designed to control the speed and direction of DC motor rotation. The advantage of the L298N motor driver module is its precision in controlling the motor, making it easier to control.(Didit Wahyu et al., 2020).

AC Dimmer

An AC dimmer is a circuit that can control the amount of AC voltage supplied to any device. The AC light dimmer module is an AC dimmer module whose PWM signal can be controlled directly by a microcontroller. The zero crossing detector feature in this module allows the microcontroller to determine the correct timing for sending the PWM signal. The dimmer circuit regulates the AC voltage switching phase across the load using TRIAC and DIAC components. The TRIAC in the dimmer circuit functions to regulate the AC voltage input, while the DIAC functions to regulate the TRIAC bias used to determine the on and off points.

Relay

A relay is an electrically operated switch and is an electromechanical component consisting of two main parts, namely an electromagnet (coil) and a mechanical (a set of switch contacts). Relays used electromagnetic principles to move the switch contacts so that with a small electric current (low power) they can conduct electricity at a higher voltage.(Fitri & Yendri, 2023).

DC Fan

A fan is essentially the same as a motor, converting electrical energy into mechanical energy, which rotates the rotor. This energy is ultimately used to move air from one side to the other. This implementation can be seen in air vents that use exhaust fans. Exhaust fans, also known as exhaust fans, are designed to draw in indoor air and then expel it outside..

Incandescent lamps

An incandescent lamp is a light source produced by passing an electric current through a filament, which then heats up and creates light. The use of incandescent lamps focuses on harnessing the heat emitted by the lit lamp for drying purposes, as an alternative to the sun.

Ultrasonic Mist Maker

An ultrasonic mist maker is a device that increases the amount of moisture in the air in a room by converting water into steam. The primary function of an ultrasonic mist maker is to maintain a room's humidity. This device works by vibrating the ultrasonic diaphragm at a very high frequency, breaking the water into fine droplets that emerge as a cool mist and then converting back into water vapor.(Jusman et al., 2020).

LCD

A liquid crystal display (LCD) is an electronic component that displays characters, numbers, letters, and even graphics. The LCD used in this final project is a 16x2 character LCD with an additional I2C module chip to make it easier for programmers to access the LCD. The use of the I2C module will save on the use of ESP pins.

Internet of Things (IoT)

*Internet of Things*IoT is a device that has the ability to collect and transfer information over the internet without human intervention. The technology contained in IoT devices that are embedded in objects will help IoT devices interact with the internal and external environment and will later assist in the decision-making process. In short, IoT is a concept for connecting all devices to the internet and having the ability to communicate with each other via the internet. IoT is a very large network of devices connected to the internet and collecting and sharing information on how to operate the device.(Rosdiani & Warmansyah, 2021).

Mit App Inventor

App Inventor is a tool for creating Android applications. The fun thing about this tool is that because it is based on visual block programming, we can create applications without any code. App Inventor is also often called visual block programming because we will see, use, arrange and drag-drop blocks which are command symbols and certain event handler functions in creating applications, and in simple terms we can call them without writing program code or coding less.(Ilham Firman Maulana, 2020).

Firebase

Firebase is a Cloud Service Provider and backend service owned by Google. Firebase is a solution offered by Google to simplify the development of mobile and web applications and is a Realtime Database. Firebase Realtime Database is a realtime database stored in the cloud and supports multiplatforms such as Android, iOS and Web. Data in Firebase will be stored in a JSON (JavaScript Object Notation) structure. The Firebase database will automatically synchronize with client applications connected to it. Multiplatform applications that use the Android, iOS and JavaScript SDKs will receive the latest data updates automatically when the application connects to the Firebase server. Firebase Realtime Database is a database platform used in realtime applications. When

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data changes occur, applications connected to Firebase will automatically update through every device (device), both website and mobile. Firebase has a complete library for most web and mobile platforms. Firebase can be combined with other frameworks such as node, java, javascript, and others.(Arvin & Rusindiyanto, 2022).

