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Design and Development of a Fuzzy Logic-Based Temperature and Humidity Control System for Cricket Breeding Enclosures

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Abstract – *Cicadas are insects that can be cultivated in Indonesia. The most common species of cicadas cultivated in Indonesia are Gryllus bimaculatus and Acheta domesticus. Cicadas are commonly used as livestock feed, including ornamental chickens, poultry, and birds, because of their high protein content. Cicadas cultivation in Indonesia is still mostly done manually, both in the process of controlling the environmental conditions around the cage and in the process of breeding cicadas eggs. One of the problems that often occurs is the temperature and humidity in the cicadas cage are not stable. Therefore, this research aims to design a system that can control the temperature and humidity in the cicadas cage. This system applies the fuzzy logic method to control actuators that can regulate the duration of spraying and the level of lighting needed in the cicadas cage based on the fuzzy rules that have been made. The components used in this system include Arduino uno, DHT22 sensor, relay, AC light dimmer, mist maker, lamp, and fan. The results of this research show that the temperature and humidity control system in a cicadas cage using fuzzy logic method with a predetermined setpoint has been realized. The accuracy testing of the DHT22 sensor obtained an error of 1.55% and a temperature accuracy rate of 98.44% and humidity of 1.66% with an accuracy rate of 97.64%. Then, the testing of the comparison results on the system and fuzzy simulation with the matlab application obtained an accuracy percentage in the mist maker testing of 97.37% and in the lamp testing of 98.81%.*

Keywords – *Cricket Breeding; Fuzzy Logic Control; Environmental Monitoring; Temperature Regulation; Humidity Management.*

I. Introduction

INDONESIA is a country rich in natural resources, including a diverse range of flora and fauna. One of the animals with significant growth and development potential is the cricket [1]. Crickets are insects that belong to the order Orthoptera and the family Gryllidae. They are cold-blooded creatures that can regulate their body temperature with the environment. The most commonly cultivated species are Gryllus bimaculatus and Acheta domesticus. Crickets are typically used as feed for livestock such as ornamental chickens and birds, due to their high protein content [2]. Hence, cultivating crickets can be a promising economic venture with a potentially profitable market due to high demand and limited supply, coupled with low production costs while ensuring quality standards that meet international market requirements.

Cricket farming presents a promising business opportunity within a relatively short period of approximately 30 days [2]. However, much of the current cricket farming practices are manual, including environmental control around the cage and the breeding process of cricket eggs [3]. Environmental factors that affect cricket development include nutritional sources, temperature, and humidity. Crickets, which thrive in environments requiring temperatures between 20°C and 32°C and humidity levels between 65% and 80%, often experience high mortality rates between 10 and 25 days due to unstable temperature and humidity conditions in the cage [4]. In manual cricket farming, maintaining stable temperature and humidity involves using lamps at night and periodically spraying water [3]. However, these methods often result in unstable conditions, leading to higher mortality rates.

To maintain stable temperature and humidity, a system has been designed utilizing advanced technology to control the temperature and humidity in the cricket cage [5]. This system uses an Arduino Uno

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as a microcontroller, equipped with a DHT22 sensor. The DHT22 sensor has been widely used in various applications for detecting temperature and humidity. [6] and [7] both successfully utilized the DHT22 sensor in monitoring room temperature and humidity. [8] and [9] applied the sensor in automatic orchid sprinklers and oyster mushroom cultivation, respectively. [10] and [11] used the DHT22 sensor in automatic fan speed control and stabilizing room temperature and humidity. [12] conducted a feasibility study on the accuracy and precision of the DHT22 sensor in measuring temperature and humidity in a greenhouse. [13] provided a comprehensive guide on using the DHT22 sensor for measuring temperature and humidity with the Arduino board. These studies collectively demonstrate the versatility and reliability of the DHT22 sensor in various practical applications.

The system also implements fuzzy logic to handle uncertain or ambiguous problems. In this study, fuzzy logic is used to control actuators that regulate the spraying duration and the lighting level needed in the cricket cage. Previous research by [3] titled "Monitoring System for Cricket Farming Based on ESP32 Microcontroller" discussed creating a monitoring system using the ESP32 microcontroller. The sensors used were the BME280 module and load cell sensor to detect temperature, humidity, and the weight of crickets.

