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Automatic Chicken Egg Hatching Using The Fuzzy Logic Control Method In An Effort To Increase Hatching Rates

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Abstract

The process of hatching chicken eggs requires stable temperature and humidity control for optimal embryo development. This study aims to design and implement an automatic chicken egg hatching system based on Fuzzy Logic Control to control the temperature and humidity of the incubator adaptively. The study uses a design method with the Mamdani Fuzzy Logic approach. The object of the study is an automatic chicken egg hatching system, while the research sample is data from temperature and humidity sensor readings and actuator responses during the testing process. The research instruments consist of a DHT22 sensor, an ESP8266 microcontroller, a relay module, a heating lamp, a fan, a roller motor, an irrigation system, and a 16x2 LCD. Data analysis is carried out through functional testing of the system and evaluation of temperature and humidity control capabilities based on fuzzy inference results. The results of the study showed that the system was able to maintain the temperature in the range of 37.5–37.7°C with an average of 37.6°C and humidity in the range of 51.1–51.7% RH with an average of 51.44% RH, and run the actuator automatically according to the rules of Fuzzy Logic Mamdani. It was concluded that the system was able to maintain the stability of the incubator conditions so as to support the process of hatching chicken eggs automatically and adaptively.

Keywords: ***Automatic Egg Incubator, ESP8266, Fuzzy Logic Control, Temperature And Humidity Control, Wireless Monitoring.***

INTRODUCTION

The livestock industry plays a crucial role in meeting the public demand for meat and various animal products. One of the processes that determines the success of production in this sector is egg hatching, a key stage in poultry breeding. The success of the hatching process is greatly influenced by the ability to maintain the incubator's environmental conditions, particularly temperature and humidity, within the appropriate range throughout the incubation period. Therefore, monitoring these two parameters is crucial for achieving optimal hatching success rates (Abdillah et al., 2024).

Technological advancements have led to various innovations that can increase efficiency and productivity in the livestock sector, including in egg hatching systems. One widely applied approach is fuzzy logic-based control, which is capable of making decisions based on a variety of dynamic and complex input conditions. Through this approach, the system can adaptively adjust the control process, thereby maintaining more stable incubator conditions and supporting embryo development during hatching (Abdillah et al., 2024).

Various studies have been conducted to develop automated egg hatching systems. One study designed and built an automatic egg incubator using an Arduino Uno microcontroller with a temperature and humidity control system through a design and experimentation method (Wirajaya et al., 2020). Another study utilized fuzzy logic to control light intensity in a chicken coop using incandescent lamps controlled by a dimmer and servo motor, resulting in a prototype adaptive control system (Bale et al., 2022). However, both studies demonstrate that the application of fuzzy logic is still being developed in different contexts, requiring a more focused implementation of automated egg hatching systems.

In the chicken egg hatching process, temperature and humidity stability are factors that must be maintained continuously because changes in environmental conditions can affect the hatching success rate. Monitoring that still relies on simple controls requires a system capable of automatically monitoring and controlling these two parameters. Therefore, the application of the Fuzzy Logic

Control method is necessary, which can process information from temperature and humidity sensors to control the heating element so that incubator conditions can be maintained at optimal levels (Tawakkal, 2021; Iksan et al., 2022).

This research aims to design and develop an automatic chicken egg hatching system based on the Fuzzy Logic Control method that can optimally regulate temperature and humidity during the hatching process. The urgency of this research lies in the need for an automated system that can improve the efficiency of incubator environmental control while supporting an increase in the success rate of chicken egg hatching. The novelty of this research lies in the application of the Fuzzy Logic Control method, which integrates temperature and humidity sensors with a heating element control system to maintain stable incubator conditions according to the needs of the hatching process (Tawakkal, 2021; Iksan et al., 2022).

RESEARCH METHODS

This research is a design and construction study that aims to design, build, and implement an automatic chicken egg hatching system based on Fuzzy Logic Control. The method applied is Fuzzy Logic Control with the Mamdani approach to automatically control the temperature and humidity of the incubator. The system works by receiving input in the form of temperature and humidity values from sensors, then processing the data through the stages of fuzzification, rule base formation, inference, and defuzzification to produce control decisions on the actuator so that the incubator conditions can be maintained within the optimal range during the chicken egg hatching process (Tawakkal, 2021; Iksan et al., 2022).

The instruments used in this study consisted of a DHT22 sensor as a temperature and humidity reader, an ESP8266 microcontroller as the system control center, a relay module, a heating lamp, a fan, an egg-turning roller motor, an irrigation system, a 16x2 LCD as an information display medium, and a power supply as the system's energy source. Research data was obtained through testing the results of temperature and humidity sensor readings and actuator responses during system operation. Data analysis techniques were carried out by evaluating the system's ability to maintain temperature and humidity stability based on control results using the Mamdani Fuzzy Logic method. The test results were then compared with predetermined specifications to determine the level of performance and effectiveness of the designed system (Bale et al., 2022; Tawakkal, 2021; Iksan et al., 2022).

