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APPLYING FUZZY LOGIC AND IOT FOR INTELLIGENT AUTOMATION IN CRAYFISH WATER QUALITY CONTROL

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Abstract

Crayfish, known for their high market value due to their substantial meat volume compared to other freshwater shrimp, necessitate improved cultivation efficiency, which can be significantly enhanced with advanced technology. In this study, we designed a highly effective automatic water quality control system specifically for crayfish cultivation that strategically integrates an Internet of Things (IoT)-based control system and a smartphone application. Uniquely, the system incorporates fuzzy logic within the decision-making algorithm, which maintains water quality by adaptively adjusting drainage and temperature control parameters based on dynamic pH and turbidity conditions. This seamless and responsive mechanism ensures optimal cultivation conditions are maintained efficiently. This study manifests that this novel IoT and fuzzy logic technology integration proved effective for automatic water quality control and monitoring. The research contribution is the pioneering integration of fuzzy logic and IoT technologies to devise an intelligent automation system for crayfish water quality control. This system offers real-time remote monitoring and control from a smartphone application and automatically adapts to varying pH and turbidity conditions, ensuring consistently optimal water quality for crayfish cultivation. Such a system holds the potential to set a new standard for precision aquaculture, elevating productivity and sustainability within the crayfish farming sector.

Key words: Automatic Control System, Crayfish, Fuzzy Logic, Internet of Things.

INTRODUCTION

Crayfish (Cherax quadricarinatus) is a group of crustaceans that live in freshwater and a type of lobster that lives in freshwater. Lobster in general has good potential to be developed as a business value. In addition to the relatively easy cultivation process, crayfish are also animals resistant to disease [1]. Crayfish has the same anatomical characteristics as sea crayfish, which have a large capita. Because crayfish are relatively smaller than lobster, crayfish are also called freshwater prawns [2].

The market demand for crayfish is quite high, requiring cultivation techniques and the selection of appropriate types of crayfish in Indonesia because crayfish are highly dependent on environmental conditions. Redclaw crayfish is a species that is very suitable for cultivation in Indonesia because it has an optimal growth rate, high economic value, and is able to adapt to the environment in Indonesia [3].

Redclaw crayfish can lay eggs 4-5 times a year, while in Queensland, Australia which is their natural habitat, red claw crayfish can only lay eggs twice a year [4] [5]. However, another problem in the cultivation of freshwater crayfish is not only the breeding period of the animal but also in water treatment. Water quality is another factor that also has an important role in supporting the survival and growth of freshwater crayfish [6]. Water treatment for lobster cultivation is currently considered less effective because it involves a lot of workers and an assessment of water conditions cannot be measured with certainty. One example of ineffective treatment is the decision of lobster farmers at the time of the water change. Lobster farmers mostly decide to drain pond water based on cloudy water conditions and the condition of weak shrimp or reduced appetite. In this case, it can cause the death of the lobster due to the wrong diagnosis of water quality. So we need technology that can help farmers automatically maintain water quality. The technology that can be used is an automatic control system.

An automatic control system functions by providing feedback from processed input data. Implementing such a system allows for automatic process control, which is more efficient than manual methods. The water quality control system was explored by maintaining pH levels, oxygen content, and water volume [7]. However, that research treated each parameter individually, which meant the system could not evaluate the overall water quality based on these three parameters. In contrast, the maintenance of freshwater lobster typically involves only water replacement, yet essential parameters to monitor include pH, temperature, and turbidity. Therefore, a more sophisticated algorithm like fuzzy logic is required, capable of evaluating water quality from multiple parameters simultaneously and making accurate decisions about when water replacement should occur. This approach is similar to the study conducted by [8], which successfully evaluated the biological conditions of rivers using multiple parameters. This fuzzy algorithm plays a crucial role in processing complex and uncertain data, enabling more accurate and efficient decision-making in the management of water quality for freshwater lobster cultivation.

An automatic control system for water quality maintenance in shrimp cultivation was successfully implemented [9]. However, the study identified a limitation in the system's monitoring range, which was only up to 136 meters. Therefore, there is a need for technology that can extend the monitoring reach to any distance, facilitating convenience for the user. The rapid advancement of internet technology influences the evolution of control systems. The incorporation of Internet technology introduces new concepts and challenges due to its progression. One such concept that merges Internet technology with physical systems is the IoT.