Further research [2] titled "Automation of Temperature and Humidity Conditioning Tool for Cricket Cages Based on Microcontroller" used Arduino Nano microcontroller, DHT22 sensor, and Rain drop sensor to detect temperature, humidity, and the presence of water for the misting system, with the pump only activating when humidity was below 75% and deactivating above 75%. Another study by [14] titled "Temperature Control System in Brooding Cages with Fuzzy Logic Using Arduino Uno Based on Mobile" used an Arduino Uno microcontroller with an LM35 temperature sensor and an ultrasonic sensor to detect temperature and control brooding cage temperature, monitored via an Android smartphone. Fuzzy logic in this study was used solely to achieve ideal temperatures based on chick behavior. This study designs a tool using fuzzy logic to control temperature and humidity specifically in cricket cages, utilizing Arduino Uno as the main controller, DHT22 sensor to detect temperature and humidity, relay, and AC light dimmer as actuators, with output results in the form of spray duration and light brightness levels. The components used in this study are:

i. DHT22 Sensor

The DHT22 sensor, as shown in Figure 1, is a single multi-sensor module with a digital output, calibrated for both temperature and humidity detection. It has a temperature measurement range of -20°C to 32°C and a humidity range of 0% to 100% [15].

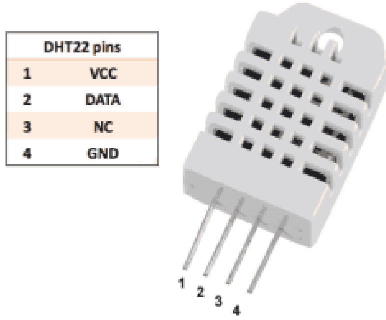

Figure 1: DHT22 Sensor

ii. Arduino Uno

The Arduino Uno, depicted in Figure 2, is a microcontroller board based on the ATmega328, featuring 14 digital input/output pins (6 of which can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It can support a microcontroller that can be connected to a computer using a USB cable and can be powered with an AC-to-DC adapter or battery [16].

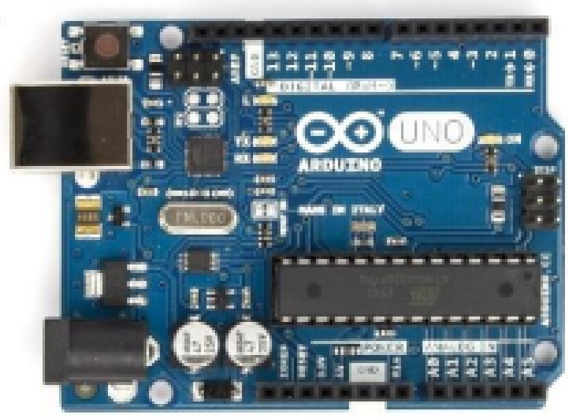

Figure 2: Arduino Uno

iii. Relay Module

The relay module, as illustrated in Figure 3, is an electronic switch that can connect and disconnect electrical circuits automatically. It consists of two main parts: the coil and the switch. Its operation is based on the electromagnetic principle, allowing the relay to be controlled by other electronic circuits [15].

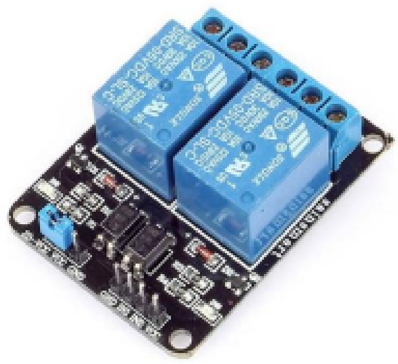

Figure 3: Relay Module

iv. AC Light Dimmer Module

The AC light dimmer module, shown in Figure 4, is a circuit that can control the amount of AC voltage delivered to its output, with an operating voltage range of 3.3V to 5V. It works by controlling the PWM signal of the AC voltage applied to the lamp [17].

