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Smart Egg Incubator Based on IoT and AI Technology for Modern Poultry Farming

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Abstract

The productivity of egg hatching in the poultry industry is often hindered by conventional methods, resulting in low hatch rates and slow production. This study introduces the UHTP (Universitas Hang Tuah Pekanbaru) Smart Egg Incubator, which incorporates Internet of Things (IoT) and Artificial Intelligence (AI) technologies, specifically the Mamdani Fuzzy Logic Algorithm, to enhance egg hatchability. The incubator features a 100-egg capacity, automatic temperature and humidity control, cooling systems, and real-time monitoring via mobile devices. It also includes a camera for movement detection, capturing images of hatching eggs, and sending notifications to users. The automatic egg-turning mechanism ensures even temperature distribution. Experimental results show that the incubator maintains optimal temperatures between 37.7°C and 38.8°C, with successful hatching observed on the 19th day. The fuzzy logic AI system effectively manages environmental changes, ensuring a stable hatching process by dynamically adjusting the conditions within the incubator. The user-friendly interface and remote monitoring capabilities provide convenience and efficiency for poultry farmers. This innovative design significantly improves hatch rates and supports the economic productivity of chicken farming, offering practical solutions for modern poultry farming. The integration of this AI technology can lead to higher profitability and sustainability in poultry farming, addressing common challenges such as inconsistent environmental conditions and labor-intensive processes, thus contributing to the advancement of agricultural practices.

Keywords: Artificial Intelligence; Fuzzy Logic Mamdani; IoT; Smart Egg Incubator

Introduction

A hatching machine or incubator is a tool that plays a very important role in poultry farming and breeding businesses, both production and hobby poultry, where its various advantages compared to natural hatching make hatching machines increasingly widely used [1], [2]. Hatching machine technology continues to experience rapid development, even though it was initially made simply, both in terms of materials and working systems, where the hatching machine was originally only a manual machine, then developed into semi-automatic to fully automatic which was able to help speed up poultry breeding more effectively and efficiently [3], [4].

The benefits are as follows: 1) Increasing the hatching percentage, namely increasing the number of eggs that hatch until it can reach 80-90% (while in natural hatching with parent birds it is only 50-60%). This can be achieved because interference from the mother and other animals can be avoided, besides being able to regulate temperature and humidity according to the needs of hatching eggs. 2) Increase egg production, where the parent bird does not need to lose 21 days of time incubating its eggs and can immediately resume egg production after its physical condition recovers. By using an incubator, eggs can be hatched directly without the mother having to incubate them. 3) Not constrained by the ability and character of the parent, where in natural hatching, it is often found that parent birds are unable to incubate all the eggs they produce, especially in high-producing chickens. Also, newly hatched chicks naturally often die due to being trampled by their parents. The use of hatching machines is also required for birds that are bred using artificial insemination in broiler and layer chicken breeding businesses [5], [6].

In the livestock business, one of the inhibiting factors is slow egg production due to breeders still using conventional methods for hatching eggs [7]. There are several obstacles faced by chicken farmers in carrying out their livestock business, namely the productivity of chickens is very low, both in egg production and growth. This situation is caused, among other things, by several factors, namely: (a) genetic factors; (b) maintenance method; and (c) inadequate feeding. Apart from that, there are other factors, namely due to extensive maintenance, chickens are left to find their own food, the layout of the chicken hatching location is inadequate and disease prevention is not carried out

[8]. The use of currently developing technology is very much needed in livestock businesses, especially in the process of hatching chicken eggs [9]. The Internet of Things connects the physical world to the Internet so you can use data from devices to increase productivity and efficiency [10]–[12]. IoT devices differ greatly in storage capacity, size, computing power, and energy supply [13], [14].