Internet of Things (IoT) is a concept of connecting regulation between objects into the internet network with the aim of realizing technology so that it can be felt in everyday life [10][11]. In the development of this technology, a new paradigm has emerged such as "Industry 4.0", which refers to being able to digitize industrial processes by utilizing the information generated and artificial intelligence based on the use of multi-sensors and limited to data acquisition systems, also known as the fourth industrial revolution [12]. In developing IoT, it must have clear goals to support system standards in the future [13]. Research on the application of automatic control systems using Internet of Things technology has been carried out for the development of Internet of Things-based Smart Homes with monitors via Android smartphones [14]. The results of this study indicate that the device can be controlled and monitored remotely as long as it is connected to the internet [15] [16].

MATERIAL AND METHODS

An automatic control system in a work process controls the process without human intervention. A method is needed to connect the control system and mobile devices such as smartphones to make it easier for users to monitor or change control system settings. Therefore, this study proposes an IoT-based control system to overcome this. According to [15]Internet of Things (IoT) is a concept or scenario where an object can transfer data over a network without requiring human-to-human or human-to-computer interaction. In short, IoT is a relationship between objects using the internet (cloud) [17]. IoT greatly facilitates human activities, such as controlling devices not limited by distance. The prototype created in the study has a working method like Fig 1.

The system created in the study has a working method like Figure 1. The workflow of the system starts with a sensor that has a function to provide water quality data, namely temperature, turbidity, and acidity. Then the microcontroller receives the data to be forwarded to the cloud for data storage and computing to determine water quality.

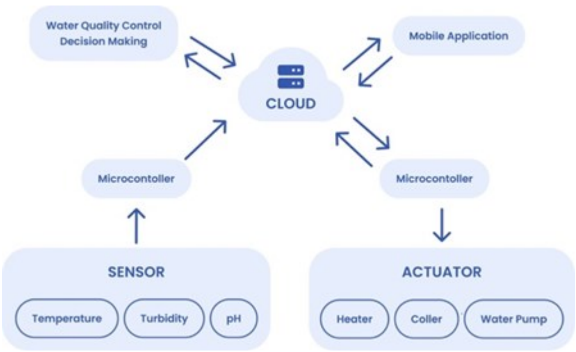

Fig 1. The flow of research prototype

Determination of water quality utilizes the Decision Making Algorithm using data on acidity and turbidity to decide whether to drain the water. If, according to the calculation algorithm, decides to drain, then the microcontroller gives orders to the water pump actuator to drain the water. To control the water temperature, the user can set the minimum and maximum temperature in the application that will be stored in the cloud. The microcontroller will adjust the work of the cooler and heater actuators by maintaining the temperature set by the user. All control system activities can be monitored through the application.

Software Design

The mobile application makes it easier for users to monitor and control the automatic control system [18]. Therefore, in this study, an application was made with the following features:

1. Farmers see data in the form of graphs and data on the latest pH, turbidity, and temperature of water conditions in the cultivation environment.
2. Farmers can view actuator activity data. The actuator activities that can be seen include data when the actuator is active, the water condition when the actuator is active, and the draining volume when the water pump actuator is active.
3. Farmers can add users to control water conditions.
4. Farmers can add users to control water conditions.
5. Farmers can change the time interval between drains

Such an application interface can be seen in Figure 2. In addition to monitoring water quality data as described. The user can also set the drain time interval for the fish to adapt to the new water. This feature exists because every freshwater crayfish cultivator has different opinions regarding the time interval for draining.

Fig 2. Mobile application

Control System & Hardware

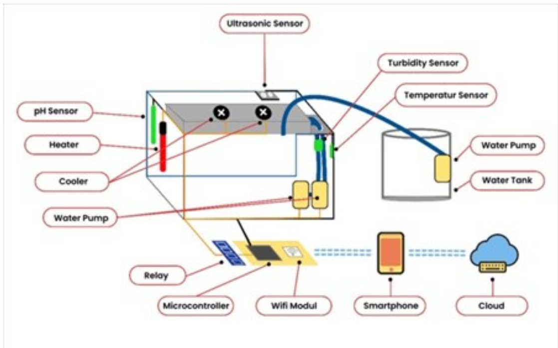

Fig 3. Control system prototipe

Hardware components are the core of our proposed prototype consisting of various elements. The prototype we developed uses several devices, as shown in Figure 3. The following are the components that we propose in this study:

Microcontroller

Microcontroller is a computer system in which all or most of its elements are packaged in one IC chip, often called a single-chip microcomputer. The microcontroller used in this prototype is Arduino Uno. A microcontroller controls sensors and actuators and sends and receives data to the cloud [19].