Fuzzy Logic

The concept of fuzzy logic itself has been around for a long time. However, fuzzy logic was only considered a new science a few years ago due to the discovery of new methods and disciplines of fuzzy logic. The appropriate method for mapping input space to output space is fuzzy logic. According to Reynaldi and Octaviano (2022), fuzzy logic is "A methodology for calculating with words (linguistic variables) as a substitute for calculating with numbers. The words used in fuzzy logic are not as precise as numbers, but words are much closer to human intuition." Regarding fuzzy logic, basically not all decisions are described by 0 or 1, but there are conditions in between the two, the area between the two is called fuzzy or disguised. In general, there are several concepts of fuzzy logic systems, as follows below: A strict set which is the membership value of an item in a particular set. A fuzzy set which is a set used to overcome the rigidity of a strict set(Fauzi & Ardhiansyah, 2022).

METHODOLOGY

This research uses the Mamdani fuzzy logic method to design and test the Temperature and Humidity in the Tempe Fermentation Room using the DHT-22 Sensor. This goes through several stages such as:

Block Diagram

This block diagram of the temperature and humidity in a tempeh fermentation chamber illustrates the working process, which utilizes a single DHT-22 sensor to automatically detect temperature and humidity. This system can detect temperature and humidity simultaneously using a single sensor. The block diagram can be seen in Figure 1 below.

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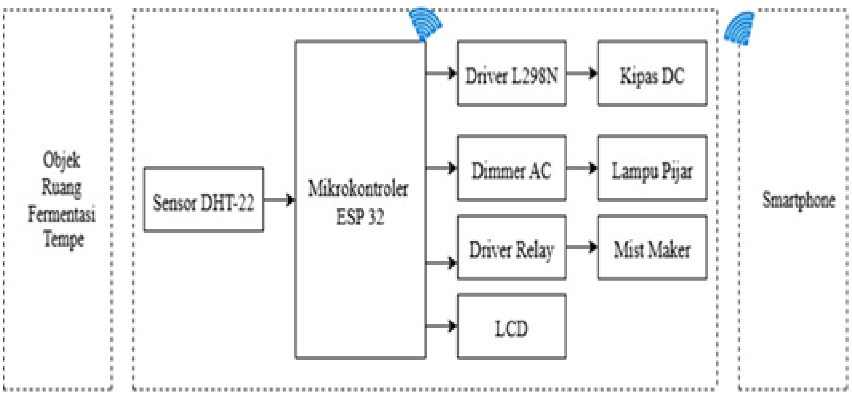

Figure 1. Block Diagram of Tempeh Fermentation Room

Work System

The system's working process begins with reading the temperature and humidity of the air in the fermentation chamber by the DHT-22 sensor, then the detected temperature and humidity are sent to the ESP 32 microcontroller which will process the data obtained. Determining the temperature and humidity setpoints and the basic rules of the fuzzy logic method in the fermentation process greatly determines the performance and response of temperature, humidity, fan speed, and lighting settings in the fermentation chamber. When the temperature reading with the DHT-22 sensor is detected to be higher than the predetermined setpoint, the fuzzy system will adjust the fan speed to be faster to help accelerate the temperature reduction and the incandescent lamp will be dimmed to prevent adding heat to the fermentation chamber. Conversely, if the temperature is detected to be lower than the setpoint, the fan speed will be reduced to maintain a stable temperature and the incandescent lamp will be bright to regulate the temperature increase. With this, the temperature in the fermentation chamber can be controlled automatically so that the tempeh fermentation process takes place more stably. If humidity is detected to fall below a predetermined minimum limit, the mist maker is activated via a relay to produce water vapor and increase humidity. Once the humidity reaches the limit, the mist maker automatically turns off. All sensor readings are then displayed in real time on the LCD. In addition to being displayed on the LCD, all data such as temperature, humidity, fan speed, and the lighting is also sent to a smartphone. This app allows the fermentation chamber's condition to be monitored remotely in real time.

Fuzzy Logic Method Design

The tempeh fermentation process is based on the results of fuzzy logic calculations. This is where the fuzzy method is used. The input variables are temperature and humidity, and the output variables are fan speed and lighting conditions. The calculation process begins with the entry of crisp input. The input values are then processed through fuzzification. The fuzzification process involves converting crisp input data (firm values) into fuzzy values in the form of sets with their respective membership functions. The fuzzy input values are then used to create rules in the inference system to serve as a reference for explaining the relationship between the input variables and the processed variables. These values cannot be used yet because they must be defuzzified first. Defuzzification is the process of converting fuzzy output variables into crisp data, which will then be used to determine fan speed and light conditions.

