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Detection of Water Quality Fluctuation Patterns with Fuzzy Logic Controller

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ABSTRACT

The quality of pond water greatly affects the success rate of fish survival. Temperature, pH, and oxygen are the 3 main things that cause changes in fluctuation patterns in gourami ponds, so it is necessary to detect fluctuation patterns in pond water quality to maintain the balance of the fish's aquatic environment, prevent premature fish deaths, and optimize fish farming results. The ideal quality of a gourami pond is if the oxygen has a value range of 3-8, the temperature has a value range of 24^0C-30^0C, and the PH has a value range of 5-8. The objectives of this study are 1) to detect patterns of changes in water quality; 2) to classify fluctuations as normal, unstable, or dangerous; and 3) to provide recommendations and automatic actions to turn on the heater, cooler, and aerator. The method used is fuzzy with inputs in the form of temperature, pH, and oxygen and outputs including circulation pumps, aerators, heaters and the status of pond water quality conditions. The results of the study showed that: 1) the device is able to detect patterns of changes in water quality where changes in water quality occur at critical hours, namely 04:00, 12:00–14:00, 21:00, and 01:00–03:00 which are influenced by temperature, pH, and oxygen conditions, 2) The status of water quality conditions is divided into three statuses, namely safe, unstable, and dangerous; and 3) The circulation pump, aerator and heater will turn on when the status condition is unstable and dangerous and will turn off when the condition of the fish pond with a capacity of 12,000 liters is in a safe status.

1. INTRODUCTION

Pond water is the main living environment for fish, small changes in the parameters and quality of pond water will affect the biological and physiological balance of fish. The quality and quantity of pond water are one of the determining factors for the success of fish farming because good water quality will cause fish to have good quality and grow optimally [1][2][3]. Detecting fluctuation patterns in water quality in fish ponds is very important, this is because fish are sensitive to changes in water parameters, sudden fluctuations will have an impact on fish health, fish growth, fish farming productivity, and the economic value of fish farming.

Water quality is controlled by several factors, namely temperature, DO, and pH, which are three things that are interrelated and are the main causes of fluctuations in pond water quality [4][5][6]. Temperatures that are too high in fish ponds due to exposure to sunlight cause a decrease in the solubility of oxygen in pond water. On the other hand, water pH also experiences daily fluctuations. When the temperature rises, DO is low and pH is outside the ideal limits, it will cause fish to become stressed, fish are susceptible to disease, their growth is disrupted, and cause premature death of fish [7]. The dynamic interaction of the three parameters can create unstable conditions in fish ponds, so detecting fluctuation patterns is very important to maintain the balance of the aquatic environment, maintain fish health, prevent fish mortality, and optimize sustainable cultivation results [8][9].

Traditional fish farming practices often face various significant challenges, one of which is related to uneven fish growth, suboptimal fish growth, and hampered productivity [10]. One of the efforts of fish farmers to maintain pond quality is through an aeration system and circulation pump in the pond. Aeration is used to increase the concentration of dissolved oxygen (DO) in water according to the desired value and oxygen is also used to eliminate ammonia oxidation [11][12]. The function of aeration working for a long time without a control system can consume a lot of electricity, so a smart strategy is needed to manage the working time of the aerator so that it can minimize electricity usage and increase the processing rate [13].

Conventional monitoring systems that are still widely used by fish farmers today require routine observation and subjective interpretation by humans [14]. In addition to being time-consuming and laborious, this approach is less effective in detecting rapid changes and complex fluctuation patterns. Therefore, a monitoring system is needed that is intelligent and responsive to changes in water quality in real time. Fuzzy Logic Controller (FLC) is one of the artificial intelligence methods that is able to handle uncertainty and complexity in systems that are difficult to model mathematically [15]. By using fuzzy logic, the system can interpret ambiguous or uncertain sensor data to produce decisions that are more adaptive and closer to human thinking. Fuzzy logic inference consists of three main modules, namely the fuzzification module, the fuzzy inference module, and the defuzzification module [16]. In the context of fish farming, the Fuzzy Logic Controller (FLC) can be used to detect uncertain and varying water quality fluctuation patterns based on historical data from continuously updated sensor values.

Detection of fluctuation patterns in temperature and pH of fish pond water using Fuzzy Logic Controller (FLC), a system designed to monitor and control environmental conditions in fish ponds with temperature and pH parameters using Fuzzy Logic Controller (FLC) which are monitored in real time [17][18][19]. The objectives of this study are 1) to detect patterns of changes in water quality; 2) to classify fluctuations as normal, unstable, or dangerous; and 3) to provide recommendations and automatic actions to turn on the heater, cooler, and aerator.