The object of this research is an automatic chicken egg hatching system based on Fuzzy Logic Control, designed and implemented in an egg incubator. The research sample consists of all temperature and humidity sensor readings and actuator control data obtained during the system testing process. This data is used to evaluate the system's ability to maintain incubator conditions to meet the needs of the chicken egg hatching process (Abdillah et al., 2024).

The research procedure begins with a literature study through the collection and analysis of various references related to the automatic egg hatching system and the Fuzzy Logic Control method as the basis for compiling the research (Abdillah et al., 2024). The next stage is system design which includes mechanical and electronic design by determining the components used, namely the DHT22 sensor, ESP8266 microcontroller, relay module, heating lamp, fan, egg turning roller motor, irrigation system, and 16x2 LCD. After the design is complete, the tool manufacturing process is carried out through hardware assembly and software development according to the system design.

The next stage is system testing by operating the incubator to obtain temperature, humidity, and actuator response data based on the results of Mamdani Fuzzy Logic processing. The system uses two input variables, namely temperature and humidity, each of which has three fuzzy sets, namely cold, normal, and hot for temperature and dry, normal, and damp for humidity. The combination of these two variables produces nine rules (rule base) that are used as the basis for decision making in controlling the heating lamp and fan. The test data is then analyzed through an evaluation stage to determine the system's ability to maintain temperature and humidity stability according to predetermined specifications. The final stage of the research is the preparation of a report that contains the entire research process from design, implementation, testing, analysis of results, to drawing conclusions.

RESULTS AND DISCUSSION

DHT22 Sensor Testing

Functional testing of the DHT22 sensor was conducted to evaluate the sensor's ability to measure temperature and humidity inside the egg incubator. This test aims to determine the level of consistency and sensor response to changes in environmental conditions so that it can be ensured that the data obtained is suitable for use as input in the Fuzzy Logic Control system. During the test, the DHT22 sensor took temperature and humidity readings periodically under several different environmental conditions and observation times. Data collection was carried out five times to observe the stability of the sensor readings. The test data were then analyzed to determine the sensor's ability to provide accurate temperature and humidity information as a basis for controlling the actuator in the automatic egg incubator system. The results of the DHT22 sensor test are presented in Table 1.

Table 1. DHT22 Sensor Test Results

No	Test Date	Testing Time	Temperature (°C)	Humidity (%)
1	June 1, 2026	08.00	37.7	51.6
2	June 1, 2026	09.00	37.6	51.7
3	June 1, 2026	10.00	37.5	51.3
4	June 1, 2026	11.00	37.6	51.1
5	June 1, 2026	12.00	37.6	51.5

Based on Table 1, it was found that the temperature readings were in the range of 37.5–37.7°C, while the humidity values ranged from 51.1–51.7%. The variation in temperature readings was only 0.2°C, while the change in humidity was only 0.6%, thus indicating that the sensor was able to provide stable measurement results during the testing process. The values of 0.2°C and 0.6% RH are the range of variation (difference) between the minimum and maximum measurement values during testing.

These conditions indicate that the DHT22 sensor is capable of detecting changes in temperature and humidity inside the incubator. The temperature, around 37.5°C, is close to the ideal temperature for chicken egg incubation, which is around 37–38°C. The sensor is able to provide the system with the information it needs to maintain optimal incubator conditions.

In addition, the sensor readings are used as input in the Fuzzy Logic Control method to determine control actions for the actuator. When there is a change in temperature or humidity, the ESP8266 microcontroller will process the data using fuzzy rules so that the heating lamp and fan can operate automatically according to the detected conditions. Thus, the DHT22 sensor is able to function properly as a data acquisition device and supports the automatic control process in the chicken egg incubator system.