RESULTS AND DISCUSSION

Testing and Analysis of Temperature Reading Results

Testing of temperature readings by the DHT-22 sensor was conducted to determine the error in the sensor readings compared to a thermohygrometer. The test data can be seen in Table 1 below.

Table 1. DHT-22 Sensor Temperature Reading Test

No of Trial	DHT-22 Sensor (◦C)	Thermo-hygrometer (◦C)	Measurement Difference	Error (%)
1	31.1	31.4	0.3	0.95
2	30.3	29.5	0.8	2.71
3	29.8	29.3	0.5	1.7
4	29.7	28.8	0.9	3.12
5	29.7	28.5	1.2	4.21
6	29.9	28.9	1	3.46
7	30.7	29.6	1.1	3.71
8	30.7	29.9	0.8	2.67
9	32.7	32.2	0.5	1.55
10	32.5	32.2	0.3	0.93
11	30.2	31	0.8	2.5
12	29.1	29	0.1	0.34
13	28.8	28.3	0.5	1.75
14	28.7	27.9	0.8	2.86
15	28.8	28.2	0.6	2.12
16	28.2	27.5	0.7	2.54
17	28.1	27.2	0.9	3.3
18	28.8	27.9	0.9	3.22
19	27.8	27.3	0.5	1.83
20	27.7	27	0.7	2.59
Total Error				48.06
Average Error =				2.40

A comparison graph of temperature readings by the DHT-22 sensor with a thermohygrometer can be seen in Figure 2 below.

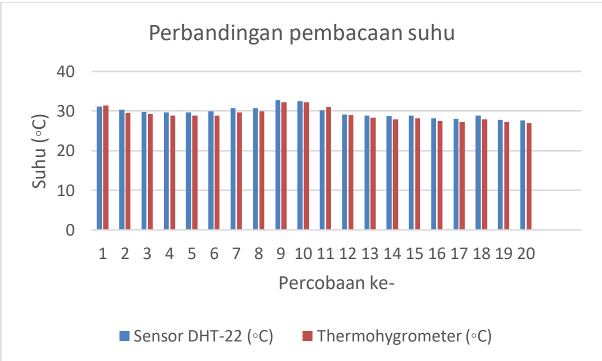

Figure 2. Temperature Reading Comparison Chart

The average error of the temperature reading by the DHT-22 sensor with the measuring instrument in the experiment above is 2.40%. Next, the accuracy of the temperature reading from the DHT-22 sensor can be calculated by:

Temperature Data Accuracy = 100% - Average Error

= 100% - 2.40% = 97.8%

Testing and Analysis of Humidity Reading Results

Testing of humidity readings by the DHT-22 sensor was conducted to assess the error in sensor readings compared to a thermohygrometer. The test data are presented in Table 2 below.

Table 2 Testing DHT-22 Sensor Humidity Readings

No of Trial	DHT-22 Sensor (%)	Thermo-hygrometer (%)	Measurement Difference	Error (%)
1	69	69	0	0
2	72	74	2	2.7
3	73	74	1	1.35
4	73	76	3	3.94
5	74	77	3	3.89
6	76	77	1	1.29
7	71	74	3	4.05
8	71	69	2	2.89
9	68	68	0	0
10	69	68	1	1.47
11	75	73	2	2.73
12	79	78	1	1.28
13	78	79	1	1.26
14	81	82	1	1.21
15	81	83	2	2.43
16	81	83	2	2.43
17	80	79	1	1.26
18	79	79	0	0
19	79	76	3	3.94
20	76	77	1	1.29
Total Error =				39.41
Average Error				1.97

A comparison graph of humidity readings by the DHT-22 sensor with a thermohygrometer can be seen in Figure 3 below.