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2. LITERATURE SURVEY

Researchers conducted a direct survey on gourami fish farmers in Singkalanya Prambon Nganjuk Village, and found that the monitoring system was mostly still using a traditional or manual system which was inefficient due to limitations and delays in response time so that handling of water quality was not optimal.

In research related to monitoring water quality fluctuations in modern fish farming, namely in real time by applying fuzzy logic to critical parameters such as temperature, pH, dissolved oxygen (DO), weather conditions, and salinity. The results of water quality fluctuations will regulate the operational control of aerators and water pumps, thereby increasing operational efficiency and productivity in aquaculture management [20]. In line with this research, namely a real-time water quality and suitability monitoring system by integrating the Tsukamoto fuzzy algorithm into an Internet of Things (IoT)-based framework. The results of the system provide information related to water quality by accurately classifying water quality into three categories, namely good, moderate, and unhealthy [21]. Water quality assessment is also needed for various purposes including consumption purposes. Fuzzy inference system (FIS) is used to determine water quality, water conditions, and categorize water quality into various categories for various water use purposes based on nine fuzzy variables used in water quality assessment, namely dissolved oxygen (DO), biological oxygen demand (BOD_5), chemical oxygen demand (COD), pH, ammonium (NH_4^+), phosphate (PO_4^{3-}), total suspended solids (TSS), turbidity, and total coliform (Tco) related to the suitability of river water for consumption [22].

Other studies examine the monitoring system with automatic correction of water quality using Arduino and Raspberry Pi 3B+ via the IoT LoRaWAN protocol, the water quality parameters maintained are temperature, pH level, redox potential, turbidity, salinity, and dissolved oxygen. This system uses sensors, microcontrollers, and web applications for data collection and monitoring of six different water quality parameters that are sent in real-time to a web application for analysis and monitoring, then automatically corrected using devices such as aquarium heaters, sodium bicarbonate distribution motors, solenoid valves, and water pumps [23]. In line with that, water quality in the form of water temperature and pH control is carried out using pH sensors, temperature sensors, and water turbidity sensors which will be connected to the ESP32 microcontroller which already has a Wi-Fi module. This system works according to the reading of sensor values and fish farmers will find it easy to control water quality automatically [24].

2. MATERIAL AND METHODS

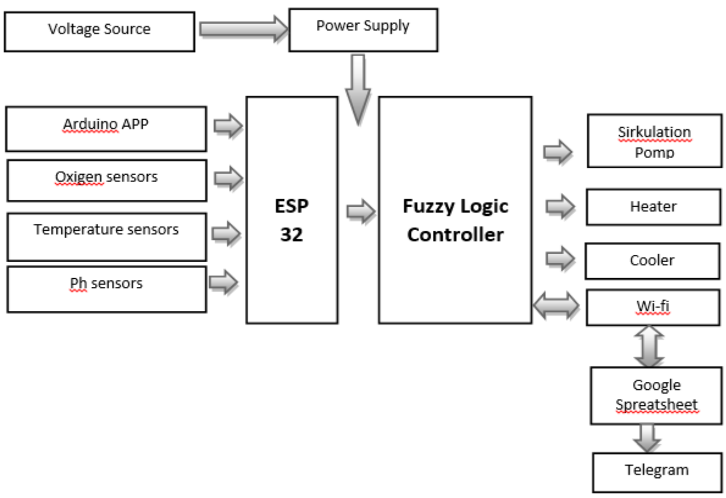

Figure 1. Block Diagram System

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Block diagram shows that the parameters measured related to water quality include temperature, DO, and pH which are used as input in determining water conditions which in turn the input from the three sensors will become a fuzzy set which ultimately becomes the basis for decisions from the output in the form of circulation pump performance time, heater, cooler, and pond status. The focus of this study is to determine the fluctuation of pond water quality in a structured and systematic manner in the gourami village of Singkalanyar Prambon Nganjuk Village. Given the major influence of seasonal and hourly variations on water quality, data collection is carried out in different time periods.

2.1. Material

This study was designed to detect and analyze data related to water quality parameters in real time. The flowchart image of water quality fluctuation pattern detection with a fuzzy logic controller (FLC) is shown in Figure 2 below.