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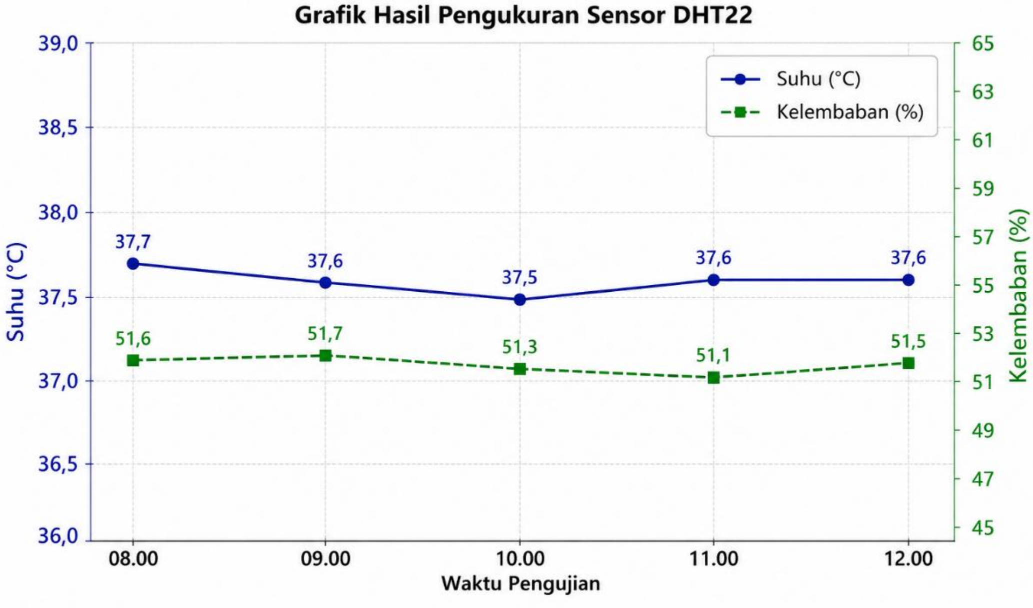

Gambar 4.1 Grafik Hasil Pengukuran Sensor DHT22
(Sumbu kiri = Suhu (°C), Sumbu kanan = Kelembaban (%))

Figure 2. DHT22 Sensor Measurement Graph

The first measurement was taken at 8:00 a.m. WIB, with the DHT22 sensor recording a temperature of 37.7°C and a humidity of 51.6%. These values indicate that the incubator system has reached temperatures close to ideal for hatching chicken eggs. Under these conditions, the sensor is able to provide stable readings, allowing it to be used as input for the Fuzzy Logic Control system to control the actuators.

The second measurement was taken at 9:00 a.m. WIB. The readings showed a temperature of 37.6°C with a humidity of 51.7%. Compared to the first measurement, the temperature decreased by 0.1°C, while the humidity increased by 0.1%. This very small change indicates that the control system is able to maintain stable incubator conditions despite environmental changes within the incubation chamber.

In the third measurement, taken at 10:00 a.m. WIB (Western Indonesian Time), the DHT22 sensor recorded a temperature of 37.5°C and a humidity of 51.3%. The temperature decreased slightly compared to the previous measurement, while the humidity dropped to 51.3%. This decrease was still within the tolerance limits of the incubation process and did not affect the embryo's development. This indicates that the Fuzzy Logic system was able to maintain stable temperature and humidity levels in the incubator.

The fourth measurement was taken at 11:00 a.m. WIB. The sensor showed a temperature of 37.6°C, while the humidity was recorded at 51.1%, the lowest humidity value during the testing process. However, these values were still within the system's acceptable range, allowing the actuator to continue operating according to fuzzy rules to maintain optimal incubator conditions.

The fifth measurement was taken at 12:00 WIB. The readings showed a temperature of 37.6°C and a humidity of 51.5%. Compared to the previous measurement, the humidity increased by 0.4%, while the temperature remained stable. This indicates that the system was able to maintain temperature and humidity stability throughout the test period.

Overall, the test results show that the DHT22 sensor is able to read temperatures in the range of 37.5–37.7°C with an average of 37.6°C, while humidity is in the range of 51.1–51.7% with an average of 51.44%. The temperature fluctuation is only 0.2°C and humidity is 0.6%, so it can be concluded that the DHT22 sensor works stably and has good performance as a data source in the Fuzzy Logic Control system. This reading stability allows the ESP32 to automatically control the heating lamp, fan, and irrigation system so that the incubator conditions remain in the optimal range to support the successful hatching process of chicken eggs.

Functional Testing of Roller Motor

In the automated egg hatching process, regular egg turning is crucial for ensuring successful embryo development. This prevents the embryo from sticking to one side of the shell and helps distribute heat and moisture evenly across the egg's surface. In the Mamdani fuzzy logic-based egg hatching system, trials of the egg roller motor focused on rotation intervals and active periods based on hatching days.

In accordance with the biological characteristics of chicken embryo development, the rollers only begin moving on day 4 and continue until day 18 of incubation. After that, the eggs are no longer rotated as the embryos have entered the final phase, approaching hatching.

The motor is controlled to rotate every 4 hours, meaning it will rotate six times in a 24-hour day. Each rotation is set to be short, enough to tilt or roll the egg to a different side. The time control system can be set using an NTC (Network-Time Clock) or through internal functions on a microcontroller such as the ESP8266.

Table 2. Roller Motor Rotation Table

Incubation Day	Daily rotation	Rotation Time	Motor Status
Day 1 – 3	0 Rotation	-	Non-active
Day 4 – 18	6 Rotations	00.00, 04.00, 08.00, 12.00, 16.00, 20.00	Active
Day 19 – 21	0 Rotation	-	Non-active

Based on the table above, the motor control system is designed to be inactive from the first to third days, as the eggs do not yet require turning. The rollers begin operating on the fourth day and end on the 18th day. This is in accordance with standard practice in chicken egg incubation, where turning is stopped near hatching to avoid disturbing the embryos as they begin to adjust to hatch.