The use of an Egg Incubator has several advantages compared to natural egg hatching, namely the hatching machine space is wider so it can accommodate more eggs than the natural brood hatching method [15], [16]. The following are various advantages of hatching eggs using an Egg Incubator compared to natural hatching: 1) The percentage of successful hatching of eggs is greater compared to natural hatching. Through a natural incubation process, only 50-60% of the eggs hatch. Meanwhile, hatching with the help of a hatching machine can increase up to 80%; 2) Egg hatching can be carried out continuously without being influenced by weather conditions. The reason is, hatching machines are usually placed indoors and all supporting components are controlled; 3) The survival rate of chicks hatched using a hatching machine is higher compared to natural hatching. The temperature changes from inside the egg to the environment are not too extreme. In contrast, chicks resulting from natural hatching must adjust to the temperature more after hatching; 4) Controlling egg quality is easier. Apart from that, the risk of bacterial contamination and disease is relatively smaller because the eggs are stored indoors [17], [18].

Previous research was conducted by [19] resulting that an egg incubator using a Raspberry Pi3 with a capacity of 4 eggs, a heater using solder heating media, and sending temperature information to a mobile device. The next research was [20], in this design the author uses a temperature control system that controls the temperature of the incubator. This system consists of a temperature sensor, heating and cooling elements and a controller. If the incubator temperature exceeds a certain value, the cooling unit will operate to lower the temperature, whereas if the temperature falls below another threshold value, the heating element will start operating to increase the temperature.

The next research is [21], a smart egg incubator system was chosen to be integrated with IoT technology. The egg incubator system has two types of sensors, namely temperature sensors and humidity sensors. This sensor is used to measure the condition of the incubator and send the data to the microcontroller system. The status conditions of the egg incubator appear on the LCD screen display. Research [22] is a cost-effective incubator for hatching poultry eggs with minimal human involvement. This paper describes the design and implementation of a prototype microcontroller-based electric incubator system. The developed incubator has optimal temperature and humidity that facilitates higher hatchability rates provided the fertility of the eggs is high. The incubator prototype was evaluated by loading it with 6 eggs deemed fertile. The percentage of hatchability obtained was 67% (4 out of 6 eggs). The remaining two eggs did not hatch because they may not have been fully fertilized.

The existing egg incubator is still not optimal, because the hatcher still has to adjust the lights and there is no automation feature to get the ideal temperature. There is no feature for monitoring the condition of the incubator room in real time, namely monitoring whether eggs hatch which can be captured by an artificial intelligence-based camera. In previous research there was only monitoring of temperature and humidity, it is necessary to develop monitoring and control of temperature and humidity using IoT-based mobile devices and intelligent systems. The use of sensors on an industrial scale is also very necessary so that equipment can work optimally.

Based on a review of previous research, the researchers developed an egg incubator product to produce a better prototype called The UHTP Smart Incubator (Universitas Hang Tuah Pekanbaru) based on the Internet of Things (IoT) and Fuzzy Logic Mamdani for artificial intelligence (AI) integration. The feature of this prototype is an incubator with a capacity of 100 eggs that has an automatic temperature monitoring and setting feature according to the ideal temperature for hatching eggs using a light bulb as an incubator heater. In addition, a cooling feature is added to lower the temperature if it is too high. The system uses Fuzzy Logic Mamdani to manage temperature and humidity control, ensuring proper adjustment based on real-time data. Monitoring of temperature conditions can be accessed through smartphones and PCs using IoT technology.

The Fuzzy Logic Mamdani algorithm was chosen for its ability to handle uncertain data and provide more adaptive control compared to conventional methods [23]. By using if-then rules based on fuzzy logic, the system can make temperature and humidity adjustments more accurately and responsively to changing environmental conditions. This allows the incubator to maintain optimal conditions around the clock, increasing hatching success rates and reducing the need for manual intervention by breeders. The implementation of fuzzy logic not only provides technical benefits, but also supports the economic sustainability of the farm by improving productivity and operational efficiency.

The Smart Egg Incubator has a camera that aims to monitor if a chicken egg hatches and provide notification on a smartphone so that the user can immediately move the chicks. The system can also detect door movement, allowing it to distinguish between human movement or broken eggs. To ensure the temperature is evenly distributed throughout the egg, a servo motor feature is added, which will move the egg automatically. The LCD screen displays the temperature and humidity inside the incubator chamber, and LED lights indicate whether the temperature is normal or not.