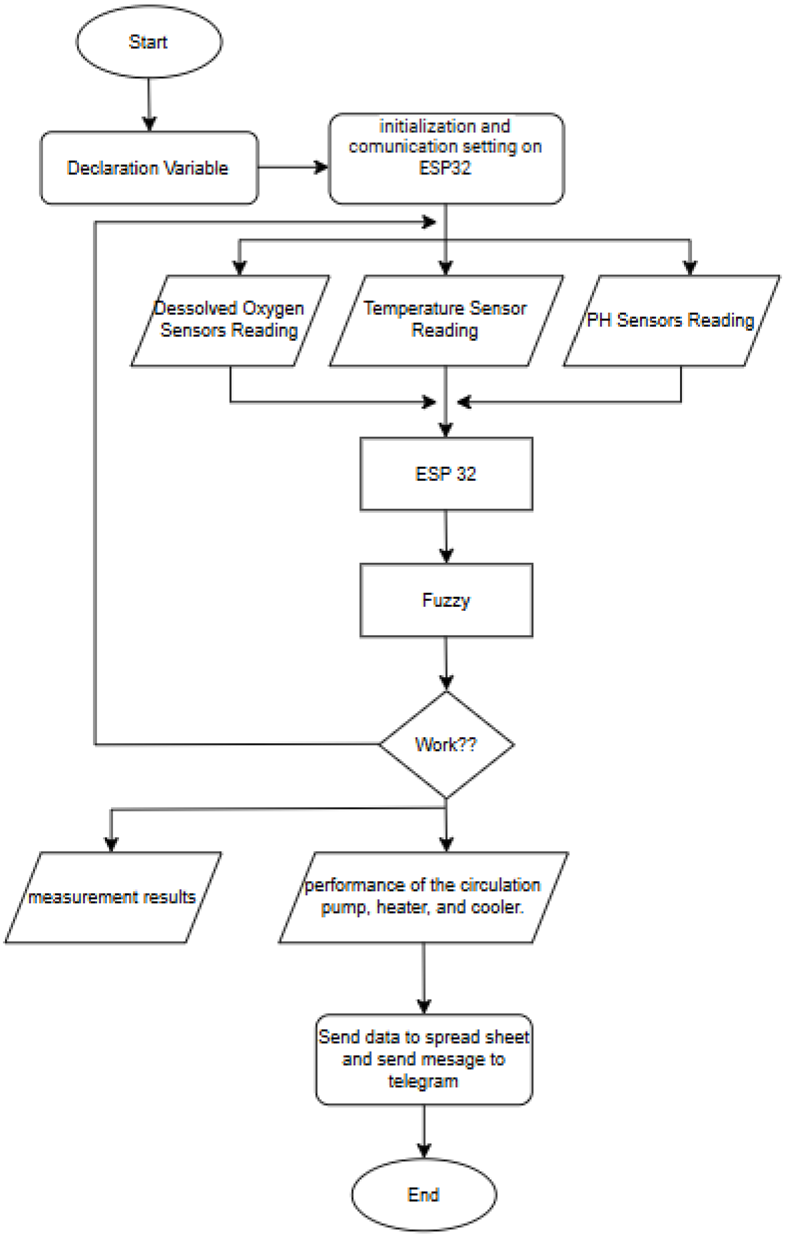

Figure 2. Flowchart for detecting water quality fluctuation patterns with a fuzzy logic controller (FLC)

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Figure 2 shows that the Detection of Water Quality Fluctuation Patterns with Fuzzy Logic Controller has an initial step, namely by declaring the required variables. ESP32 functions to read data from three sensors, namely temperature sensor, DO sensor, and PH sensor. Data from these three sensors is collected by ESP32 via Analog/Digital Input communication, then the sensor data obtained will be processed using the Fuzzy Logic Controller (FLC) method and will determine the status of water quality fluctuations and the performance of the circulation pump, heater, and aerator according to the sensor readings after that ESP32 uses serial communication to send the reading results from the three inputs. Fuzzy decisions to the Arduino IDE serial monitor to save data to Google Spreadsheet, then ESP sends an email to the address configured by the user automatically.

The materials and hardware used include: 1) Temperature sensor that has a strong casing, heat resistant and waterproof, this sensor has 64 bits that can be connected to sensors in the same data path. In this study, the temperature is divided into three criteria, namely cold, ideal, and hot; 2) oxygen sensor, used to determine the amount of oxygen content in water, in this study oxygen is divided into three criteria, namely low criteria, ideal criteria, and high criteria. Good water quality will have an ideal oxygen content, this is because if the oxygen content in the water is too low it will cause fish stress, increase ammonia production in fish, stunted fish growth, stress, weakness and cause premature death in fish, while the amount of oxygen in water that is too high will cause gill damage, gas bubble disease (GBD), fish are susceptible to disease, stress, and osmotic imbalance; 3) PH sensor, used to measure the alkalinity and acidity levels of pond water, in this study pH is divided into three criteria, namely acid, ideal, and alkaline. The PH content in the water must be ideal because if it is too acidic and alkaline it will disrupt fish metabolism and cause fish death; 4) ESP 32 is a microcontroller equipped with wifi and Bluetooth connectivity features [25]. In this study, it is the main component of the pond water quality control system.