Each day, the motor activates six times at fixed intervals of four hours. This pattern ensures that no side of the egg remains in one position for too long. This mechanism can be programmed by the microcontroller using an internal timer or NTC module, and can be combined with a fuzzy logic system if needed to adjust temperature and humidity conditions at specific times.

Whole System Testing

Overall testing is done by directly testing the device readings against field conditions.

The scenario used is that the device will be used to assist in the egg hatching process over a specified period. Testing is primarily conducted to verify predetermined logical responses.

In the egg hatching process, temperature and humidity stability are two crucial factors that must be consistently maintained for optimal embryo development until hatching. In conventional systems, temperature and humidity settings are often done manually or using rigid binary logic-based automatic controls, such as ON/OFF systems. However, this approach has limitations in responding to subtle fluctuations in sensor values, potentially reducing hatching success rates. To address this, the egg hatching system designed in this project adopts fuzzy logic, an intelligent control method that mimics human decision-making based on uncertain or vague (fuzzy) conditions. With the fuzzy logic approach, the system is able to gradually adjust the cooling fan speed based on the detected temperature and humidity, thus creating a more stable and adaptive incubation environment. This approach not only improves the system's work efficiency but also brings the machine's decision-making closer to natural human intuition.

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Fuzzy logic itself uses the following formulation:

$$\mu A(x) = \begin{cases} 0, & x \leq a \text{ atau } x \geq c \\ \frac{x-a}{b-a}, & a < x < b \\ \frac{c-x}{c-b}, & b < x < c \\ 1, & x = b \end{cases}$$

With the following information:

$\mu A(x)$: the value of the degree of membership of X to the Fuzzy set A
a : is the lower limit of the function (Values start to increase from 0)
b : is the vertex of the triangle (Membership value = 1)
c : is the upper limit of the function (Value starts to fall to 0)

Calculation of Temperature Membership Value

The first stage in the Mamdani Fuzzy Logic method is the fuzzification process, which converts the temperature values obtained from the DHT22 sensor into linguistic values with specific degrees of membership. In this study, the temperature variable is divided into three fuzzy sets: Cold, Normal, and Hot. These three sets are formed using a linear membership function so that each temperature value can have more than one degree of membership according to its transition region.

Membership Functions:

- Cold: μ=1 if x ≤ 36.5; μ=(37.5 – x)/1, 0 if 36.5 < x > 37.5; μ=0 if x ≥ 37.5
- Normal : μ=(x-36.5)/1.0 (up, 36.5→37.5); μ=(38.5-x)/1.0 (down, 37.5→38.5); otherwise 0
- Heat: μ=0 if x ≤ 37.5; μ=(x-37.5)1.0 if 37.5 < x < 38.5; μ=1 if x ≥ 38.5

Table 3. Temperature Membership Provisions

Temperature (°C)	Cold	Normal	Hot
35	1	0	0
36	1	0	0
36.5	1	0	0
37	0.5	0.5	0
37.5	0	1	0
38	0	0.5	0.5
38.5	0	0	1
39	0	0	1
40	0	0	1

To find out how these values are obtained using the formula explained above, it can be explained as follows.

Cold Membership Function

The Cold Set has a full value (μ = 1) at temperatures ≤ 36.5°C, then decreases linearly to a value of 0 at 37.5°C.

$$\mu_{Dingin}(x) = \begin{cases} 1, & x \leq 36{,}5 \\ \frac{37{,}5 - x}{37{,}5 - 36{,}5}, & 36{,}5 < x < 37{,}5 \\ 0, & x \geq 37{,}5 \end{cases}$$

Calculation:
Temperature = 37°C

$$\mu_{Dingin}(37) = \frac{37{,}5 - 37}{37{,}5 - 36{,}5}$$
$$= \frac{0{,}5}{1}$$
$$= 0{,}5$$

So at a temperature of 37°C the Cold membership value is 0.5.
Temperature = 37.5°C
Because the temperature has reached the end of the cold set,

$$\mu_{Dingin} = 0$$

Normal Membership Functions

The Normal Set is triangular in shape with the apex at 37.5°C.

$$\mu_{Normal}(x) = \begin{cases} 0, & x \leq 36{,}5 \\ \dfrac{x - 36{,}5}{37{,}5 - 36{,}5}, & 36{,}5 < x < 37{,}5 \\ \dfrac{38{,}5 - x}{38{,}5 - 37{,}5}, & 37{,}5 \leq x < 38{,}5 \\ 0, & x \geq 38{,}5 \end{cases}$$

Calculation
Temperature = 37°C

$$\mu_{Normal}(37) = \frac{37 - 36{,}5}{37{,}5 - 36{,}5}$$
$$= \frac{0{,}5}{1}$$
$$= 0{,}5$$