The novelty of this research lies in the comprehensive integration of IoT and Fuzzy Logic Mamdani for AI to create a more efficient and user-friendly egg incubator. Unlike previous models, The UHTP Smart Incubator not only automates temperature and humidity control using fuzzy logic but also provides real-time data access and intelligent monitoring capabilities. These advancements contribute to increased hatching rates, better productivity and greater economic benefits for chicken farmers. By addressing specific gaps in existing research and offering unique technological solutions, this study makes a significant contribution to the field of poultry farming technology.

Method

The stages in this study are shown in the following **Figure 1**:

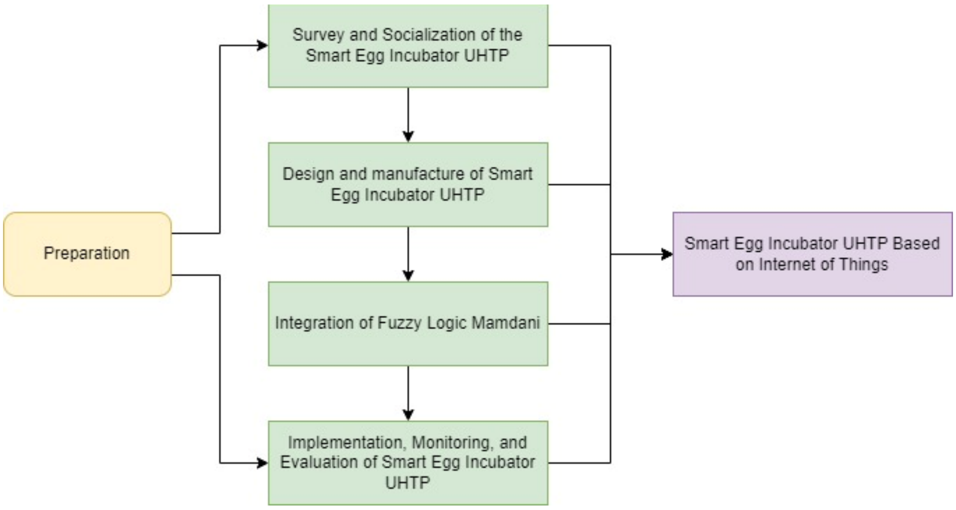

Figure 1. Research methodology

The stages of implementing the activities are as follows:

1) *Survey and Socialization of the IoT-based Smart Egg Incubator*
   The survey of the incubator equipment location was carried out at the Central Chicken Farmers in Pekanbaru City, Indonesia. From the survey results, information was obtained regarding the livestock situation and several problems faced by the farmers. After conducting the location survey, further outreach was conducted about the importance of using an IoT-based egg incubator to maximize chicken production and improve the community's economy.

2) *Design and Manufacture of the UHTP Smart Incubator Based on the Internet of Things (IoT)*
   The UHTP Smart Incubator employs a Raspberry Pi 3 microcontroller to process data and control functions. The SHT35 temperature sensor ensures accurate monitoring of temperature and humidity [24]. A cooling system with fans activates when the temperature exceeds the threshold, while incandescent lamps provide necessary warmth. Movement detection is achieved through PIR sensors and a web camera, allowing real-time observation. Servo motors automate egg turning for even temperature distribution. An LCD display shows current temperature and humidity readings. The system is powered by a reliable power supply and features a LAN module for internet connectivity, enabling remote monitoring and control through IoT technology. The monitoring process can be carried out in real-time at a location far from the incubator or remotely with the help of the internet [25]. At the design stage, testing will also be conducted on the functional performance of the Smart Egg Incubator UHTP.

3) *Integration of Fuzzy Logic Mamdani*
   After completing the design and manufacturing stages, the integration of the Mamdani Fuzzy Logic Algorithm is carried out to control temperature and humidity automatically. This algorithm is chosen for its ability to handle uncertain data and provide more adaptive control compared to conventional methods. The fuzzy system uses if-then rules based on fuzzy logic to make more accurate and responsive adjustments to temperature and humidity in response to changes in environmental conditions.

