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Implementation of Fuzzy Logic in the Monitoring and Controlling System for Temperature and pH of Fry Aquarium Water Betta Fish Based on the Internet of Things

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***Abstract* – A problem faced by betta fish farmers is the difficulty in monitoring and controlling the temperature and pH of the water in betta fish fry ponds. This condition causes many deaths of Betta fish fry which results in a reduction in the supply of Betta fish seeds. To overcome this problem, a system based on the Internet of Things was developed(IoT) which can monitor in real time and control the temperature and pH of the water in the Betta fish fry pond. This system is implemented in an aquarium equipped with artificial intelligence in decision making which aims to keep the temperature and pH of the aquarium water stable. The components used in this system include ESP32, DS18B20 temperature sensor, water pH sensor, Thermo Electric Cooler (TEC), heater, DC pump, and fuzzy logic implementation. The results of system testing for 14 days showed that the system was able to monitor and control the temperature and pH of the aquarium water, maintaining ideal conditions for Betta fish fry with an average temperature of 28.79°C and an average water pH of 7.45. The system also succeeded in reducing the mortality rate of Betta fish fry, as proven in comparative tests between aquariums without system implementation and aquariums with system implementation. In this trial, each aquarium was filled with 30 betta fish fry. The results showed that the aquarium with system implementation was able to reduce the death rate of Betta fish fry by 5 or 16.67% from a total of 30 fish. Meanwhile, aquariums without system implementation had a death rate of 12 betta fish fry or 40% of the total of 30 betta fish fry.**

Keywords: Fuzzy Logic, Temperature Control, pH Control, Betta Fish, IoT.

I. Introduction

Betta fish or Betta Splendens is a species of freshwater fish originating from Indonesia. This fish is known for its beautiful, colorful body and long, ribbon-like fins. Since ancient times, Betta fish have undergone a breeding process focused on ornamental fish needs. This breeding is expected to improve the aesthetic appearance of Betta fish, producing various stunning varieties of Betta fish. The role of Betta fish as ornamental fish is increasingly prominent, the beauty and ease of care for Betta fish are the main reasons behind their popularity in the world of ornamental fish [1].

Betta fish are a tough type of fish and can be kept in small aquariums. Uniquely, Betta fish are often sold in retail stores in glasses or glass bottles without any filtration or aeration process. Even though the popularity of Betta fish continues to increase, a deep understanding of the environmental needs and welfare of Betta fish remains an important aspect in keeping them [2]. So it is very necessary to pay close attention to ensure optimal environmental conditions for the welfare of betta fish.

When it comes to spawning betta fish, there are a number of problems that can cause stress to betta fish, hindering their ability to mate. The breeding efforts of the Betta fish pair itself are vulnerable and need careful handling. This condition can lead to the risk of death in the early stages of development of Betta fish fry after breeding [3]. Several factors that influence the success of raising Betta fish fry involve aspects such as type of feed, water quality, presence of pests and potential for disease. Betta fish habitat characteristics such as water pH 6.5-8, water temperature 24-30°C, and the ability of Betta fish to survive in low oxygen levels caused by the presence of a labyrinth cavity similar to human lungs in fish. Siamese fighting fish [4]. Adjustments to these conditions need to be made according to the needs and behavior of Betta fish in their natural habitat. This has an important role in supporting optimal growth and survival of betta fish fry.

Currently, most betta fish farmers still carry out maintenance manually. The challenge in caring for fish manually is when the fish owner is busy or has other activities that make it difficult to monitor and maintain pond water quality consistently [5].

Caring for Betta fish fry can be more effective by using tools and systems that can control the water quality in the aquarium or Betta fish fry pond. In research conducted by Rahmat Salfitrah, he has succeeded in creating a system for monitoring and controlling the temperature and pH of Betta fish fry aquarium water using the KNN method [6]. The system created uses an Arduino as a microcontroller, and an LCD to display the sensor values read in the aquarium water and will classify the sensor values to determine the action of the actuator.

