Design and development smart aquaculture in freshwater pond based on fuzzy logic.

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Abstract. This research has the topic of Smart Aquaculture in freshwater ponds. Aquaculture or fish farming in Indonesia still monitors and manages ponds manually. Temperature, pH, and water turbidity are important parameters for the survival of fish in ponds. Therefore, it is necessary to design a tool that can monitor and control ponds automatically. This system worked by reading the pH, temperature, and water turbidity sensors. The microcontroller utilized the sensor readings to control the peristaltic pump for liquid pH, water pump, and valve operations. Subsequently, the sensor readings were transmitted to the ESP32, which further forwarded the sensor data to the cloud database. Applications that were integrated with the cloud database display sensor reading data. The system utilized Fuzzy Logic Control with the Mamdani method to automate its operation. The inputs for the fuzzy logic control included pH, temperature, and turbidity, while the outputs consisted of the peristaltic pump, valve, and water pump. This system successfully adjusts the control conditions of temperature 35°C, pH 5, and turbidity 1200 NTU, bringing them back to the normal setpoint, which is a temperature of 32°C, pH between 6-8, and turbidity of 150 NTU, and maintains them at these values.

Keyword: aquaculture, fuzzy logic control, pond management, real time monitor

1 Introduction

Aquaculture is the activity of producing and breeding aquatic animals or organisms in a controlled condition [1]. One of the main factors for the success of aquaculture is maintaining water quality. Water quality is controlled by several factors, such as the acidity or alkalinity of the water (pH), turbidity that can cause changes in water colour, and water temperature [2]. Aquaculture production has become a significant contributor to Indonesia's food industry by supplying animal protein. The aquaculture sector also plays a crucial role in Indonesia's economy, particularly in terms of job providing, foreign exchange income, and strengthening national economic growth [3]. In 2018, the aquaculture sector managed to produce over 15 million tons of major fishery commodities. However, this figure gradually decreased in the following year, with a production volume of only 14.7 tons [4]. The decline in production is directly influenced by a significant decrease in the number of fish farmers, which reached 42.27% during 2019 and 2020. The decrease in the number of fish farmers can be attributed to challenges in maintaining conventional fish ponds, which require significant time, effort, and costs [4]. This research aims to assist fish farmers in monitoring their ponds using IoT (Internet of Things) technology. The integration of sensor readings and combination with internet-based applications will make it easier for fish farmers to monitor their aquaculture ponds from anywhere. Automatic management of pond quality, aided by fuzzy control, will facilitate fish farmers in efficiently managing their ponds.

2 Related Works

Automation in monitoring and managing ponds can be a solution to optimize resources and costs in fish farming processes. Research by Karim et al. [5] developed a prototype for monitoring pH, temperature, and water level in fish ponds. However, in that prototype, actuator control was still manually controlled, limiting automatic pond management. Implementing automation in actuator control can enhance effectiveness and efficiency. In this context, fish farmers can save time previously used for controlling and monitoring fish ponds. Therefore, an integrated system with a controller is needed to operate actuators automatically in a closed-loop system. Research by Ramadhan et al. [6] developed an Internet of Things (IoT)-based water quality management system. This research analyzed water quality using parameters such as pH value, total dissolved solids (TDS), and turbidity, employing fuzzy inference system. The system classified water quality into three categories: good (meeting quality standards), fair, and poor (contaminated). The measurement results

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can be accessed online via the Internet of Things (IoT). Furthermore, the research proposed the use of fuzzy control to classify sensor data used in monitoring fish ponds and generate output to control the actuators connected to the system. In automated pond management, applications for monitoring ponds can be designed, as demonstrated in the research by Sukrismon et al. [7]. In this application, users can access a menu to monitor parameters such as temperature, pH, water level, and turbidity, viewing the values obtained from the sensors used. This application is supported by a cloud database, Firebase. Firebase is a real-time database that is freely available and offers various features that help developers focus on the application's interface. Firebase provides convenient features for managing and configuring how the application functions effectively. To access Firebase, a smartphone connected to the internet is required. Additionally, Firebase can be used to store data obtained from these sensors.