4) *Implementation, Monitoring, and Evaluation of the UHTP Smart Egg Incubator*
   Monitoring activities were carried out by distributing questionnaires to participants, containing five indicators of satisfaction and feasibility in using the IoT-based egg incubator. Next, evaluation is carried out based on the percentage of eggs that hatch while the egg incubator machine is in use. If the percentage of eggs that hatch is very high, the egg hatching machine is deemed suitable for use [3].

Results and Discussion

The aim of developing the prototype is that the research team plans to develop the results of the previous prototype product to produce a better prototype called the UHTP Smart Incubator where the feature of the prototype is an incubator with a capacity of 100 eggs which has an automatic temperature monitoring and setting feature according to temperature. ideal for hatching eggs using a light bulb. Added cooling feature to lower the temperature if the temperature is too high. Monitoring temperature conditions can be accessed via smart phones and PCs using Internet of Things technology [26]. The Smart Egg Incubator can carry out movement detection which aims to automatically monitor if chicken eggs are hatching and provide notifications on the smart phone so that users can immediately move the chicken, and the system can detect door movements so that it can differentiate between human movement or hatching eggs. So that the temperature that hits the egg can be evenly distributed to all parts of the egg, a feature using a servo motor is added which will move the egg automatically so that the temperature can hit the egg evenly. The LCD display feature will display the temperature and humidity in the incubator room, and the addition of LED lights to indicate whether the temperature is normal or abnormal.

A. Analysis

The UHTP Smart Incubator is a smart machine for automatically incubating chicken eggs using Internet of Things technology. The advantages of this prototype are that it is equipped with automatic temperature monitoring and control features, LED and LCD displays that detect if an egg hatches, an automatic egg driver for even temperature distribution, IoT technology for controlling and sending information to smart phone or PC devices [27] and modern and elegant prototype design. The social impact of implementing the prototype is that it can increase knowledge and motivate the community, especially breeders, to increase productivity. The economic impact is to improve the economy of chicken farmers because productivity increases. The proposing team can provide income, namely from sales of prototype products to the public or chicken breeders.

B. System Design

The UHTP Smart Incubator has features with industry specifications so that the tool can work optimally. In automatic temperature monitoring and regulation using the SHT35 Temperature sensor with industry specifications according to the ideal temperature for hatching eggs using a light bulb as heating [26]. A Raspberry Pi3 microcontroller is needed to function as a data processing center whose job is to process all incoming and outgoing data. Add a cooling feature to lower the temperature if the temperature is too high. Monitoring temperature conditions which can be accessed via smart phone and PC using Internet of Things technology [25]. The Smart Egg Incubator can carry out movement detection which aims to automatically monitor using a PIR sensor if a chicken egg hatches and provide a notification on the smart phone so that the user can immediately move the chicken, and the system can detect the movement of the door so that it can differentiate between the movement of a human or an egg hatch. So that the temperature that hits the egg can be evenly distributed to all parts of the egg, a feature has been added using a servo motor which will move the egg automatically so that the temperature can hit the egg evenly, Digital Programmable Timer Delay Relay for controlling the rotation timer on the servo motor. An LCD display feature that will display the temperature and humidity in the incubator room, and the addition of an LED light to indicate whether the temperature is normal or abnormal. The design plan for the UHTP Smart Incubator prototype can be seen **Figure 2**.