Wifi Modul

The wifi module is an additional electronic device for microcontrollers such as the Arduino UNO that can connect to wifi. The wifi module works by providing IP services to Arduino and PCs to connect to the internet [20].

Sensor

The sensors used are Temperature, Turbidity, Acidity, and Ultrasonic sensors. Sensors play a role in providing data on environmental conditions according to their function. Acidity, turbidity, and ultrasonic sensors provide data on water quality conditions. At the same time, the ultrasonic sensor provides water level data that can be used to calculate the volume of water at the time of draining.

Actuator

An actuator is a name given to a device that converts input energy into mechanical energy [21]. The working principle of the actuator is to convert analogue electrical energy into other quantities. The actuator used is a water cooler, a heater as a water heater, and a water pump as a water drain.

The microcontroller plays an important role in the control system because it functions to regulate all functions in the control system [22]. The following is the workflow of the control system:

1. The control system checks the water level of the aquarium to check the condition of the aquarium is filled with water or not. This activity uses ultrasonic sensors to get distance data.
2. The control system optimizes the water temperature by regulating the activity of water cooling and water heating
3. The control system checks the condition of the water quality to be drained or not. This process begins by taking pH and turbidity data from the sensor. After that, the control system uses the Sugeno Fuzzy Inference System method to determine the drain volume.

Decision-Making Method Fuzzy

The method analysis stage is an activity to model the method to overcome the problems studied. The stages that must be carried out in implementing fuzzy logic are determining the membership function, rule base, inference, and defuzzification.

Fuzzy Membership Function

Fuzzification is mapping crisp (numeric) values into fuzzy sets and determining the degree of membership in fuzzy sets. The value used results from data on turbidity and pH in the water environment. In this experiment, the linguistic variable of the pH set is divided into 3: acid, optimal, and alkaline. The linguistic values for each group are Acid (0-7.75), Optimal (6-9.5), and Base (7.75-14). The linguistic variables of the cloudiness set are divided into clean, optimal, and cloudy. The linguistic values for each group are Clean (0-52.5), Optimal (25-80), and Turbid (80-+∞).

Rule Base

After fuzzification, the following process determines fuzzy rules or rule bases. These rules are used to determine the volume of water taken during draining. The output value range is 0% drain with a constant value of 0, 30% drain with a constant value of 30, and 50% drain with a constant value of 50. The rules obtained are nine rules symbolized as R1-R9, including:

1. [R1] If pH is Acidic and Turbidity is Net, then the drain is 30% of the water volume.
2. [R2] If the pH is Acidic and Turbidity is Optimal, then the drain is 30% by volume of water.
3. [R3] If the pH is Acidic and the Turbidity is Danger, then the drain is 50% by volume of water.
4. [R4] If pH is Optimal and Turbidity is Clean, then the drain is 0% by volume of water.
5. [R5] If pH is Optimal and Turbidity is Optimal, then the drain is 0% by volume of water.
6. [R6] If pH is Optimal and Turbidity is Dangerous, then the drain is 30% by volume of water.
7. [R7] If the pH is alkaline and the turbidity is clean, then the drain is 30% of the water volume.
8. [R8] If the pH is alkaline and turbidity is optimal, then the drainage is 30% of the water volume
9. [R9] If the pH is alkaline and the turbidity is dangerous, then the drain is 50% of the water volume

Table 2. Testing Scenario.

Component	Scenario	Expected results
pH Sensor	Compare the result of the pH sensor with the result of a pH buffer powder solution with values of 4.00 and 9.18	pH sensor obtains the same value as the pH buffer powder
Temperature Sensor	Compare the result of the temperature sensor by comparing it with a thermometer	Temperature sensor obtains the same value as the thermometer
Ultrasonic Sensor	Compare the distance measured by the ultrasonic sensor with the distance measured by a ruler	Ultrasonic sensor obtains the same value as the distance measured by the ruler
Turbidity Sensor	Compare the result of the turbidity sensor with distilled water to obtain a value of 0 mg/L	Turbidity sensor obtains a value of 0 mg/L when tested with distilled water