Based on existing problems and previous research, the author created a system that can control and monitor water quality in Betta fish fry aquariums using the fuzzy method. The fuzzy method is a controller that does not require an exact mathematical model of the system in question and shows excellent resistance to external disturbances [7]. The advantage of the fuzzy controller is its ability to respond quickly in transient situations and a fast response time so it is very suitable for controlling the temperature and pH of Betta fish fry aquarium water.

II. BASIC THEORY

Wateris a medium for fish farming activities, therefore understanding water quality is very important. Good water quality (according to cultivation standards) will be able to support optimal growth rates for fish cultivation. Based on knowledge and literature studies, the most important thing in managing water quality in the media for keeping Betta fish fry in a closed room is the temperature and pH parameters of the water which will greatly influence the survival of Betta fish fry [3].

ESP32 is a microcontroller equipped with high-speed Wi-Fi, making it very suitable for supporting the implementation of Internet of Things (IoT) systems and Bluetooth capabilities while using low power [8]. ESP32 is a development of the NodeMCU ESP8266 which has the disadvantage of not having a Bluetooth module but has the same function as an electronic circuit controller and also supports the development of Internet of Things (IoT) application systems.

Figure 1. NodeMCU ESP32

DS18B20is the latest temperature sensor from Maxim with the ability to read temperatures in the range of 9 to 12 bits, covering -55°C to 125°C with an accuracy level of around 0.5°C [9].

Figure 2. DS18B20 Temperature Sensor

pH sensorsis a glass electrode formed from glass bubbles that are sensitive to pH at the tip and contains a chloride solution that knows the pH as well as the reference electrode. To increase its functionality, this pH sensor is equipped with a data acquisition module. This module is responsible for converting the sensor output into a voltage on the analog pin, and at the same time has characteristics that cause the resulting voltage to become greater as the acid level in the pH of the water increases [10].

Figure 3. Water pH sensor

Heater is a device used to increase the water temperature according to predetermined parameters. The heater will activate when the water temperature is outside the specified range of parameters [11].

Figure 4. Water Heater

The Peltier device is a thermoelectric module (TEC) coated with thin ceramic and containing bismuth telluride rods inside. When a DC voltage is applied, one side becomes hot while the other side becomes cold (Peltier effect), or vice versa when heat is supplied to the hot side of the Peltier and cooling is supplied to the cold side (temperature difference), resulting in an electric current (Seebeck effect). For cooling (TEC), the hot side of the Peltier needs to be cooled down as much as possible with a heatsink and fan (as well as thermal paste to maximize cooling). The temperature difference between the two sides of the Peltier is about 60 degrees, and the Peltier should also be placed between heatsinks to ensure maximum heat dissipation [12].

Figure 5. Thermoelectric Module

Ultrasonic sensor is a device that utilizes sonar principle to measure distance. This sensor consists of two ultrasonic transducers, each functioning as a transmitter and a receiver. Its operation is based on the reflection of ultrasonic sound waves to measure the distance of an object from the sensor position. Ultrasonic waves are sound waves with frequencies above 20 kHz. The ultrasonic transmitter emits sound waves with a frequency of 40 kHz, and when these waves hit an object, they are reflected back and received by the ultrasonic receiver. The time taken to receive the reflected sound wave is used as the basis for measuring the distance from the sensor to an object. In the system designed in this research, ultrasonic sensors are used as the upper and lower limits of the aquarium water level [13].

Figure 6. Ultrasonic Sensor

The pumps used in this study are two DC pumps which function as controllers for the aquarium water pH. In this system, the first pump, known as the "out" pump, is used to drain water from the aquarium until it reaches the lower water level limit, which is 17 cm from the ultrasonic sensor. The second pump is the "in" pump, which is used to pump water from the water reservoir into the aquarium until it reaches the upper water level limit, which is 8 cm from the ultrasonic sensor [14].