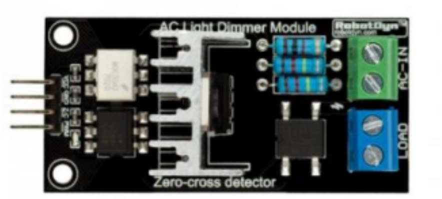

Figure 4: AC Light Dimmer Module

II. Research Methods

Based on the research conducted, a system for controlling the temperature and humidity in a cricket cage using the fuzzy logic method consists of two microcontrollers, Arduino Uno 1 and Arduino Uno 2, connected via serial communication RX TX. Arduino Uno 1 is connected to the DHT22 sensor, a 16x2 LCD, and contains the fuzzy logic program. Arduino Uno 2 is connected to actuators such as relays, an AC light dimmer module, and lamps.

The objective of this research is to maintain stable temperature and humidity in the cricket cage using fuzzy logic, as shown in Figure 5. Arduino Uno 1 processes the data from the DHT22 sensor, classifying it based on the temperature and humidity levels in the cage, and displays this data on the LCD. The data is then transmitted via serial communication RX TX to

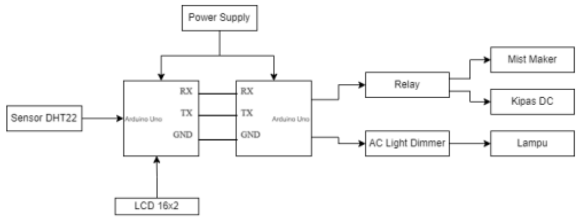

Figure 5: Overall System Block Diagram

Arduino Uno 2, which controls the actuators such as the relay to activate the mist maker and fan for spraying water mist into the cage, and the AC light dimmer to adjust the lighting level in the cage.

i. System Design

The system design for the temperature and humidity control system in the cricket cage is shown in Figure 6.

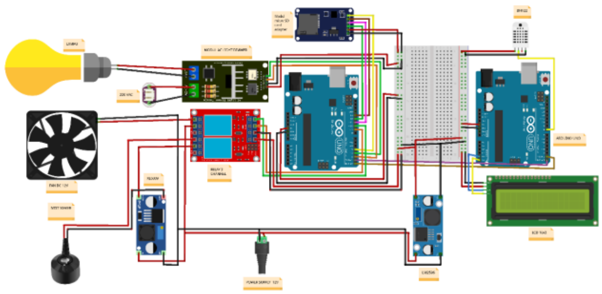

Figure 6: System Wiring Diagram

The Arduino Uno is powered by a 12V adapter. This device controls the temperature and humidity. Arduino Uno, connected to the DHT22 sensor, detects temperature and humidity. The serial communication between the Arduinos controls the mist maker and fan connected to the relay as actuators, and the lamp connected to the AC light dimmer as a heater in the cricket box. The LCD displays the detection results from the DHT22 sensor.

ii. Fuzzy Logic System Flowchart

Based on Figure 7, the process starts by initializing the DHT22 sensor, reading the input variables of temperature and humidity. The fuzzification process converts the crisp input values into fuzzy values using membership functions for temperature (cold, normal, and hot) and humidity (dry, humid, and wet).

The inference stage creates a set of rules to determine the fuzzy output using the Mamdani method with IF-THEN statements and the AND operator. The defuzzification stage converts the fuzzy output back into crisp values using the Centroid or Center of Area