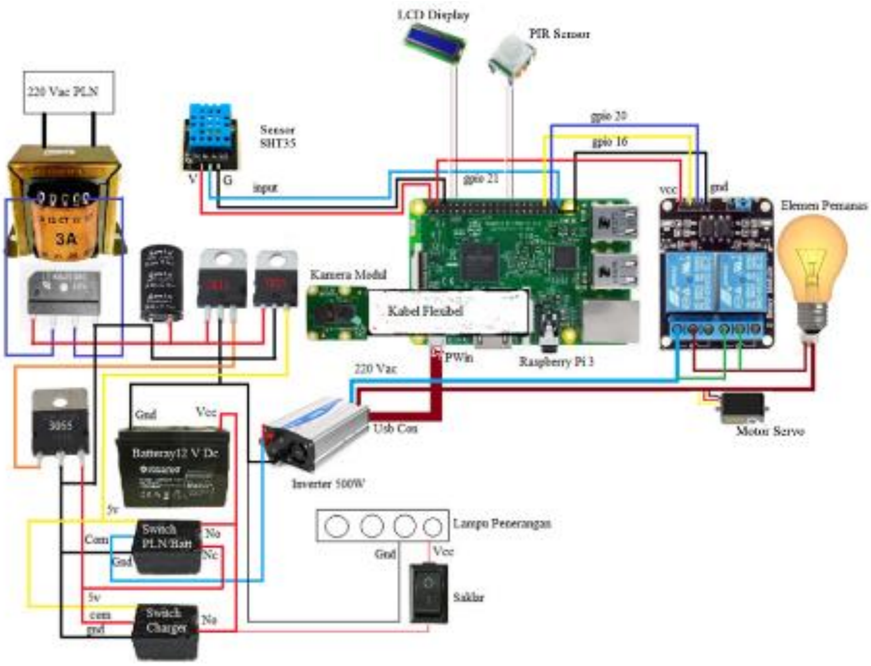

Figure 2. Tool Circuit Design

An explanation of the function of each series of tools or electronic components that will be used can be seen in the **Table 1**.

Table 1. Function of each tool

No	Component Name	Function
1	Raspberry Pi	Control the entire system on the incubator and connect devices to the WiFi network [28], [29]
2	Pir Sensor	Chicken egg movement detection sensor [30]
3	Door Sensors	Movement detection sensor on the door
4	Web Camera	The camera monitors the area in the incubator to send images when the eggs hatch
5	SHT35 temperature sensor	Measuring air temperature and humidity values [31]
6	LCD 1602	Displays temperature and humidity on the incubator
7	Digital Programmable Timer Delay Relay	Rotation timer controller on servo motor
8	LY2 relay	Turns the incandescent light on and off
9	Servo Motors	Move the egg container so that the eggs are evenly exposed to the light
10	Fan	Incubator area cooler
11	Incandescent lamps	Incubator heating lamp
12	Led Lamp	Marks whether the temperature is normal or abnormal
13	Power Supplies	Provides voltage and electric current to the device
14	LAN Module	As a device to connect the incubator to the internet network using a LAN cable

The physical design of the prototype to be developed can be seen in the **Figure 3**.

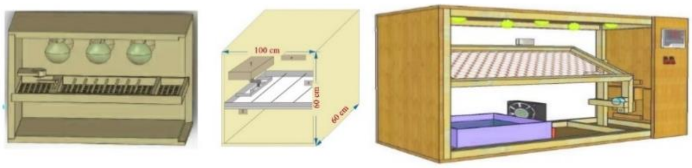

Figure 3. Prototype design to be developed

The UHTP Smart Incubator is implemented at the Riau Chicken Breeding Center and a Validation Test will be carried out in the relevant environment, namely the Riau Chicken Breeding Center, so that it is hoped that the prototype can work optimally according to community needs.

To ensure optimal temperature and humidity conditions within the Smart Egg Incubator UHTP, the Mamdani Fuzzy Logic Algorithm has been implemented. **Table 2** outlines the fuzzy rules that govern the operation of the heater and fan based on the current temperature and humidity readings. These rules are designed to provide precise and adaptive control, thereby enhancing the efficiency and effectiveness of the incubation process.

Table 2. Fuzzy Rules for Temperature and Humidity Control

Rule No	Temperature (°C)	Humidity (%)	Heater Status	Fan Status
1	< 37.0	< 50	On	Off
2	< 37.0	50 - 70	On	Off
3	< 37.0	> 70	On	On
4	37.0 - 38.0	< 50	Off	Off
5	37.0 - 38.0	50 - 70	Off	Off
6	37.0 - 38.0	> 70	Off	On
7	> 38.0	< 50	Off	On
8	> 38.0	50 - 70	Off	On
9	> 38.0	> 70	Off	On

C. Results

The made incubator tool has a capacity of 100 eggs that can be accommodated. The way this tool or machine works is to carry out the incubation process without a parent using an incandescent lamp. The UHTP Smart Incubator technology that has been completed can be seen in the **Figure 4** dan **Figure 5**.