Figure 7. DC Pump

ThingSpeak is an internet of Things (IoT) platform that allows users to collect, manage and analyze data from various connected devices. ThingSpeak offers cloud services that make it easy for users to create and manage IoT projects. One of ThingSpeak's key features is its ability to integrate data from multiple sources, such as sensors, microcontrollers, and other IoT devices [15].

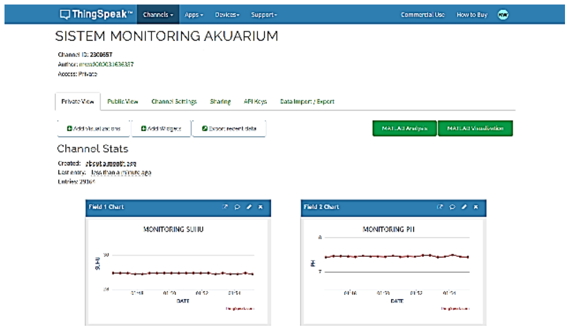

Figure 8. Display of ThingSpeak Software

Fuzzy Logic is a field of Artificial Intelligence (AI). Artificial Intelligence is computer science that studies machines (computers) that can act like humans or even better. Fuzzy Logic is a method for finding solutions to problems that are considered unclear [16]. In its solution, fuzzy logic uses linguistics such as in explaining water temperature, namely cold, normal, hot.

Fuzzy logic There are four stages in decision making, namely:

1. Fuzzification
   Fuzzification is a step of transforming input values from classic crisp sets into fuzzy values consisting of linguistic variables and membership functions.
2. Inference
   The process of inference involves reasoning on information or knowledge already existing in the environment, with the aim of generating information or new knowledge.
3. Defuzzification
   Defuzzification process changes the fuzzy output value to the original value (crisp set). The defuzzification method used in this study is the centeroid method [17], the defuzzification equation for the centeroid method is:

$$\bar{y} = \frac{\int_{Y-min}^{Y-max} y.\mu Y(y)dy}{\int_{Y-min}^{Y-max} \mu Y(y)dy}$$

4. System Implementation
   The final stage involves the application of models that have been made using the fuzzy logic method into the control system of temperature and pH levels in the aquarium used for the betta fish fry care.

III. Methods

The stages of the research method are the steps used in conducting research presented in the form of a comprehensive block diagram. In this study, there are two stages, namely the software design stage integrated with the fuzzy method and the hardware design stage.

A. *Software Design*

Software design is crucial for mathematical processing throughout the entire program. The essence of this software design lies in implementing the Mamdani fuzzy method for decision-making by actuators such as heaters, peltiers, and DC pumps. The software design in this system involves developing a system that will operate automatically based on readings from the sensors used, namely ultrasonic sensors, pH sensors, and DS18B20 temperature sensors. The flowchart of the software system design can be seen in Figure 5.