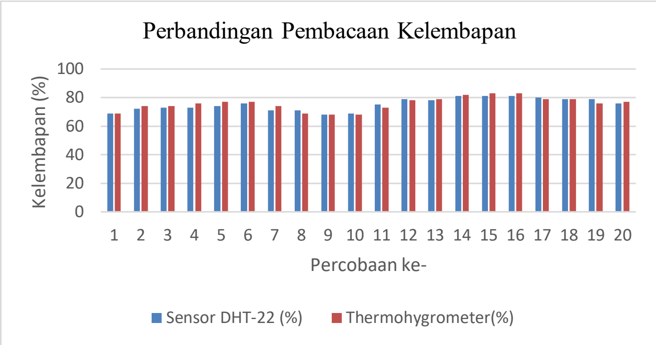

Figure 3. Humidity Reading Comparison Chart

The average error of the temperature reading by the DHT-22 sensor with the measuring instrument in the 20 experiments above is 1.97%. Next, the accuracy of the humidity reading from the DHT-22 sensor can be calculated by:
Temperature Data Accuracy = 100% - Average Error
= 100% - 1.97% = 98.03%

Mamdani Fuzzy Logic Testing and Analysis

This stage is carried out to test the accuracy level of Mamdani fuzzy logic with DHT-22 sensor input and DC fan and incandescent lamp output using MATLAB. The purpose of this calculation is to examine the accuracy level of Mamdani fuzzy logic. The testing of Mamdani fuzzy logic with MATLAB with 15 different data can be seen in Table 3 below.

Table 3. Comparison Results of Fuzzy Mamdani Output

No	Input		Output Microcontroller		Output Matlab		Error(%)	
	t (°C)	h (%)	Fan	Light	Fan	Light	Fan	Light
1	31.5	68.4	128	124	128.7	125	0.54	0.80
2	31.7	69.2	128	124	128.6	125	0.46	0.80
3	32	68	128	125	128.9	125	0.69	0.00
4	32.1	69.5	138	115.2	139	115.1	0.71	0.08
5	32.3	70.7	156	97.7	157	97.5	0.63	0.20
6	32.2	71.2	148	106	148	106	0.00	0.00
7	31.5	74.7	210	41.8	211	41.5	0.47	0.72
8	30.7	74	208	43.7	209.1	43.8	0.52	0.22
9	29.8	79	194	59.1	195.1	58.8	0.56	0.51
10	32.5	68	172	81.9	173.1	81.6	0.63	0.36
11	32.4	69.3	164	89.6	165.2	89.3	0.72	0.33
12	29.6	76.4	180	74.3	180	74	0.00	0.40
13	29.9	75.4	201	51.5	202.1	51.1	0.59	0.78

14	30.6	67.9	123	125	123.5	125	0.40	0.00
15	30.3	67.8	118	125	118.4	125	0.33	0.00
Average							0.48	0.34

Table 4.5 shows a comparison of the fuzzy Mamdani output between the microcontroller and Matlab. The table above shows an average error for the DC fan of 0.48% and an average error for the lamp of 0.34%. A comparison graph of the microcontroller output and Matlab output can be seen in Figure 4 below.

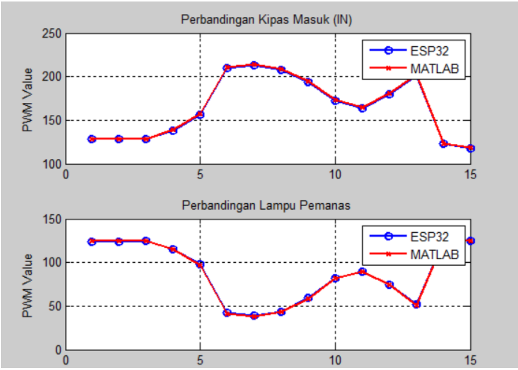

Figure 4. Fuzzy Output Comparison Graph

The comparison graph shows no significant difference between the output from the microcontroller and MATLAB. Therefore, it can be concluded that the use of the fuzzy control system in the tempeh fermentation chamber can function well.

CONCLUSIONS AND RECOMMENDATIONS

StudyThis device is capable of automatically regulating temperature and humidity and periodically sending data to the Firebase Realtime Database, so it can be monitored in real-time through the MIT App Inventor application. The DHT-22 sensor was successfully applied to detect temperature and humidity in the tempeh fermentation room, with a temperature reading accuracy of 97.8% and a humidity accuracy of 98.03%. Overall, the device that has been designed is able to maintain the temperature and humidity of the fermentation room in ideal conditions with a setpoint range of 27-35°C and a humidity of 60-80% and successfully carried out for 22-24 hours.

FURTHER STUDY

The system designed by the author still has many shortcomings, for future improvements and developments, for further research it is recommended to add a load cell sensor to determine changes in tempeh weight before and after fermentation.

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