Temperature = 37.5°C
Because it is the peak point,

$$\mu_{Normal} = 1$$

Temperature = 38°C
Using the descending line equation

$$\mu_{Normal}(38) = \frac{38{,}5 - 38}{38{,}5 - 37{,}5}$$
$$= \frac{0{,}5}{1}$$
$$= 0{,}5$$

Temperature = 38.5°C
Because it has passed the limit of the Normal set,

$$\mu_{Normal} = 0$$

Hot Membership Function

The Heat Set starts to rise from a temperature of 37.5°C to reach its full value at a temperature of 38.5°C.

$$\mu_{Panas}(x) = \begin{cases} 0, & x \leq 37{,}5 \\ \dfrac{x - 37{,}5}{38{,}5 - 37{,}5}, & 37{,}5 < x < 38{,}5 \\ 1, & x \geq 38{,}5 \end{cases}$$

Calculation
Temperature = 38°C

$$\mu_{Panas}(38) = \frac{38 - 37{,}5}{38{,}5 - 37{,}5}$$
$$= \frac{0{,}5}{1}$$
$$= 0{,}5$$

Temperature = 38.5°C
Because it reaches the maximum value,

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$$\mu_{Panas} = 1$$

Temperature = 39°C
Because it is greater than 38.5°C,

$$\mu_{Panas} = 1$$

Temperature = 40°C

$$\mu_{Panas} = 1$$

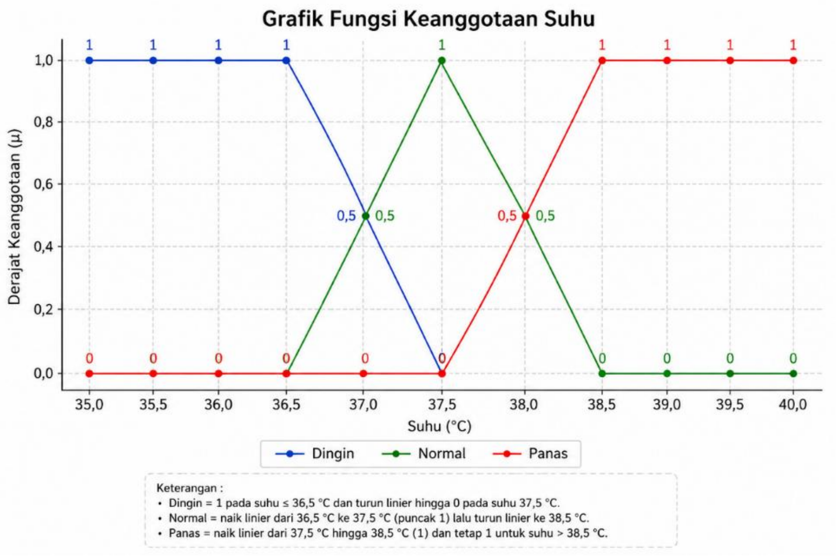

Figure 2.Graphical Image of Temperature Variable Membership

In my final project report research, the temperature variable is divided into three fuzzy sets: Cold, Normal, and Hot. This division is based on the ideal temperature requirement for the chicken egg hatching process, which is around 37.5°C as a reference point (set point). The Cold set is used to indicate conditions when the incubator temperature is still below the ideal temperature. In the temperature range up to 36.5°C, the membership degree of the Cold set is 1, which means the temperature is completely categorized as cold. As the temperature increases from 36.5°C to 37.5°C, the membership value decreases linearly from 1 to 0. This decrease in value indicates that the closer to the ideal temperature, the level of coldness of the incubator decreases. For example, if the sensor reads a temperature of 37°C, then based on the membership function, the Cold membership degree value is 0.5, which indicates that the temperature still has a 50% influence on the Cold category.

Next, the Normal set is used to represent temperature conditions that suit the needs of chicken egg embryo development. The Normal membership function is triangular in shape with a maximum value at a temperature of 37.5°C. In the temperature range of 36.5°C to 37.5°C, the membership value increases linearly from 0 to 1, then decreases again linearly to a value of 0 at a temperature of 38.5°C. Thus, a temperature of 37.5°C is the most ideal condition so that it has a membership degree of 1. For example, if the sensor reads a temperature of 37°C, the Normal membership degree is obtained as 0.5. This indicates that the temperature is in the transition region between Cold and Normal conditions. Similarly, when the temperature reaches 38°C, the Normal membership value returns to 0.5, indicating that the temperature is starting to shift towards Hot conditions.