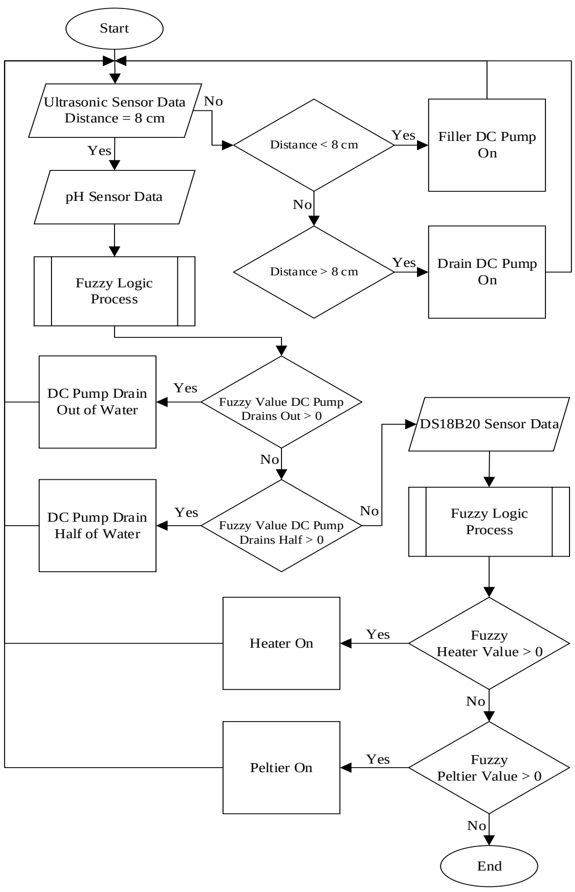

Figure 9. System Flowchart

B. *Hardware Design*

In hardware design, the selection of components used to create a monitoring and control system for temperature and pH of Betta fish fry aquarium water is encompassed. This system is designed using the ESP32 microcontroller and is equipped with a DS18B20 temperature sensor and a pH sensor to read the parameters needed to determine water quality levels, namely water temperature and pH. Each sensor will convert sensor readings into voltage units which are then processed in an analog-to-digital converter (ADC). Data obtained from the sensors will then be processed by the ESP32 microcontroller, which has been combined with fuzzy logic. Fuzzy logic will function as a data processor produced by sensors to determine what output will be carried out by the actuators used, such as heaters, peltiers, and DC pumps, by utilizing linguistic variables contained within fuzzy logic. As a result, levels of off, medium, and strong will be obtained for the output provided by the heaters and peltiers. Meanwhile, the levels of the DC pump will be off, draining halfway, and fully draining for the output generated by the DC pump. The hardware design can be seen in Figure 6.

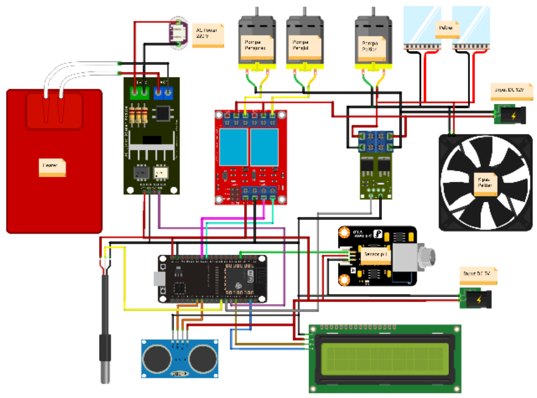

Figure 10. Overall system circuit

C. *Data Processing*

After going through the stages of hardware and software design, the next step is data processing. There are two Mamdani fuzzy methods created to be implemented in this system, one for temperature data processing and another for pH data processing. In the fuzzy temperature input, there are five membership functions consisting of cold, cool, normal, warm, and hot. It then generates output actions to be taken by the heater and peltier. Meanwhile, in the fuzzy pH input, there are five membership functions consisting of very acid, acid, neutral, alkaline, and highly alkaline. It then produces output actions to be taken by the DC pump.

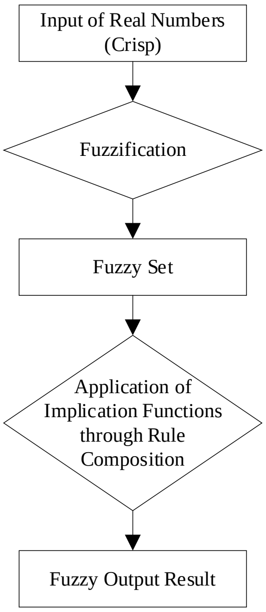

Figure 11. Flowchart of Fuzzy Mamdani Method Process

To obtain the output determination to be carried out by the heater, peltier, and DC pump, process of forming fuzzy sets, also know as fuzzification, is required from the two input sensors. On the DS18B20 temperature sensor, five parameters are taken, namely cold, cool, normal, warm, hot. These five parameters are members of the set of degrees of membership. The different rules for the five parameters are as follows:

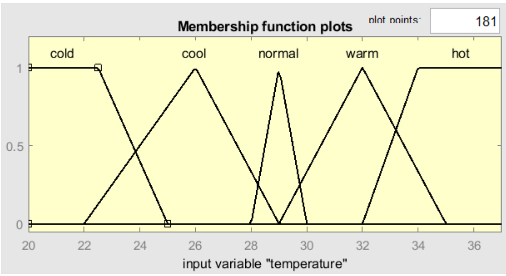

Figure 12. DS18B20 Temperature Sensor Rule Base

1. Fuzzy set of temperature (°C) variables

$$\mu_{Cold}[x] = \begin{cases} 1, & x \leq 20 \\ \frac{x-20}{22.5-20}, & 20 \leq x \leq 22.5 \\ \frac{25-x}{25-22.5}, & 22.5 \leq x \leq 25 \\ 0, & x \geq 25 \end{cases}$$

$$\mu_{Cool}[x] = \begin{cases} 0, & x \leq 22 \text{ or } x \geq 29 \\ \frac{x-22}{26-22}, & 22 \leq x \leq 26 \\ 1, & 26 \leq x \leq 29 \\ \frac{29-x}{29-26}, & 29 \leq x \leq 29 \\ 0, & x \geq 29 \end{cases}$$

$$\mu_{Normal}[x] = \begin{cases} 0, & x \leq 28 \text{ atau } x \geq 30 \\ \frac{x-28}{29-28}, & 28 \leq x \leq 29 \\ 1, & 29 \leq x \leq 30 \\ \frac{30-x}{30-29}, & 30 \leq x \leq 30 \\ 0, & x \geq 30 \end{cases}$$

$$\mu_{Warm}[x] = \begin{cases} 0, & x \leq 29 \text{ or } x \geq 35 \\ \frac{x-29}{32-29}, & 29 \leq x \leq 32 \\ 1, & 32 \leq x \leq 35 \\ \frac{35-x}{35-32}, & 35 \leq x \leq 35 \\ 0, & x \geq 35 \end{cases}$$

$$\mu_{Hot}[x] = \begin{cases} 0, & x \leq 32 \text{ or } x \geq 40 \\ \frac{x-32}{34-32}, & 32 \leq x \leq 34 \\ 1, & 34 \leq x \leq 40 \\ \frac{40-x}{40-34}, & 40 \geq x \leq 40 \\ 0, & x \geq 40 \end{cases}$$

The pH sensor takes five parameters, namely very acidic, acidic, neutral, alkaline, highly alkaline. These five parameters are members of the set of degrees of membership. The different rules for the five parameters are as follows:

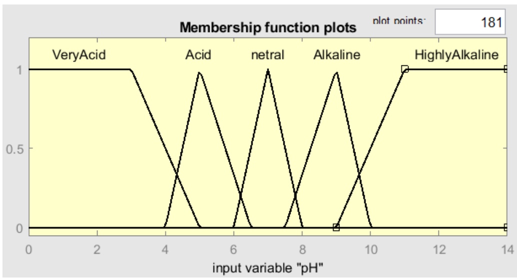

Figure 13. pH Sensor Rule Base

2. Fuzzy set of pH variables

$$\mu_{VeryAcid}[x] = \begin{cases} 1, & x \leq 0 \\ \frac{5-x}{5-3}, & 3 \leq x \leq 5 \\ 0, & x \geq 5 \end{cases}$$

$$\mu_{Acid}[x] = \begin{cases} 0, & x \leq 4 \text{ or } x \geq 6.5 \\ \frac{x-4}{5-4}, & 4 \leq x \leq 5 \\ 1, & 5 \leq x \leq 6.5 \\ \frac{6.5-x}{6.5-5} & 6.5 \leq x \leq 6.5 \\ 0, & x \geq 6.5 \end{cases}$$