3 Methodology

3.1. Proposed System

To maintain good water quality in the pond, it is necessary to monitor and manage the water quality effectively. This system utilizes temperature, turbidity, and pH sensors to assist in the monitoring process of the aquaculture pond. To facilitate effective monitoring and management of the pond, a smart aquaculture system has been designed to work automatically. Figure 1 represents the design of the smart aquaculture system. This smart aquaculture system utilizes several sensors to monitor the desired parameters. The sensors used are pH, temperature, and turbidity sensors. These sensors are connected to the Arduino Mega2560 Pro Mini microcontroller. The Arduino is connected to a Wi-Fi module called ESP32. Additionally, several actuators are used, namely the Proportional Valve, Water Pump, Peristaltic DC Pump, and Heater.

The sensor readings received by the Arduino are used as inputs for fuzzy logic control. These inputs are used to determine the activation level of the fuzzy rules. The activation of these rules is used to generate fuzzy outputs. The fuzzy outputs are then used to control the actuators. To maintain the pond temperature, the Proportional Valve and Water Pump are used. The Proportional Valve is used to control the amount of water entering the pond, while the Water Pump is used to remove hot water from the pond. The water circulation will continue until the temperature sensor reading matches the desired setpoint. This same principle is also applied to maintain the turbidity level within the normal range. Dirty water will be drained, and clean water will enter the pond. When the temperature is cold, the heater will turn on until the sensor reading reaches the setpoint. To maintain the pH level of the pond within the normal range, a liquid is required to increase or decrease the pH. When the pond's pH is acidic, the pH-increasing liquid will be added to the pond. Conversely, if the pond's pH is basic, the pH-reducing liquid will be added to the pond. The Peristaltic DC Pump is used to transfer the liquid from the bottle to the pond.

The sensor data from the Arduino will be sent to the Wi-Fi module through serial communication. The Wi-Fi module, which is connected to the internet, will send the sensor data to a Cloud Database. The Cloud Database will be connected to an Android-based application. The application is used to monitor the pond's condition from anywhere.

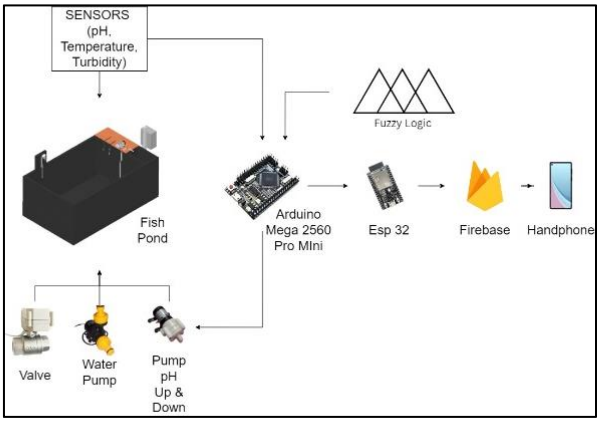


Fig. 1. Full System of Smart Aquaculture

3.2. Fuzzy Logic Control

Fuzzy logic control is a rule-based control system that uses linguistic variables and fuzzy sets to process ambiguous data. This approach enables machines to think more like humans. Fuzzy logic defines 0 and 1 as definite truths but also encompasses various degrees of truth between 0 and 1 [8].
In the context of water quality control in ponds, the use of fuzzy systems can help understand uncertain and varying changes in pH, temperature, and turbidity. The flexibility in processing linguistic data allows fuzzy logic to make control decisions that adapt to varying environmental conditions. Fuzzy systems have easy adaptability when operating in different environments. Furthermore, fuzzy systems can handle non-linear relationships between inputs and system responses, enabling them to control actuators with fast and accurate responses [8].

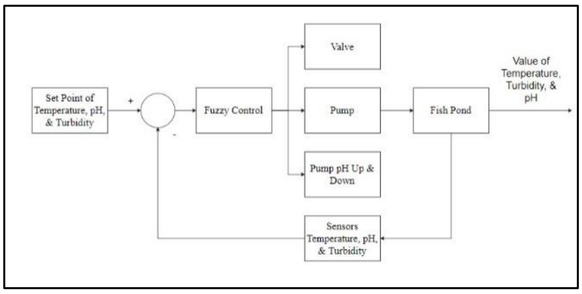


Fig. 2. Diagram Block of Fuzzy Logic Control

3.2.1. Fuzzification

Fuzzification is the process of transforming numerical variables into membership degrees in linguistic sets [9]. Sensor values represent numerical values that will be used as inputs in the fuzzification process. In this system, there are three inputs: temperature, turbidity, and pH, as well as four outputs: Valve, Water Pump, pH Up, and pH Down.