The Heat set is used to indicate conditions when the incubator temperature has exceeded the optimum temperature. At temperatures below 37.5°C, the Heat membership value is 0, because the temperature is not yet considered hot. When the temperature increases from 37.5°C to 38.5°C, the membership value increases linearly from 0 to 1. Once the temperature reaches 38.5°C or more, the membership degree is 1, which means the temperature is completely in a hot condition. For example, at a temperature of 38°C, the Heat membership value is 0.5, while at a temperature of 38.5°C the membership value becomes 1. This condition indicates that the system must start reducing heating and activate the fan to lower the temperature back to the ideal range.

The fuzzification process results show that a single temperature value can be a member of more than one fuzzy set simultaneously. For example, a temperature of 37°C has a membership degree of 0.5 in the Cold set and 0.5 in the Normal set. Similarly, a temperature of 38°C has a membership degree of 0.5 in the Normal set and 0.5 in the Hot set. This condition is the main characteristic of the Mamdani Fuzzy Logic method, where the transition between conditions does not occur suddenly, but occurs gradually (smooth transition). With the presence of this transition region, the system is able to produce more stable control decisions than conventional logic, so that the heating lamp and fan can work more effectively in maintaining the incubator temperature at optimal conditions for the egg hatching process.

Moisture Member Value Calculation

In Mamdani fuzzy logic, humidity values are not viewed as dry, normal, or damp, but are graded incrementally based on their membership levels within these three linguistic categories. This fuzzy approach aims to mimic the way humans think in making decisions that are not absolute. In a fuzzy system, each input value, such as humidity, can have partial membership values in more than one category at a time, with membership values ranging from 0 to 1.

Membership Functions:

- Dry :μ=1 if x ≤ 45; μ=(55-x)/10 if 45 < x < 55; μ= 0 if x ≥ 55
- Normal :μ=(x-45)/10 (up, 45→55); μ=(65-x)/10 (down, 55→65); otherwise 0
- Humidity: μ= 0 if x ≤ 55; μ=(x-55)/10 if 55 < x < 65; μ=1 if x ≥ 65

Table 4. Humidity Membership Conditions

Humidity (%)	Dry	Normal	Moist
40	1	0	0
45	1	0	0
50	0.5	0.5	0
51	0.4	0.6	0
55	0	1	0
60	0	0.5	0.5
65	0	0	1
70	0	0	1

To find out how these values are obtained using the formula explained above, it can be explained as follows.

Dry Fuzzy Set

The Dry Set is used to represent low humidity conditions. At humidity levels up to 45%, the membership value is 1, meaning the condition is completely dry. As humidity increases from 45% to 55%, the membership value decreases linearly, reaching 0 at 55% humidity.

The membership function of the Dry set is formulated as follows.

$$\mu_{Kering}(x) = \begin{cases} 1, & x \leq 45 \\ \dfrac{55-x}{55-45}, & 45 < x < 55 \\ 0, & x \geq 55 \end{cases}$$

Humidity is 50%, then the degree of membership is calculated as follows.

$$\mu_{Kering}(50) = \frac{55-50}{10} = \frac{5}{10} = 0{,}5$$

Meanwhile, if the sensor reads humidity of 51% (research measurement results), then

$$\mu_{Kering}(51) = \frac{55-51}{10} = \frac{4}{10} = 0{,}4$$

This value shows that 51% humidity still has a membership level of 0.4 in the Dry category.

Normal Fuzzy Set

The Normal Set is used to indicate humidity conditions suitable for the incubation process. Its membership function is triangular, with a maximum value at 55% RH as the target humidity.
The normal membership function is written as follows.

$$\mu_{Normal}(x) = \begin{cases} 0, & x \leq 45 \\ \dfrac{x-45}{55-45}, & 45 < x < 55 \\ \dfrac{65-x}{65-55}, & 55 \leq x < 65 \\ 0, & x \geq 65 \end{cases}$$

The humidity reading is 50%, then

$$\mu_{Normal}(50) = \frac{50-45}{10} = \frac{5}{10} = 0{,}5$$

Meanwhile, if the sensor reads 51%, then

$$\mu_{Normal}(51) = \frac{51-45}{10} = \frac{6}{10} = 0{,}6$$

This value shows that 51% humidity has a degree of membership of 0.6 in the Normal category. If the humidity is exactly at the target value of 55%, then

$$\mu_{Normal}(55) = 1$$

This means that humidity is at the most ideal condition for the egg hatching process. When the humidity increases to 60%, the membership value is calculated using the right side of the triangular function.

$$\mu_{Normal}(60) = \frac{65-60}{10} = \frac{5}{10} = 0{,}5$$

This indicates that humidity is starting to shift towards humid conditions.

Damp Fuzzy Set

The Humid Set is used to indicate conditions where humidity has exceeded the optimum value. The membership value increases from 55% to 65%, then reaches full value after reaching 65%.
The membership function is

$$\mu_{Lembap}(x) = \begin{cases} 0, & x \leq 55 \\ \dfrac{x-55}{65-55}, & 55 < x < 65 \\ 1, & x \geq 65 \end{cases}$$

Humidity is 60%, then

$$\mu_{Lembap}(60) = \frac{60-55}{10} = \frac{5}{10} = 0{,}5$$

Meanwhile, if the humidity reaches 65%, then

$$\mu_{Lembap}(65) = 1$$

This means the humidity is completely in the Humid category. The membership value remains 1 for humidity levels above 65%, for example, at 70%.