$$\mu_{Netral}[x] = \begin{cases} 0, & x \leq 6 \text{ or } x \geq 8 \\ \frac{x-6}{7-6}, & 6 \leq x \leq 7 \\ 1, & 7 \leq x \leq 8 \\ \frac{8-x}{8-7}, & 8 \leq x \leq 8 \\ 0, & x \geq 8 \end{cases}$$

$$\mu_{Alkaline}[x] = \begin{cases} 0, & x \le 7.5\ or\ x \ge 10 \\ \frac{x-7.5}{9-7.5}, & 7.5 \le x \le 9 \\ 1, & 9 \le x \le 10 \\ \frac{10-x}{10-9}, & 10 \le x \le 10 \\ 0, & x \ge 10 \end{cases}$$

$$\mu_{HighlyAlkaline}[x] = \begin{cases} 0, & x \le 9\ or\ x \ge 14 \\ \frac{x-9}{11-9} & 9 \le x \le 11 \\ 1, & 11 \le x \le 14 \\ \frac{14-x}{14-11} & 14 \le x \le 14 \\ 0, & x \ge 14 \end{cases}$$

using Mamdani's fuzzy method. There are two fuzzy systems that are going to be in the process, namely, the fuzzy system for temperature input, and the fuzzy system for pH input. Each such system will have its own output such as temperature input that has heater and peltier output as in table 1.

Table 1. Temperature Fuzzy Rules

Rule	Input	Ouput	
	Temperature (°C)	Heater	Peltier
1	Cold	Strong	Off
2	Cool	Medium	Off
3	Normal	Off	Off
4	Warm	Off	Medium
5	Hot	Off	Strong

Whereas for fuzzy systems the pH input will produce one output as a DC pump, where the DC pump will act as an automatic water replacement system when one of the rules on the fuzzy pH system is active as described in table 2.

Table 2. pH Fuzzy Rules

Rule	Input	Ouput
	pH	DC Pump Drainage and Filling
1	Very Acidic	Drain Out
2	Acid	Drain Half
3	Netral	Off
4	Alkaline	Drain Half
5	Highly Alkaline	Drain Out

The fuzzy temperature and pH input system has no correlation with each other, on tables 1 and 2 gives a detailed overview of how the system responds to each temperature condition and pH separately to maintain optimal aquarium water conditions. The author also describes several conditions where the temperature and pH input results experience several possibilities that occur at the same time producing different outputs also for each fuzzy system. Therefore, in table 1 the temperature input system will produce the heater and the peltier output, whereas in table 2 the pH input system would produce the output in the form of the action of a DC pump. Thus, the defusification process in this system produces two independent outputtes, namely heater-peltier and DC pump based on the temperature conditions and the pH of the water in the aquarium. These two separate sets of defusifification results provide precise control over each water condition parameter, adjusting the system response to the exact conditions.

One of the techniques used in the defusification process is the centeroid method, also known as the Center of Gravity method (COG). In this context, the center of gravity or centeroids can be regarded as a point along an axis that balances the gap between the areas on the left and right. The calculation of centeroids is done using the following equation:

$$\bar{y} = \frac{\int_{Y-min}^{Y-max} y.\mu Y(y)dy}{\int_{Y-min}^{Y-max} \mu Y(y)dy}$$

IV. Results and Discussion

A. Results

The temperature and pH control system for Betta fish fry aquarium water using the fuzzy logic method aims to control and maintain good and ideal aquarium water temperature and pH for Betta fish fry.

Figure 14. System Realization and Implementation

The image above shows the physical form of the tool which was built by combining three sensors, namely the DS18B20 temperature sensor, pH sensor and ultrasonic sensor. Where the results of the temperature sensor and pH sensor readings will be used in a fuzzy logic system, while the ultrasonic sensor is used as a water level limit trigger when draining and filling the aquarium water. The ideal water temperature for Betta fish fry is 28°C-30°C and the ideal water pH for Betta fish fry is in the range of 6.5-8 [4][6]. The fuzzy method used in this research is the Mamdani fuzzy method or commonly known as the Min-Max method [7].