The membership function for temperature consists of three categories: normal, warm, and hot with a range of (0-60 °C). Table 1 illustrates the membership function for temperature. The pH membership function also consists of three categories, as shown in Table 2. As for turbidity, its membership function is divided into three categories described in Table 3. Turbidity concentration is measured in NTU (Nephelometric Turbidity Units).

Table 1. Membership function for temperature.

Category	Range (°C)			
Normal	25	25	28	34
Warm	32	37	37	42
Hot	40	45	60	60

Table 2. Membership function for pH.

Category	Range			
Acid	0	0	4	7
Normal	5.8	7	7	8.4
Alkali	7.5	12	12	14

Table 3. Membership function for turbidity.

Category	Range (NTU)			
Clear	0	0	0	400
Turbid	100	625	625	1250
Very Turbid	900	1500	1500	3000

Table 4. Membership function for valve.

Category	Range			
Slow Pump (sp)	0	0	7	50
Middle Pump (mp)	35	60	60	83
Fast Pump (fp)	65	85	100	100

Table 5. Membership function for water pump.

Category	Range			
Slow Valve (sv)	0	0	7	50
Middle Valve (mv)	25	79	79	128
Fast Valve (fv)	100	128	150	150

Table 6. Membership function for pH up pump.

Category	Range			
Slow Pump pH Up (spup)	0	0	33	50
Middle Pump pH Up (mpup)	33	78	78	121
Fast Pump pH Up(fpup)	75	115	130	130

Table 7. Membership function for pH down pump.

Category	Range			
Slow Pump pH Down (spdn)	0	0	33	50
Middle Pump pH Down (mpdn)	33	65	65	121
Fast Pump pH Down (fpdn)	83	115	130	130

The membership function for the Valve output is measured in the degree of valve opening. The degree of valve opening depends on the Duty Cycle applied to the valve. Table 4 shows the membership function for the Valve output. The membership function for the Water Pump output is measured based on how fast the pump rotates. This membership function is described in Table 5. Tables 6 and 7 are the membership function tables for the pH Up and pH Down pumps. The membership function for each input and output uses a trapezium membership function.

3.2.2. Fuzzy Rules and Inference Engine

Fuzzy rules are a set of rules or strategies used to connect input conditions with actions to be taken to control actuators [9]. Fuzzy rules consist of if-then statements, where if represents measurable conditions and then represents the decision or action to be taken based on the occurring conditions [10]. The inference engine is used to evaluate the rules based on the membership values defined in those rules. The evaluation of these rules aims to generate appropriate decisions or actions to maintain the pool conditions. In this process, the inference engine uses logical operations such as AND, OR, and NOT to evaluate the rules. This system uses the AND logic to combine the membership levels that have been defined [11]. Table 8 represents the rule set for Valve control, Pump control, pH Up and pH Down control.

3.2.3. Defuzzification

Defuzzification is the process of converting linguistic fuzzy sets into crisp values used to control the system or provide output to actuators. The defuzzification process is influenced by decision-making based on the fuzzy sets that have been defined. Defuzzification is performed to transform fuzzy output values into precise values. This system has four outputs, and each output undergoes fuzzification based on the environmental conditions [12].

3.3. Application and Communication Devices

Communication between microcontrollers is crucial in this system to support the transmission of application data. This system utilizes Arduino and Wi-Fi modules. Arduino is used to receive data from sensors and send it to the Wi-Fi module through serial communication. Serial communication transmits data by sending bits sequentially through a single communication path. The Wi-Fi module, connected to the internet, is responsible for sending data to the cloud database. The data received by Arduino will be sent by the Wi-Fi module to the cloud database. Data from the cloud database will be used to display sensor reading values in the application.

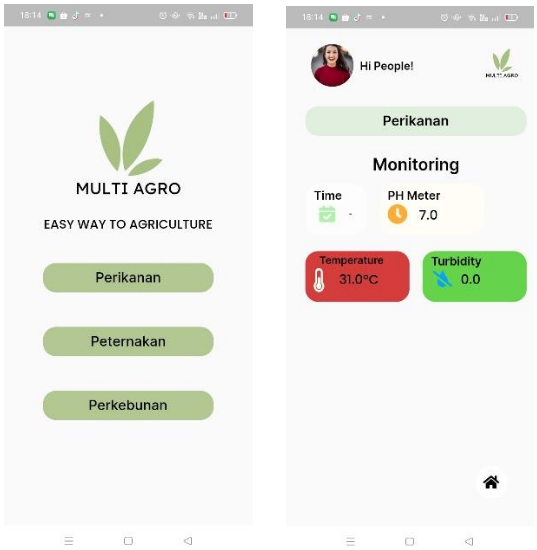
Fig. 3. Application and communication device.