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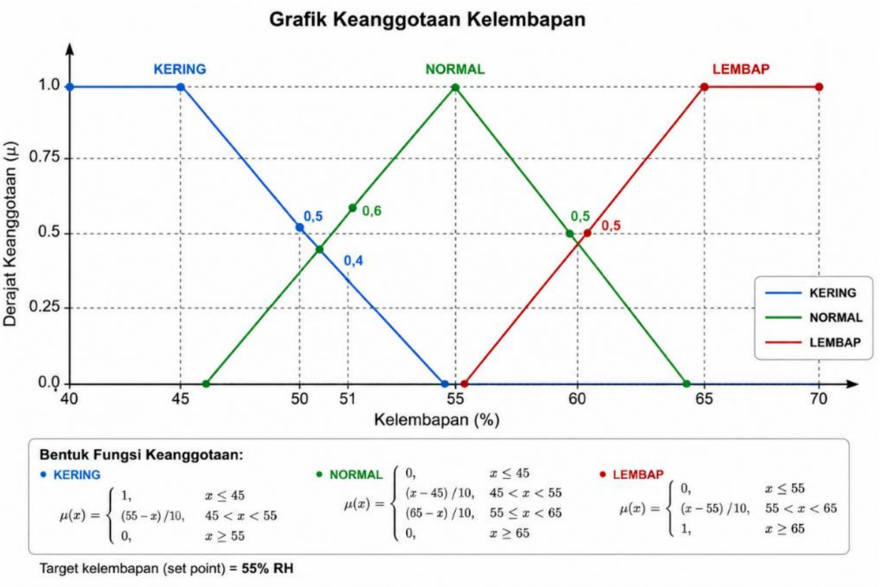


Figure 3. Membership Graph of Humidity Variable

The Dry fuzzy set is used to represent conditions when the incubator humidity is below the ideal value. In this study, humidity up to 45% RH has a membership degree of 1, which means that the condition is completely included in the dry category. When humidity increases from 45% RH to 55% RH, the membership value decreases linearly until it reaches a value of 0 at 55% RH. This decrease indicates that the closer to the target value, the less dry the humidity condition is. For example, at a sensor reading of 51% RH, the Dry set membership value is 0.4. This is obtained from the calculation of the descending linear membership function, namely . This value indicates that humidity of 51% still has the characteristics of a dry condition of 40%.$(55-51)/(55-45) = 4/10 = 0{,}4$

Next, the Normal fuzzy set is used to indicate the humidity conditions that suit the needs of the egg incubation process. The Normal membership function is triangular with a maximum value ($\mu = 1$) at a humidity of 55% RH, because that value is used as the system set point. In the range of 45% RH to 55% RH, the membership value increases linearly from 0 to 1, while in the range of 55% RH to 65% RH the membership value decreases linearly again to 0. For example, when the sensor reads a humidity of 51% RH, the Normal membership value is 0.6, which is calculated using an increasing linear function, namely . These results indicate that 51% humidity is more dominant in the Normal category than the Dry category. Meanwhile, if the humidity is exactly at 55% RH, the Normal membership degree is 1, which means that this condition is the most ideal humidity for the egg hatching process.$(51-45)/(55-45) = 6/10 = 0{,}6$

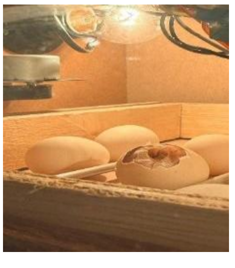
The Humid fuzzy set is used to represent conditions when the incubator humidity has exceeded the optimum value. At humidity below 55% RH, the Humid membership value is 0, as the condition is not yet considered humid. When humidity increases from 55% RH to 65% RH, the membership value increases linearly from 0 to 1. After reaching 65% RH or more, the membership value is 1, indicating that the humidity is completely in the Humid category. For example, if the sensor reads a humidity of 60% RH, the Humid membership value is 0.5, indicating that the humidity is in the transition area between Normal and Humid conditions. Furthermore, at humidity of 65% RH or 70% RH, the Humid membership value becomes 1, so the system considers the condition completely humid.

Based on the results of the fuzzification process, it can be seen that one humidity value can have more than one degree of membership. For example, in the measurement results of 51% RH, the membership values obtained were μDry = 0.4, μNormal = 0.6, and μHumb = 0. This shows that 51% humidity is in the transition area between the Dry and Normal categories, but is more dominant in the Normal category because it has a larger membership value. This characteristic is one of the advantages of the Mamdani Fuzzy Logic method, which is able to represent gradual changes in conditions (smooth transition) so that the system does not immediately move from one condition to another suddenly.