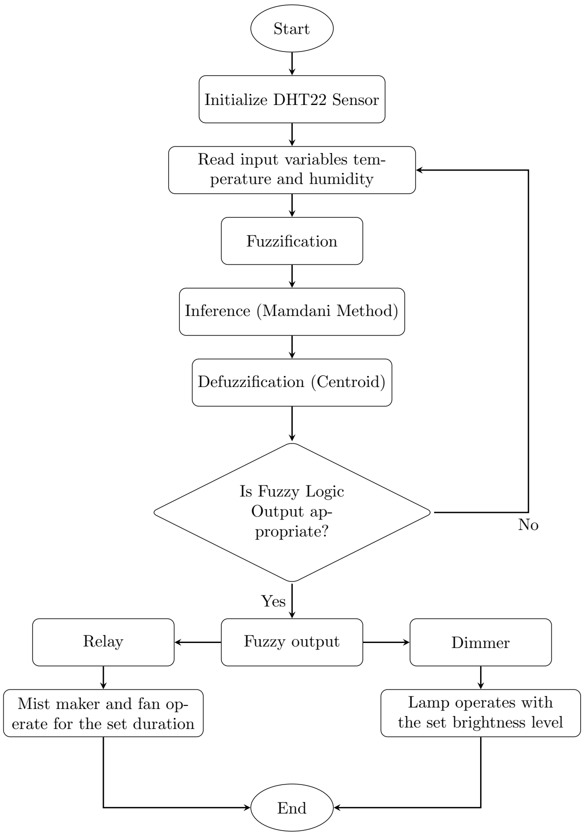

Figure 7: Fuzzy Logic Flowchart

(CoA) method. If the output is suitable, the relay controls the misting duration, and the dimmer controls the lamp's brightness. If the output is not suitable, the fuzzification process is repeated.

iii. Mamdani Fuzzy Logic

This research uses the fuzzy logic method to determine the duration for the mist maker and lamp brightness. The fuzzy logic used is Mamdani fuzzy logic, which involves several stages to achieve the desired set point:

Creating fuzzy sets is the initial stage in the fuzzy process, also known as fuzzification, which converts crisp input values into fuzzy values (linguistic variables) [18]. With F = Function, V = Variable, HF = Fuzzy Set, D = Domain, and SP = Universe of Discourse.

This stage involves the rules used in the fuzzy set, known as if-then rules. The rules are derived from the membership functions of each variable determined during the fuzzification process [18]. There are nine rules in this study.

The evaluation stage in the fuzzy rules, or the decision-making stage, is based on the fuzzy input and fuzzy rules, or the process of converting fuzzy input into fuzzy output using the predefined rules (IF-THEN) in the fuzzy knowledge base [19]. This stage uses the Mamdani fuzzy method.

Table 1: Fuzzy Logic Sets

F	V	HF	D	SP
input	temperature	cold	[0 26]	[0 40]
		normal	[24 30]	
		hot	[28 40]	
	humidity	dry	[0 65]	[0 100]
		humid	[60 80]	
		wet	[75 100]	
output	mist maker & fan	short	[0 10]	[0 30]
		medium	[8 20]	
		long	[18 30]	
	lamp	dim	[0 30]	[0 100]
		bright	[25 75]	
		very bright	[70 100]	

The defuzzification process is the reverse of fuzzification. In this process, the output obtained from the inference stage (converting the results from the inference stage into definite or crisp output values) is obtained using the predefined membership function [20]. This stage uses the Centroid method to find the center point.

III. Results and Discussion

This research was conducted to determine the success of the tool that has been made and whether the system has operated and adhered to the design. Testing was carried out by testing the sub-systems and the entire tool. The overall design results of the tool using the fuzzy method will be compared with MATLAB simulations as well as comparing the breeding of crickets using the tool and without the tool or conventionally. The research was conducted for 7 days or 1 week, with data collection carried out every hour. Each cage contains crickets weighing 500g.

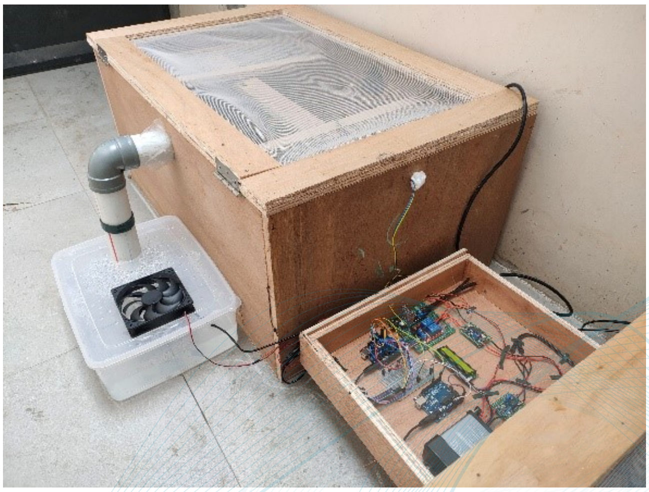

Figure 8: Research tool setup

Testing of the DHT22 sensor and 16x2 LCD was conducted to determine whether the sensor used functions properly. The test was performed by calibration using a measuring instrument, namely the HTC-1 digital thermo-hygrometer, as shown in Figure 9.