Figure 4. UHTP Smart Egg Incubator Display

Figure 5. Display of the UHTP Smart Egg Incubator Control Box

The UHTP Smart Incubator has features with industry specifications so that the tool can work optimally. In automatic temperature monitoring and regulation using the SHT35 Temperature sensor with industry specifications according to the ideal temperature for hatching eggs using a light bulb as heating.

D. Test Results

After completing the design stage of the UHTP Smart Egg Incubator, the equipment testing stage was then carried out. The testing process was carried out with the aim of finding out whether the egg incubator machine that had been made could function as expected, as shown in the Table 3:

Table 3. Hardware Component Testing

No	Test Items	Function	Results	
			Valid	*Invalid*
1	Raspberry Pi	Control the entire system on the incubator and connect devices to the WiFi network	√	
2	Pir Sensor	Chicken egg movement detection sensor	√	
3	Door Sensors	Movement detection sensor on the door	√	
4	Web Camera	The camera monitors the area in the incubator to send images when the eggs hatch	√	
5	SHT35 temperature sensor	Measuring air temperature and humidity values	√	
6	LCD 1602	Displays temperature and humidity on the incubator	√	
7	Digital Programmable Timer Delay Relay	Rotation timer controller on servo motor	√	
8	LY2 relay	Turns the incandescent light on and off	√	
9	Servo Motors	Move the egg container so that the eggs are evenly exposed to the light	√	
10	Fans	Incubator area cooler	√	
11	Incandescent lamps	Incubator heating lamp	√	

No	Test Items	Function	Results	
			Valid	*Invalid*
12	Led Lamp	Marks whether the temperature is normal or abnormal	√	
13	Power Supplies	Provides voltage and electric current to the device	√	
14	LAN Module	As a device to connect the incubator to the internet network using a LAN cable	√	

From the test results of the hardware components in the table above, it can be concluded that overall the electronics, sensors and IoT components have worked as expected. The next stage of testing is to carry out the functional components of the UHTP smart egg incubator so that it runs according to the expected function. The results of the incubator monitoring functional testing can be seen in the following **Table 4**.

Table 4. Incubator Monitoring Functional Testing

No	Testing Scenarios	Test Cases	Expected Results	Test Result	Conclusion
1	Egg Chamber Temperature is at an invalid value	Egg room temperature ≥ 38.8° C	The incandescent light in the egg hatching room is off, the fan is on	According to expectations	Valid
2	The egg chamber temperature is at a valid value	Egg room temperature < 37.7° C	The incandescent light in the egg hatching room is on, the fan is off	According to expectations	Valid
3	Sending images via camera to telegram when movement occurs in the incubator room	There is movement in the incubator area	The camera captures images of the incubator room and sends them to Telegram	According to expectations	Valid
4	The egg holding container moves around according to the specified timer	Setting the timer via the Timer Delay Relay every 1 hour the egg container moves	The egg holder moves via a servo motor every 1 hour	According to expectations	Valid
5	Sending temperature and humidity status parameters of the incubator room via the mobile application	The mobile application is accessed to monitor the temperature and humidity status of the incubator room	The application can display the temperature and humidity conditions of the incubator in real time	According to expectations	Valid

From the results of tests that have been carried out on the UHTP Smart Incubator which runs as expected and the components, the incubator is suitable for use.

Figure 6. Documentation of UHTP Smart Egg Incubator Testing in Relevant Environments

The benchmark for the success of developing the UHTP Smart Incubator prototype is seen from the success of the prototype in carrying out the egg hatching process as well as the success of the tools for maintaining temperature and humidity. From the results of monitoring and evaluation of the Smart Egg Incubator UHTP, temperature threshold data was obtained from 34.3° C to 39.5° C and humidity 57-67% as shown in the following **Table 5**.