Inference

Decision-making using fuzzy logic is also known as the Fuzzy Inference System Algorithm. One of the inference methods is Sugeno. Sugeno is an inference method for rules represented in the form of IF-THEN, where the output (consequent) of the system is not a fuzzy set but a constant or linear equation [23]. Sugeno's Fuzzy Inference System is divided into two models, namely Order Zero and Order One. This study uses a Zero Order model because the desired output is a constant whose equation can be seen in Equation (1).

$$IF\ (x1\ is\ A1\ ) \circ (x2\ is\ A2\ ) \circ (x3\ is\ A3\ ) \circ \ldots \circ (xN\ is\ AN)\ THEN\ z = k \quad (1)$$

$A1$ = Fuzzy set as antecedent
k = Constant as antecedent
$\circ$ = Operator 0R or AND

Defuzzy

The process of calculating the weighted average of all fuzzy implication rules. In this research, defuzzification is carried out by calculating the Weight Average (WA) [24], which can be seen in Equation (2).

$$WA = \frac{(a_1 * z_n) + (a_1 * z_n) + \cdots + a_n * z_n}{a_1 + a_2 + a_3 + \cdots + a_n} \quad (2)$$

a_1 = Value of the nth rule predicate
z_n = nth output value index (constant)
WA = Average score

Evaluation

The evaluation of the testing process involves verifying the proper functionality of the sensors. This is done by requiring the device to act in accordance with the given case study scenarios. The testing scheme for the sensors is outlined in Table 1.

Subsequently, the fuzzy algorithm employed is tested by comparing the results of manual calculations with the system's output to ensure the algorithm's accuracy.

This evaluation is conducted on a prototype container measuring 70 cm in length, 40 cm in width, and 40 cm in height, as depicted in Figure 4. After the design phase, a series of experimental scenarios are performed to assess the temperature, pH, and turbidity conditions to determine whether the control system is functioning properly.

Additionally, given the system's feature that allows the setting of intervals between drainage events, testing is carried out by setting specific drainage time intervals and then comparing it with the control system's performance to verify if it operates as programmed.

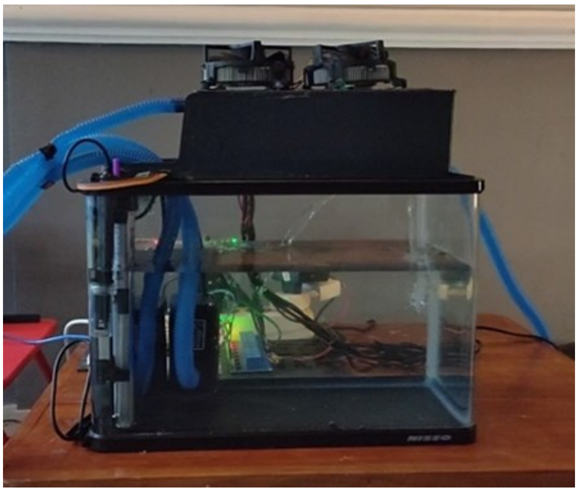

Fig 4. Container Prototype

RESULT AND DISCUSSION

This chapter describes the implementation of application and control systems, the application of the Sugeno Fuzzy Inference System method, and testing.

Application system implementation

In this study, the user interface was created to make it easier for users to use the application. The application has six pages: login, logout, water condition data, actuator data, and settings. The water data page, as shown in Figure 2, contains data on cultivated water quality, including ph, turbidity, and temperature data. The actuator data page, as shown in Figure 2, includes data on when the actuator is active, the condition of the water when the actuator is active, and the draining volume when the water pump actuator is active. To suit the needs of farmers, a settings page was built to set the optimum temperature for water conditions and the duration of time between drains in the cultivation environment, as shown in Figure 2.

Calculation of drain decision

The calculation of the Sugeno fuzzy inference system method in this study used a sample of ph data of 6.5 and turbidity of 52.5. The first step is to determine the membership function of ph and turbidity data. The pH membership function in this study, with a value of 6.5, is included in the acid and optimal membership function. Meanwhile, the turbidity membership function in this study, with a value of 52.5, is included in the optimal membership function. After that, the fuzzification process is carried out to change the crisp data into fuzzy data. The following is the calculation of fuzzification:

μphAcid (6.5) $= \frac{7-6{,}5}{7-6},\ 6 \le x \le 7 = 0{,}5$

μphOptimal (6.5) $= \frac{6{,}5-6}{7-6},\ 6 \le x < 7 = 0.5$

μkrOptimal (6.5) $= \frac{52{,}5-25}{52{,}5-25},\ 25 \le x < 52{,}5 = 1$

Information :