Figure 9: DHT22 Sensor Testing with LCD

Testing was performed using a hairdryer and a fan to raise and lower the room temperature, while a water spray and hairdryer were used to manipulate humidity, moistening and drying the room air. From the calibration results, differences, errors, and accuracy between the sensor readings and the measuring instrument are shown in Tables 2 and 3 where $\mathscr{D}$ is Digital thermo hygrometer.

Table 2: Temperature Testing Results

No	DHT22	$\mathscr{D}$	Difference	Error (%)	Accuracy (%)
1	28.9	29	0.1	0.34	99.66
2	29.5	30	0.5	1.66	98.34
3	30.3	30.9	0.6	1.94	98.06
4	31.6	31.9	0.3	0.94	99.06
5	31.5	32.2	0.7	2.17	97.83
..	..	..	..	..	..
20	42.1	42.6	0.5	1.17	98.83
	Average		0.58	1.55	98.44

The results of the sensor test after data collection 20 times with a data collection interval of 15 seconds showed that the temperature differences between the DHT22 sensor and the HTC-1 ranged from 0°C to 1.8°C with an average difference of 0.58°C, an error of 1.55%, and a temperature accuracy of 98.44%.

The results of the sensor test after data collection 20 times with a data collection interval of 15 seconds showed that the humidity differences between the DHT22 sensor and the HTC-1 ranged from 0 to 1.7 with an average difference of 0.93, an error of 1.16%, and a humidity accuracy of 97.64%.

Table 3: Humidity Testing Results

No	DHT22	$\mathscr{D}$	Difference	Error (%)	Accuracy (%)
1	70,3	72	1,7	2,36	97,64
2	72,4	73	0,6	0,82	99,18
3	73,4	74	0,6	0,81	99,19
4	74,2	74	0,2	0,27	99,73
5	75,4	75	0,4	0,53	99,47
..	..	..	..	..	..
20	94,5	93	1,5	1,61	98,39
	Average		0,935	1,16	97,64

The overall system testing was conducted by integrating all devices into a complete system. Data collection was performed by comparing the system conventionally and automatically with the developed tool. Data collection was conducted from August 24 to August 30, 2023, using cricket boxes with dimensions of 90 cm long, 60 cm wide, and 40 cm high.

Table 4: Data on August 24, 2023

Time	Temperature (°C)	Humidity (%)	Mist Maker (Seconds)	Lamp
00:00:00	27	76	10	50
01:00:00	27	79	5	50
02:00:00	28	79	5	31
03:00:00	29	78	7	31
04:00:00	29	81	4	31
05:00:00	29	79	6	31
..	..	..	..	..
23:00:00	29	81	4	31

Based on Table 4, it represents the temperature and humidity monitoring data conducted on August 24, 2023. Data collection was performed for one day hourly, from 00.00 to 23.00. Figures 10 and 11 show the temperature and humidity graphs.