Table 5. Temperature and humidity threshold testing

No	Testing to	Temperature	Humidity	Information
1	First	34.3	57	Lights On, Fan Off
2	Second	35.0	58	Lights On, Fan Off
3	Third	36.0	58	Lights On, Fan Off
4	Fourth	39.5	68	Lights Off, Fan On
5	Fifth	37.2	63	Lights On, Fan Off
6	Sixth	36.8	61	Lights On, Fan Off
7	Seventh	39.3	67	Lights Off, Fan On

The results of the UHTP Smart Incubator temperature and humidity threshold test in the table above show that at temperatures below the normal incubation temperature limit, namely 37.7° C, the tool will turn on the lights and turn off the fan to increase the temperature to the normal temperature limit, namely 37.7° C to 38.8° C. If the incubator has reached the maximum temperature of the normal temperature, namely 38.8°C, the incubator will turn off the lights and turn on the fan to the minimum normal temperature. To regulate the temperature, it is necessary to control the lights periodically and for humidity, it is necessary to fill the water tank with enough water until the temperature and humidity are appropriate. On the 18th day, signs of the eggs begin to appear with small cracks in the eggs and it takes a day for them to hatch completely. From a test sample of 20 eggs, 3 eggs were successfully hatched in 19 days.

Figure 7 illustrates the results of the fuzzy logic testing for the UHTP Smart Egg Incubator. This testing was conducted to assess the system's ability to maintain optimal temperature and humidity conditions. The graph plots temperature and humidity readings across various test instances, alongside annotations indicating the status of the heater and fan at each point. These results demonstrate how the Mamdani Fuzzy Logic Algorithm effectively manages environmental conditions within the incubator to ensure successful egg incubation.

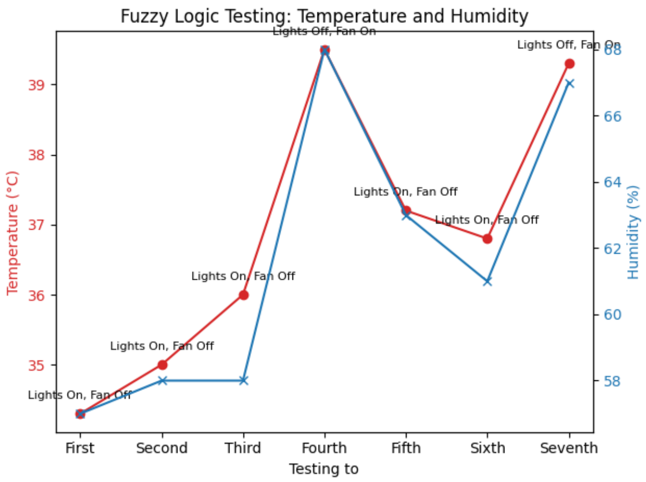

Figure 7. Fuzzy Logic Testing for Temperature and Humidity

Figure 7 presented here showcases the results of the fuzzy logic testing for the UHTP Smart Egg Incubator, focusing on temperature and humidity control. The red line represents the temperature (°C) readings, while the blue line represents the humidity (%) readings across seven different test instances. Each data point is annotated with the status of the heater and fan, indicating whether they were on or off during the test. For instance, during the fourth test, the temperature peaked at 39.5°C with the lights off and the fan on, ensuring the temperature was regulated effectively. The annotations such as "Lights On, Fan Off" and "Lights Off, Fan On" demonstrate the real-time adjustments made by the fuzzy logic system to maintain optimal incubation conditions. This visual representation confirms the efficiency of the Mamdani Fuzzy Logic Algorithm in dynamically adjusting the environmental parameters to achieve the desired conditions for egg incubation.

The level of user satisfaction with the tool (usability) can be determined by filling out a questionnaire by laying hen breeders. The questionnaire is a USE (Usefulness, Satisfaction, Ease of use and learning) questionnaire. This questionnaire contains 16 statement items with a total of 30 respondents. Test characteristics are divided into 4 categories of user satisfaction, namely usefulness, ease of use, ease of learning, and satisfaction. The accumulated score data obtained from 10 respondents for the UHTP Smart Incubator Prototype is as **Table 6**.