2.2 Method

Fuzzy Logic Controller (FLC) is a fuzzy logic-based control system used to handle complex, uncertain, or difficult to mathematically model systems [26]. The Mamdani type Fuzzy Logic Controller (FLC) is ideal for non-deterministic decision-making systems, such as water quality monitoring, because it allows processing of linguistic and fuzzy information, and provides adaptive results to changing environmental conditions. In the context of this study, inputs are fed into a fuzzy rule-based system, which then produces outputs based on the inputs received. Specifically, this study combines three main input parameters, namely: temperature, PH, and DO. The membership function of each input parameter plays an important role in determining the number of fuzzy rules, with three membership functions given for each parameter, resulting in a total of 27 fuzzy rules. The outputs produced are the performance of the circulation pump, heater, aerator, and water quality status.aerator, and water quality status.

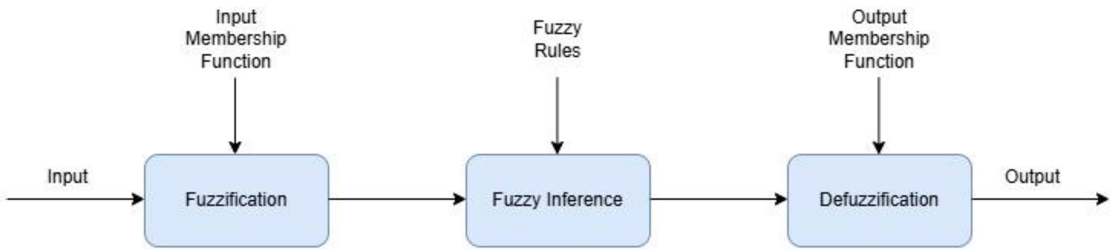

Figure 3. Fuzzy Logic Inference Structure

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Membership function is used to determine how inputs such as temperature, pH, and turbidity are classified flexibly, not absolutely. Membership function is shown in the Figure 4 below.

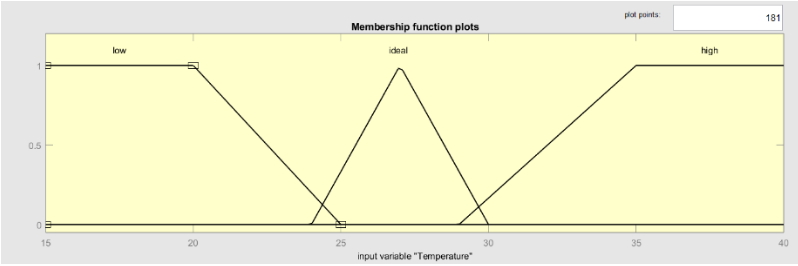

Figure 4. Membership Function Input Temperature

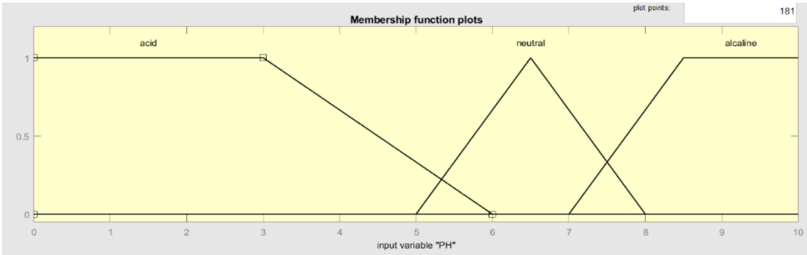

Figure 5. Membership Function Input PH

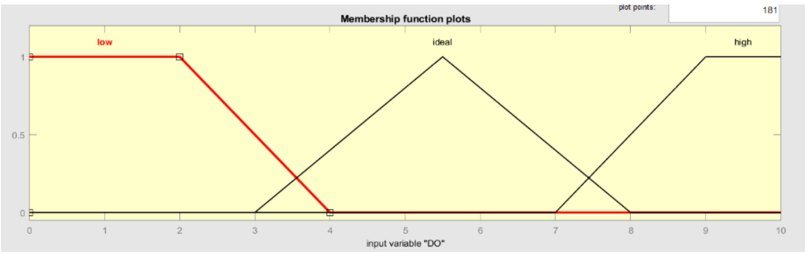

Figure 6. Membership Function Input DO

The rules or rule base created using the Fuzzy Mamdani method, there are twenty-seven rules using the MATLAB application shown in Figure 7 below.