This application is designed to facilitate breeders in monitoring pond conditions. The first page of the application provides a menu option for the environment to be monitored. The fishery page presents the sensor values used, such as pH, temperature, and turbidity. All of this aims to provide convenience in monitoring and controlling the pond's environmental conditions through an application connected to Arduino and the Wi-Fi module. These values will be continuously updated as the Arduino reads the sensors. When the power is off, the sensor values will no longer be sent to the cloud database. Therefore, a battery is required as a backup power source so that when the main power is off, the system can still function and send sensor values to the cloud database.

4 Experiment

Fig. 4. Prototype of smart aquaculture system.

This section contains the results of control testing on the monitored parameters. The testing was conducted on an aquarium with dimensions of 70 cm x 55 cm x 32 cm. The turbidity, temperature, and pH sensors that are being used have undergone a calibration process. The purpose of this calibration is to ensure that the values generated by the sensors match the actual conditions inside the pond. To evaluate the accuracy of these sensors, comparisons are made using appropriate measuring instruments for each measured parameter. Figure 1 shows the prototype of the smart aquaculture system. The application has been successfully developed. Figure 5 (a) represents home menu that provides options to select the environment to monitor and (b) represents the monitoring page for fisheries, displaying values of temperature, pH, and turbidity. The first test is the temperature control test. This test aims to determine the system's control when the temperature is not in a normal condition. The second test is the pH control test. This test is conducted to observe the system's decision in handling acidic and alkaline pond pH. Finally, there is the turbidity testing. The turbidity test aims to determine the system's response when the environment is not in a normal state.



(a) (b)

Fig. 5. **(a)** Home menu of the application and **(b)** the display page of the fisheries monitor.

4.1 Temperature Control Testing

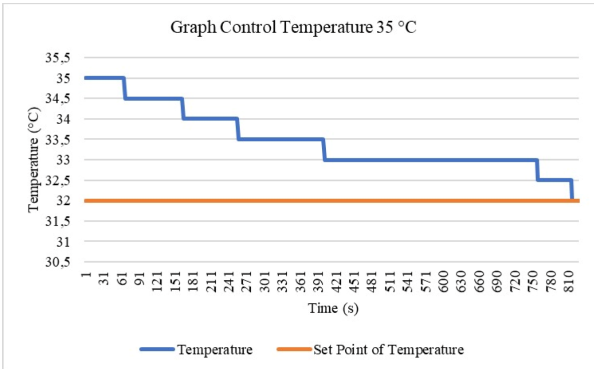


Fig. 6. Temperature control at 35 °C.

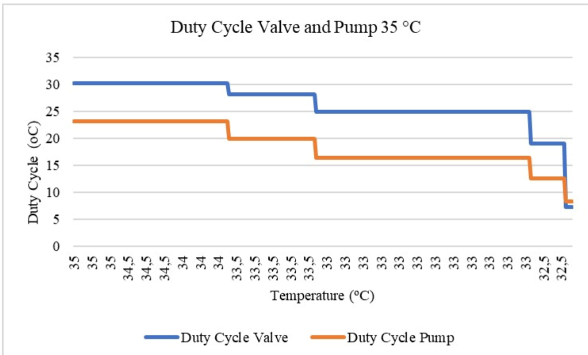


Fig. 7. Duty cycle valve and pump for temperature control at 35° C.

Table 8. The rule set for Valve control, Pump control, pH Up and pH Down control.