Table 6. Results of Respondent Responses

No	Statement	Respondent*					Score	% Score
		1	*2*	*3*	*4*	*5*		
Usefulness								
1	This tool helps me work more effectively and productively	0	0	1	2	7	46	92
2	This tool is very Useful	0	0	0	2	8	48	96
3	This tool saves me time when using it	0	0	1	4	5	44	88
4	This tool fits my needs and expectations	0	0	2	3	5	43	86
Ease of Use								
1	This tool is easy to use	0	0	0	2	8	48	96
2	This tool is practical for users	0	0	0	3	7	47	94
3	There is no difficulty in using this tool	0	0	2	1	7	45	90
4	I can use this tool without written instructions	0	0	3	1	6	43	86
Ease of Learning								
1	I learned to use this tool quickly	0	0	1	2	7	46	92
2	I can easily remember how to use this tool	0	1	1	3	5	42	84
3	It was easy for me to learn to use this tool	0	0	3	1	6	43	86
4	I quickly became skilled at using this tool	0	0	3	1	6	43	86
Satisfaction								
1	I am satisfied with this tool	0	0	0	3	7	47	94
2	I would recommend this tool to others	0	0	2	3	5	43	86
3	This tool works as I want	0	0	1	2	7	46	92
4	This tool is comfortable to use	0	0	0	3	7	47	94
Total							721	90.1 3%

* 1: Strongly disagree; 2: Disagree; 3 : Somewhat Agree; 4 : Agree; 5 : Strongly Agree

Based on data on the level of user satisfaction with the UHTP Smart Egg Incubator, it can be seen that the level of user satisfaction reached an average value of 90.13%, this shows that the UHTP Smart Incubator is suitable for use in the egg hatching process, apart from that, the UHTP Smart Incubator is based on Internet of Things (IoT) can also make the egg hatching process easier and can increase the economic productivity of chicken farming business groups in Pekanbaru City, Indonesia. The findings demonstrate significant improvements over conventional hatching methods and previous incubator models. The UHTP Smart Egg Incubator 's integration of IoT and AI technologies provides a comprehensive solution for maintaining optimal incubation conditions and enhancing hatching success rates.

When compared to previous studies, such as Purwanti [19] who used a Raspberry Pi 3 for a smaller capacity incubator, the UHTP Smart Incubator showcases advancements in scalability and automation. Additionally, studies like Kutsira [22] highlighted the need for minimal human involvement, which is effectively addressed by the UHTP Smart Egg Incubator's automatic control and monitoring features.

Conclusion

Based on the results of the research, it can be concluded that the normal incubation temperature limit is 37.7°C. The tool will turn on the lights and turn off the fan to increase the temperature to the normal range of 37.7°C to 38.8°C. If the incubator reaches the maximum temperature of 38.8°C, it will turn off the lights and turn on the fan to reduce the temperature. From the experiment, chicken eggs hatched on the 19th day using the UHTP Smart Egg Incubator. Temperature and humidity can be monitored in real time via a mobile device using Internet of Things (IoT) technology, and if an egg hatches, the camera will take a picture of the condition of the incubator room and send it to the user via Telegram. The fuzzy logic testing results showed effective management of temperature and humidity, as illustrated in the graph. For example, during the fourth test, the temperature peaked at 39.5°C with the lights off and the fan on, indicating the system's capability to adjust conditions dynamically to maintain optimal incubation parameters. The level of user satisfaction reaches an average value of 90.13%, indicating that the UHTP Smart Incubator is suitable for the egg hatching process. Additionally, the UHTP Smart Incubator based on IoT provides convenience in the egg hatching process and can increase the economic productivity of chicken farming business groups. Future research could focus on several areas to further enhance the UHTP Smart Egg Incubator. These include testing with larger capacities and different types of eggs, developing more energy-efficient systems, incorporating advanced AI for predictive maintenance and optimized hatching conditions, improving the user interface, and conducting long-term robustness testing. Performing a comprehensive cost-benefit analysis to evaluate the economic impact of widespread adoption in various farming communities will also be valuable. Addressing these areas will optimize the incubator to meet the diverse needs of poultry farmers and significantly contribute to the advancement of agricultural practices.

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