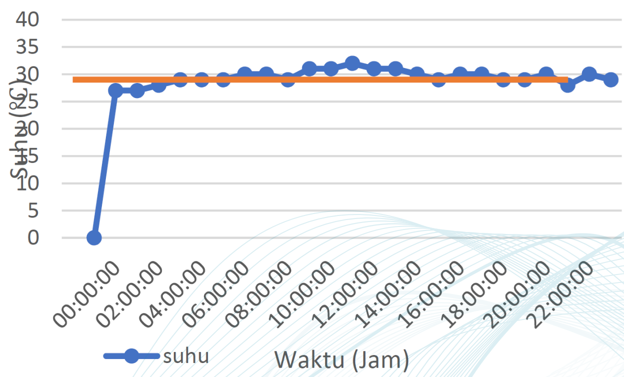

Figure 10: Temperature Change Graph

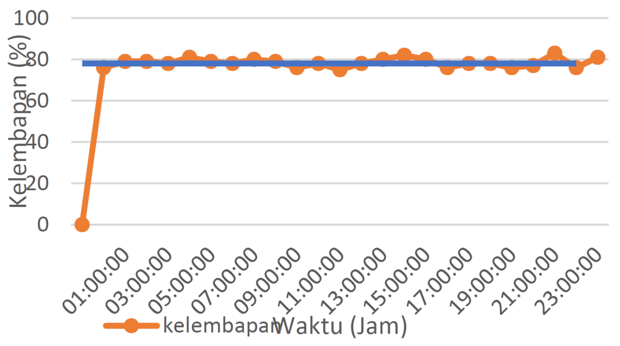

Figure 11: Humidity Change Graph

Based on the obtained data, it shows that the temperature and humidity values change every hour. The determined set points are 29°C for temperature and 78% for humidity. The initial temperature was set by the fuzzy system at 27°C, with a delay time at 03.00 for 3 hours. The rise time to reach 90% was at 01.00, one hour from the initial system temperature difference. The peak time occurred at 11.00, 11 hours after the initial temperature. Table 5 shows these values.

Table 5: System Temperature and Humidity Response

	Temperature	Humidity
Delay Time (Td)	3 hours	3 hours
Rise Time (Tr)	1 hour	0 hours
Peak Time (Tp)	11 hours	21 hours
Overshoot	10.34%	6.41%
Settling Time (Ts)	0 hours	0 hours
Error Steady State (Ess)	0%	3.84%

The overshoot of the maximum peak response was 10.34%, with a settling time within a ±2% range at 00:00 for 0 hours and a steady state error of 0%. For humidity, the initial setting was 76%, reaching 78% with a delay time at 03.00 for 3 hours. The rise time to 90% was at 00.00, zero hours from the initial humidity difference. The peak time occurred at 21.00, 21 hours after the initial humidity. The overshoot of the maximum peak response was 6.41%, with a settling time within a ±2% range at 00.00 for 0 hours and a steady state error of 3.84%. It can be concluded that the system successfully maintained the temperature and humidity at the set points.

In this study, 3 data points were taken daily at 06.00, 12.00, and 18.00 WIB to compare the measurement results of the developed tool and MATLAB simulation, as well as to assess the consistency of the fuzzy logic on the tool with the fuzzy logic in MATLAB, as shown in Tables 6 and 7.

Based on Table 6, for temperature measurements between 28 to 32°C and humidity between 74 to 82%, the mist maker output on the tool ranged from 4 to 14 seconds. The MATLAB simulation showed output values from 4.4 seconds, rounded to 4 seconds, to 14.1 seconds, rounded to 14 seconds. Differences in output values between the tool and MATLAB simulations may be due to rounding differences or data type differences, where the tool uses integer data types while MATLAB uses float data types. The average accuracy for the mist maker was 97.37%.

Based on Table 7, for temperature measurements between 28 to 32°C and humidity between 74 to 82%, the lamp output on the tool ranged from 13 to 50, which are positive integers. The MATLAB simulation showed output values from 13.5, rounded to 13, to 14.1, rounded to 14. Differences in output values between the tool and MATLAB simulations may be due to rounding differences or data type differences. The average accuracy for the lamp was 98.81%.

With 500g of crickets in each cage, using the control system and conventionally.

Figure 12: Condition of Crickets in Cage Using System

In Figure 12, with a measured temperature of 27-32°C and humidity of 74-83%, the average temperature from August 24 to August 30, 2023, was 29.45°C, and the average humidity was 78.82%. These averages were within the set point ranges, although some data points showed temperatures ≤ 29 and humidity $\geq 78\%$.

In the cricket cage without a temperature and humidity control system, observations were conducted for 7 consecutive days, as shown in Figure 13.

The final result showed a decrease in the cricket population due to water spraying only at specific times. In this study, water spraying was performed at 06.00 and 17.00, causing temperature and humidity imbalances in the cricket cage, which should have been maintained. The crickets in the controlled cage weighed 17g, while the crickets in the uncontrolled cage weighed 15g, resulting in a 2g difference.