Rule	Temperature	Turbidity	pH	Valve	Pump	Pump pH Up	Pump pH Down
1	IF Normal	AND Clear	AND Acid	Then sv	AND sp	AND fpup	AND spdn
2	IF Normal	AND Clear	AND Normal	Then sv	AND sp	AND spup	AND spdn
3	IF Normal	AND Clear	AND Alkali	Then sv	AND sp	AND spup	AND fpdn
4	IF Normal	AND Turbid	AND Acid	Then mv	AND mp	AND spup	AND spdn
5	IF Normal	AND Turbid	AND Normal	Then mv	AND mp	AND spup	AND spdn
6	IF Normal	AND Turbid	AND Alkali	Then mv	AND mp	AND spup	AND spdn
7	IF Normal	AND Very Turbid	AND Acid	Then fv	AND fp	AND spup	AND spdn
8	IF Normal	AND Very Turbid	AND Normal	Then fv	AND fp	AND spup	AND spdn
9	IF Normal	AND Very Turbid	AND Alkali	Then fv	AND fp	AND spup	AND spdn
10	IF Warm	AND Clear	AND Acid	Then mv	AND mp	AND spup	AND spdn
11	IF Warm	AND Clear	AND Normal	Then mv	AND mp	AND spup	AND spdn
12	IF Warm	AND Clear	AND Alkali	Then mv	AND mp	AND spup	AND spdn
13	IF Warm	AND Turbid	AND Acid	Then mv	AND mp	AND spup	AND spdn
14	IF Warm	AND Turbid	AND Normal	Then mv	AND mp	AND spup	AND spdn
15	IF Warm	AND Turbid	AND Alkali	Then mv	AND mp	AND spup	AND spdn
16	IF Warm	AND Very Turbid	AND Acid	Then fv	AND fp	AND spup	AND spdn
17	IF Warm	AND Very Turbid	AND Normal	Then fv	AND fp	AND spup	AND spdn
18	IF Warm	AND Very Turbid	AND Alkali	Then fv	AND fp	AND spup	AND spdn
19	IF Hot	AND Clear	AND Acid	Then fv	AND fp	AND spup	AND spdn
20	IF Hot	AND Clear	AND Normal	Then fv	AND fp	AND spup	AND spdn
21	IF Hot	AND Clear	AND Alkali	Then fv	AND mp	AND spup	AND spdn
22	IF Hot	AND Turbid	AND Acid	Then fv	AND mp	AND spup	AND spdn
23	IF Hot	AND Turbid	AND Normal	Then fv	AND mp	AND spup	AND spdn
24	IF Hot	AND Turbid	AND Alkali	Then fv	AND fp	AND spup	AND spdn
25	IF Hot	AND Very Turbid	AND Acid	Then fv	AND fp	AND spup	AND spdn
26	IF Hot	AND Very Turbid	AND Normal	Then fv	AND fp	AND spup	AND spdn
27	IF Hot	AND Very Turbid	AND Alkali	Then fv	AND fp	AND spup	AND spdn

The water temperature in the aquarium will increase during the day. The increase in water temperature in the aquarium is allowed to reach 35 °C. The system is activated, and the valve and pump start operating. Figure 6 shows the system starting to run, and water circulation begins, gradually reducing the temperature in the aquarium. Figure 7 shows the response of the actuators when the temperature decreases. The response of the actuators can be observed through changes in the duty cycle of the valve and the pump. Changes in the duty cycle affect the pump's speed, while in the valve, it affects the ball's opening. These changes will continue until the temperature value reaches the setpoint. The time required to return the water conditions to normal temperature from 35 ^{o}C Celsius is 810 seconds.

4.2 pH Control Testing

pH testing is performed to determine the system's response when the pH is not in a normal condition. The pH value commonly changes when the fish have been fed. After feeding, the fish produce a considerable amount of waste, resulting in high ammonia levels. This high ammonia level causes the pH value to become acidic. Additionally, the fish respiration process also causes the pH value to decrease. Figure 8 shows the acidic pH condition of the aquarium. The acidic pH condition activates the peristaltic pump to flow pH Up fluid into the aquarium.

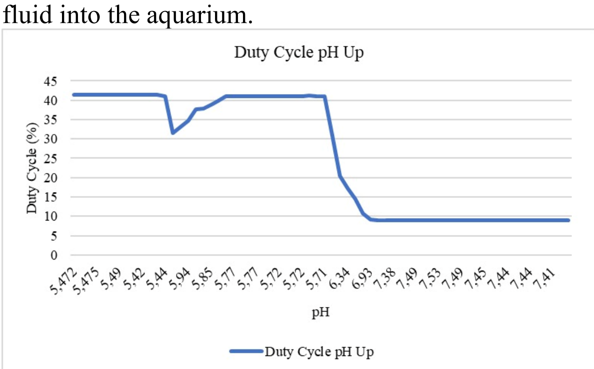


Fig. 8. pH control at pH 5.