B. DS18B20 Temperature Sensor Testing

This test is carried out to evaluate the sensor's performance in measuring temperature accurately. The sensor testing process involves comparing the reading results from the DS18B20 sensor with data obtained from a digital thermometer as a reference. The purpose of this test is to assess the extent of error on the DS18B20 sensor by comparing the temperature reading values between the DS18B20 sensor and a digital thermometer.

Table 3. DS18B20 Sensor Test Data

No.	DS18B20 Sensor (°C)	Thermometer (°C)	Error (%)
1	26,68	26,8	0,4
2	27,73	27,8	0,2
3	28,75	28,9	0,5
4	28,97	29	0,1

C. pH Sensor Testing

This trial was carried out to evaluate the ability of the pH sensor to measure water pH accurately. The sensor testing process involves comparing the results of the pH sensor readings with data obtained from the pH meter as a reference. The purpose of this test is to assess how much error occurs in the pH sensor by comparing the water pH reading value between the pH sensor and the pH meter.

Table 4. pH Sensor Test Data

No.	Sensor pH	pH Meter	Error (%)
1	5,0	5,1	1,9
2	5,75	5,7	0,8
3	6,37	6,4	0,4
4	7,98	8,0	0,2

D. Test Results for the pH and Water Temperature Control System

This test aims to determine the performance of the entire system, whether the system is able to maintain the pH and temperature of the aquarium water so that it can reduce the death rate of Betta fish fry. The testing method for this system is to compare the pH, water temperature and number of Betta fish fry in aquariums without a system and aquariums with a system. The experiment was carried out for 14 full days with the same treatment for feeding 3 times a day, namely morning, afternoon and evening. Each of the aquarium is filled with 30 three-week-old betta fish fry, which will then be compared between aquariums implementing the system and aquariums without implementing the system. Here’s a graph of the test results.

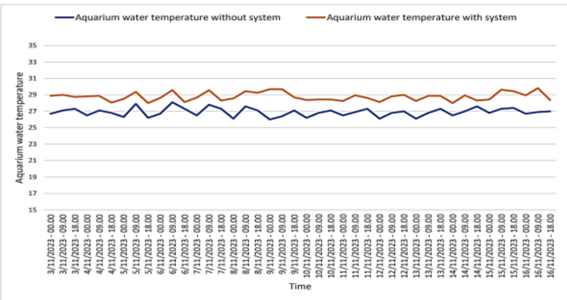

Figure 15. Aquarium Water Temperature Comparison Chart

From the test graph above, it can be seen that during the 14 days of testing, the system was able to maintain the ideal water temperature for betta fish fry, namely in the range of 28°C to 30°C [3]. It can be seen from the table above, the water temperature without implementing the system shows that the water temperature The aquarium is not at the ideal temperature for Betta fish fry with an average water temperature of 26.90°C. Meanwhile, the water temperature in the aquarium with the implementation of the system shows that the water temperature has been able to stabilize to the ideal water temperature for Betta fish fry with an average water temperature of 28.79°C, with the average water temperature produced from the aquarium with the implementation of the system being able to It was analyzed that even though the temperature was unstable and experienced ups and downs, the fuzzy system was able to maintain the ideal temperature for Betta fish fry according to the defuzzy results.