Table 6: Comparison of fuzzy data between the device and Matlab on the mist maker

Day	Data Collection	Time	Temp (°C)	Humidity (%)	fuzzy Device	fuzzy Matlab	Difference Mist Maker (s)	Error Mist Maker (s)	Accuracy Mist Maker (s)
1	1	06.00	30	78	7	7.1	0.1	1.4	98.6
	2	12.00	31	78	7	7.1	0.1	1.4	98.6
	3	18.00	28	78	7	7.1	0.1	1.4	98.6
2	1	06.00	29	78	7	7.5	0.5	6.66	93.34
	2	12.00	32	82	4	4.4	0.4	9.09	90.91
	3	18.00	31	79	7	7.1	0.1	1.4	98.6
3	1	06.00	29	78	6	6.3	0.3	4.76	95.24
	2	12.00	30	75	7	7.1	0.1	1.4	98.6
	3	18.00	30	80	4	4.4	0.4	9.09	90.91
4	1	06.00	29	78	7	7.1	0.1	1.4	98.6
	2	12.00	32	75	14	14	0	0	100
	3	18.00	31	81	7	7.1	0.1	1.4	98.6
5	1	06.00	29	75	14	14	0	0	100
	2	12.00	30	78	7	7.1	0.1	1.4	98.6
	3	18.00	31	78	7	7.1	0.1	1.4	98.6
6	1	06.00	29	79	6	6.3	0.3	4.76	95.24
	2	12.00	31	78	7	7.1	0.1	1.4	98.6
	3	18.00	30	78	7	7.1	0.1	1.4	98.6
7	1	06.00	28	78	14	14	0	0	100
	2	12.00	32	74	14	14	0	0	100
	3	18.00	29	79	6	6.3	0.3	4.76	95.24
				Average Accuracy					97.37

Table 7: Comparison of Measurement Data from Measuring Instruments and MATLAB Simulation

Day No.	Sampling Period	Time	Temp. (°C)	Humidity (%)	Fuzzy Device	Fuzzy MATLAB	Difference (sec)	Error (%)	Accuracy (%)
1	1	06:00	30	78	13	13.5	0.5	3.7	96.3
	2	12:00	31	78	14	14.1	0.1	0.7	99.3
	3	18:00	28	78	50	50	0	0	100
2	1	06:00	29	78	31	31.7	0.7	2.2	97.8
	2	12:00	32	81	13	13.5	0.5	3.7	96.3
	3	18:00	30	75	14	14	0	0	100
3	1	06:00	29	79	31	31.7	0.7	2.2	97.8
	2	12:00	31	75	14	14	0	0	100
	3	18:00	28	78	13	13.5	0.5	3.7	96.3
4	1	06:00	28	78	50	50	0	0	100
	2	12:00	32	75	14	14	0	0	100
	3	18:00	30	75	14	14	0	0	100
5	1	06:00	29	79	31	31.7	0.7	2.2	97.8
	2	12:00	31	75	14	14.1	0.1	0.7	99.3
	3	18:00	31	78	14	14	0	0	100
6	1	06:00	29	79	31	31.7	0.7	2.2	97.8
	2	12:00	31	75	14	14.1	0.1	0.7	99.3
	3	18:00	31	78	14	14	0	0	100
7	1	06:00	28	78	50	50	0	0	100
	2	12:00	32	74	14	14	0	0	100
	3	18:00	29	79	31	31.7	0.7	2.2	97.8
				Average Accuracy					**98.81**

IV. Conclusion

Based on the results of the research, several conclusions can be drawn: A temperature control system of 29.45°C and a humidity control system of 78.82% were realized in the cricket cage using the fuzzy logic method. The comparison between the fuzzy method on the measuring tool and MATLAB simulation showed an accuracy

Figure 13: Condition of Crickets in Cage Without System

percentage of 97.37% for the mist maker and 98.81% for the lamp. The DHT22 sensor testing results showed an average temperature reading error of 1.55% with an accuracy of 98.44% and an average difference of 0.58. The humidity reading error was 1.66% with an accuracy of 97.64% and an average difference of 0.93. In the controlled cricket cage with 50 crickets, the weight was 17g, while in the uncontrolled cage, the weight was 15g, resulting in a 2g difference.

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