μkr = Turbidity membership function

μph = pH membership function

The next step is to find the antecedent membership value (α). The antecedent membership value is obtained from the rulebase rule with the min operation. In this case study, the users are r2 and r5. The following is the calculation to find the alpha value:

μphAcid (6.5) = (7 - 6,5) / (7 - 6), 6 ≤ x ≤ 7 = 0,5

μphOptimal (6.5) = (6,5- 6) / (7 -6), 6 ≤ x < 7 = 0.5

μkrOptimal (6.5) = (52,5- 25) / (52,5 -25), 25 ≤ x < 52,5

The next step is to find the antecedent membership value (α). The rulebase rule with the min operation obtains the antecedent membership value. In this case study, the users are R2 and R5. Here's the calculation to find the alpha value:

α2 = μphAcid ∩ μkrOptimal
= min (0,5∩ 1)
= 0.5

α5 = μphOptimal ∩ μkrOptimal
= min (0,5 ∩ 1)
= 0.5

The next step is defuzzification to get the crips value. The result of defuzzification is used to determine the drain volume. In this case study, the value of constant (z2) α2 is 30, and the value of constant (z5) α5 is 0. The following is the calculation of the defuzzification process:

Implementation of control system

The prototype developed in this study used several tools, namely an aquarium, a plastic box for water coolers, hoses, three aquarium pumps, water tanks, two fans, two penalties, a heater, Arduino Uno, Bread Board, ESP8266 wifi module, 16 channel relay. , male-to-male jumper cables, resistors, male-to-female jumper cables, ultrasonic sensors, pH sensors, temperature sensors, and turbidity sensors. The series of tools and the physical form of the prototype can be seen in Figure 3. Implementation of the Sugeno Fuzzy Inference System method to support water drainage decisions using Arduino IDE software and the C programming language. The results of the process are used to determine the volume of the drain. The input data obtained results from the Turbidity sensor obtaining turbidity data and the pH sensor obtaining water pH data. The Sugeno Fuzzy Inference System method will run when the sensor sends a digital signal to the Arduino UNO. After that, the digital signal is converted into new constants such as pH and turbidity data. Furthermore, the pH and turbidity data were computed using the method to obtain the value of the draining volume.

Testing

The sensors used in this study were successfully tested and performed as expected, following the scenarios outlined in Table 1. The fuzzy logic algorithm testing also achieved 100% accuracy by comparing the algorithm's output with manual calculations done using Microsoft Excel and direct computations from the control system. The results of these comparisons are presented in Table 2.

Additionally, an experiment was conducted to test the system's response to drainage intervals set at 5 minutes using the application. The control system successfully recognized when drainage had occurred and initiated the subsequent drainage 5 minutes later. Furthermore, the rate at which the water cooling system reduced the temperature was tested. The target temperature was set to 28 degrees Celsius through the application. During the test, when the ambient temperature was set at 34 degrees Celsius, the system was able to cool down to 28 degrees within 24 minutes.

Table 2. Elicitation Technique with Following Qualitative Evaluation

No.	Input		Defuzzification results	
	pH	Turbidity (mg/l)	Manual (percent)	System (percent)
1	9	25	24	24
2	6.5	60	23.8	23.8
3	7	80	30	30
4	6.5	52.5	15	15
5	2	10	30	30
6	7	0	0	0
7	7	15	0	0
8	6	0	30	30
9	6.4	100	42	42
10	9	120	46	46

CONCLUSION

Integrating the fuzzy algorithm into our system has proven effective, enabling it to make informed drainage decisions by evaluating pH and turbidity levels simultaneously, thereby enhancing operational efficiency. Coupled with the latest IoT technology, this system surpasses the previous 136-meter range limitation of radio module technology, as used by Garum in 2016. It offers real-time remote monitoring and control capabilities through a smartphone application. This adaptability ensures that the water quality is consistently optimized for crayfish cultivation. With its potential to redefine industry benchmarks, this system is poised to significantly improve productivity and promote sustainability in the crayfish farming sector, heralding a new era of precision aquaculture.

FUTURE WORK

To enhance the current research, it is advised to adopt multi-agent fuzzy logic for better water quality management in larger ponds. Transitioning to the MQTT protocol could improve server interactions by providing real-time data updates more efficiently compared to the HTTP request method. Additionally, consider integrating a variety of sensors along with an automated feeding control system to ensure a more robust and holistic approach to aquaculture management.

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