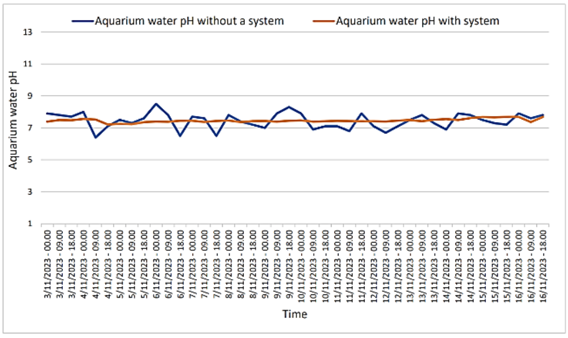

Figure 16. Comparison graph of aquarium water pH

From the pH test graph above, it can be seen that during the 14 days of testing, the average pH value of aquarium water without implementing the system shows that the average pH value of aquarium water is 7.44, it's just that the pH of aquarium water can be out of the ideal pH value limit for Betta fish fry, as per data on 06 November 2023 at 00:00 WIB the water pH value reached 8.5, likewise on 09 November 2023 at 18:00 WIB the water pH value reached 8.3. Meanwhile, the pH value of the water in the aquarium with the system implemented shows that the pH value of the aquarium water is stable with an average pH value of 7.45, although the comparison between the average pH value of the aquarium water without the system implementation and the aquarium where the system is implemented is not too far, however Aquariums that implement the system are much better at maintaining the stability of the pH of the water so that it does not leave the ideal pH limit for Betta fish fry, so that the fuzzy system has carried out its duties well according to the defuzzy results.

Based on the results of the overall system test which was filled with 30 betta fish fry and tested for 14 days, data on the water pH was stable in the range of 6.5 to 8 with an average water pH of 7.44, and the water temperature also stable in the value range of 28°C to 30°C with an average water temperature of

28.79°C. This shows that the implementation of fuzzy logic in the system for monitoring and controlling water temperature and pH in cultivating betta fish fry has succeeded in keeping the pH and temperature of the aquarium water stable, as evidenced by the death rate of betta fish fry in aquariums with the implementation of the system totaling 5 or 16.67 % of a total of 30 betta fish fry. Meanwhile, in aquariums without implementing the system, the death rate for Betta fish fry was 12 or 40% of the total of 30 Betta fish fry. A comparison of the mortality rate for Betta fish fry can be seen in the graph below.

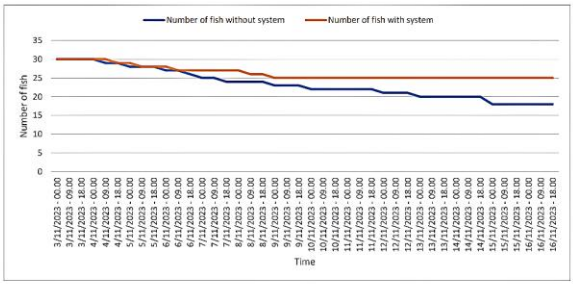

Figure 17. Comparison graph of mortality rates for Betta fish fry

Apart from influencing the mortality rate of betta fish fry, the research results of Agun Permata Sari and friends also stated that temperature also has a real influence on the growth rate and survival of betta fish fry. The optimal temperature for growth rate is found at ± 29.00°C [3]. This can be proven by comparing the size of the betta fish fry in the picture below.

Figure 18. Comparison of Betta Fish Fry Sizes

The Betta fish fry samples in the picture above were taken from each aquarium that was 5 weeks old. From the picture above we can analyze that the growth rate of Betta fish fry in aquariums with system implementation is faster than Betta fish fry in aquariums without system implementation.

V. Conclusion

This aquarium water temperature and pH control system using the fuzzy logic method can help betta fish breeders in automatically controlling the temperature and pH of the aquarium water for betta fish fry. The fuzzy system is able to make decisions in maintaining optimal water temperature and pH for Betta fish fry with an average temperature of 28.79°C and an average water pH of 7.44. So the system is able to reduce the death rate of Betta fish fry with a death rate of 5 or 16.67% of the total of 30 Betta fish fry. Apart from that, the system is able to support the growth rate of Betta fish fry by influencing the temperature of the aquarium water. Betta fish breeders can also monitor the temperature and pH conditions of aquarium water in real time via the ThingSpeak website anywhere and at any time.

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