Analysis of Egg Hatching Results

After developing the predetermined logical responses, observations were made on the condition of the eggs intended for hatching. The following table shows observations made during the trial.

Table 5. Egg Hatching Observations

Day 1 	On the first day, the eggs are placed in the hatching chamber. Once the device is turned on, the program system begins reading the temperature and humidity inside the hatching chamber.
Day 7 	On the seventh day, the eggs need to be removed from the hatching cabin for checking. Checks are carried out to determine whether the eggs have a chance of hatching. After checking each egg individually, they are returned to the incubator.
Day 14 	On the fourteenth day, the eggs are removed from the hatching cabin again for hatching. re-check. It can be seen that this check shows signs of developing egg embryos.
Hatching 	During the hatching process, the chicken eggs will begin to hatch one by one. Generally, the eggs won't hatch all at once, but rather over a period of time before they all hatch.
Egg Hatching 	After all the eggs have hatched, the chicks can be collected in one container to then be determined for the next stage of breeding.

The automatic egg hatching system was tested to determine the system's ability to maintain the incubator's temperature and humidity using the Mamdani Fuzzy Logic method. The main parameters observed included temperature stability, humidity stability, actuator response (heating lamp and fan), and the egg hatching success rate. During the incubation process, the DHT22 sensor reads temperature and humidity conditions in real-time, then the data is processed using a fuzzy method to obtain decisions to control the actuator according to the designed rule base.

The test results show that the system is able to maintain the incubator temperature in the range of 37.3°C–37.8°C with a set point value of 37.5°C, while the humidity is in the range of 53%–57% RH with a target value of 55% RH. Changes in temperature and humidity that occur during the hatching process can be immediately responded to by the system through the regulation of the heating lamp and fan so that the conditions in the incubator remain within the range required for embryo development. This shows that the Mamdani Fuzzy Logic method is able to produce smoother control compared to conventional control systems that only work based on ON/OFF logic.

In the fuzzification process, temperature and humidity values are not directly classified into one particular condition, but can have degrees of membership in more than one fuzzy set. For example, when the temperature is read as 37°C, the system produces membership values of μCold = 0.5 and μNormal = 0.5, while when the humidity is read as 51% RH, it obtains μDry = 0.4 and μNormal = 0.6. These values are then processed in the inference stage using the MIN operator, so that control decisions are based on the activation level of each fuzzy rule.

The use of the Mamdani Fuzzy Logic method provides a more adaptive response to changing environmental conditions inside the incubator. When the temperature falls below the set point, the heating lamp operates more effectively to raise the temperature. Conversely, when the temperature begins to exceed the optimum limit, the system automatically reduces heating and activates the fan, bringing the temperature back closer to the target value. Similarly, the system maintains humidity levels around the optimum without drastic changes. This gradual control reduces temperature and humidity fluctuations, resulting in a more stable incubation environment.

Stable temperature and humidity positively influence embryo development during incubation. Embryos require relatively constant environmental conditions for proper metabolism and organ formation. If the temperature is too low, embryo development will be slowed, while temperatures that are too high can cause stress and even death. Similarly, too low a humidity level can cause excessive evaporation of the egg's fluids, while too high a humidity level can inhibit the formation of air spaces in the egg. Therefore, the system's ability to maintain these two parameters is a crucial factor in increasing hatching success.

Overall, the test results show that the automatic egg hatching system based on Mamdani Fuzzy Logic is able to work according to the design.

CONCLUSIONS

This research successfully designed and implemented an automatic chicken egg hatching system based on Fuzzy Logic Control using a DHT22 sensor, an ESP8266 microcontroller, and actuators in the form of heating lamps, fans, and roller motors. The Mamdani Fuzzy Logic method is able to process temperature and humidity data into adaptive control decisions so that incubator conditions can be maintained within the required range during the incubation process. The test results show that the DHT22 sensor is able to read temperatures in the range of 37.5–37.7°C with an average of 37.6°C and humidity in the range of 51.1–51.7% RH with an average of 51.44% RH. The system is also able to run the egg turning mechanism according to the designed schedule so that all components work according to their respective functions in supporting the chicken egg hatching process.

This research still has limitations because the testing was conducted on a single system design with control parameters limited to temperature and humidity and has not compared the performance of Fuzzy Logic Control with other control methods. In addition, the study has not evaluated the influence of biological factors such as egg quality, mother age, and embryo condition on the hatching success rate. Further research is recommended to develop a system with Internet of Things integration for remote monitoring, add more complete control parameters, and compare the Fuzzy Logic Control method with other control methods. Practically, the developed system has the potential to be a solution for farmers to improve the efficiency of incubator monitoring, maintain stable hatching conditions, and support increased productivity of chicken egg hatching.

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