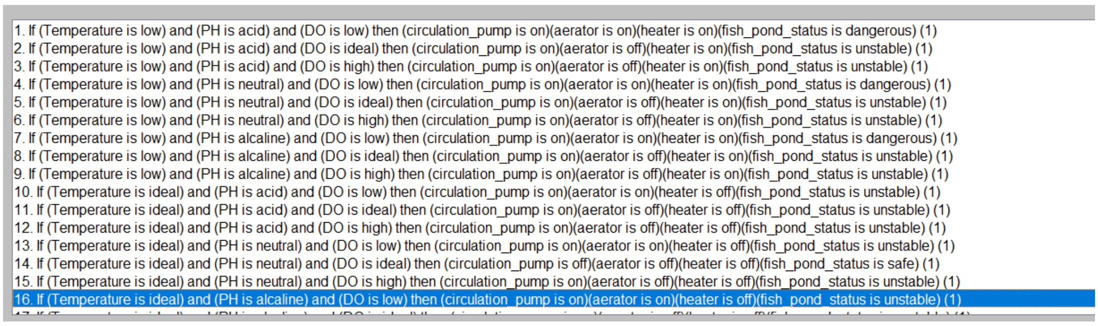
1. If (Temperature is low) and (PH is acid) and (DO is low) then (circulation_pump is on)(aerator is on)(heater is on)(fish_pond_status is dangerous) (1)
2. If (Temperature is low) and (PH is acid) and (DO is ideal) then (circulation_pump is on)(aerator is off)(heater is on)(fish_pond_status is unstable) (1)
3. If (Temperature is low) and (PH is acid) and (DO is high) then (circulation_pump is on)(aerator is off)(heater is on)(fish_pond_status is unstable) (1)
4. If (Temperature is low) and (PH is neutral) and (DO is low) then (circulation_pump is on)(aerator is on)(heater is on)(fish_pond_status is dangerous) (1)
5. If (Temperature is low) and (PH is neutral) and (DO is ideal) then (circulation_pump is on)(aerator is off)(heater is on)(fish_pond_status is unstable) (1)
6. If (Temperature is low) and (PH is neutral) and (DO is high) then (circulation_pump is on)(aerator is off)(heater is on)(fish_pond_status is unstable) (1)
7. If (Temperature is low) and (PH is alcaline) and (DO is low) then (circulation_pump is on)(aerator is on)(heater is on)(fish_pond_status is dangerous) (1)
8. If (Temperature is low) and (PH is alcaline) and (DO is ideal) then (circulation_pump is on)(aerator is off)(heater is on)(fish_pond_status is unstable) (1)
9. If (Temperature is low) and (PH is alcaline) and (DO is high) then (circulation_pump is on)(aerator is off)(heater is on)(fish_pond_status is unstable) (1)
10. If (Temperature is ideal) and (PH is acid) and (DO is low) then (circulation_pump is on)(aerator is on)(heater is off)(fish_pond_status is unstable) (1)
11. If (Temperature is ideal) and (PH is acid) and (DO is ideal) then (circulation_pump is on)(aerator is off)(heater is off)(fish_pond_status is unstable) (1)
12. If (Temperature is ideal) and (PH is acid) and (DO is high) then (circulation_pump is on)(aerator is off)(heater is off)(fish_pond_status is unstable) (1)
13. If (Temperature is ideal) and (PH is neutral) and (DO is low) then (circulation_pump is on)(aerator is on)(heater is off)(fish_pond_status is unstable) (1)
14. If (Temperature is ideal) and (PH is neutral) and (DO is ideal) then (circulation_pump is off)(aerator is off)(heater is off)(fish_pond_status is safe) (1)
15. If (Temperature is ideal) and (PH is neutral) and (DO is high) then (circulation_pump is on)(aerator is off)(heater is off)(fish_pond_status is unstable) (1)
16. If (Temperature is ideal) and (PH is alcaline) and (DO is low) then (circulation_pump is on)(aerator is on)(heater is off)(fish_pond_status is unstable) (1)

Figure 7. Rule Base

The description of membership functions and fuzzy rule parameters is important in forming if-then conditions that govern the fuzzy inference system. The rule viewer for detecting water quality fluctuation patterns with a fuzzy logic controller (FLC) is shown in Figure 8 below.

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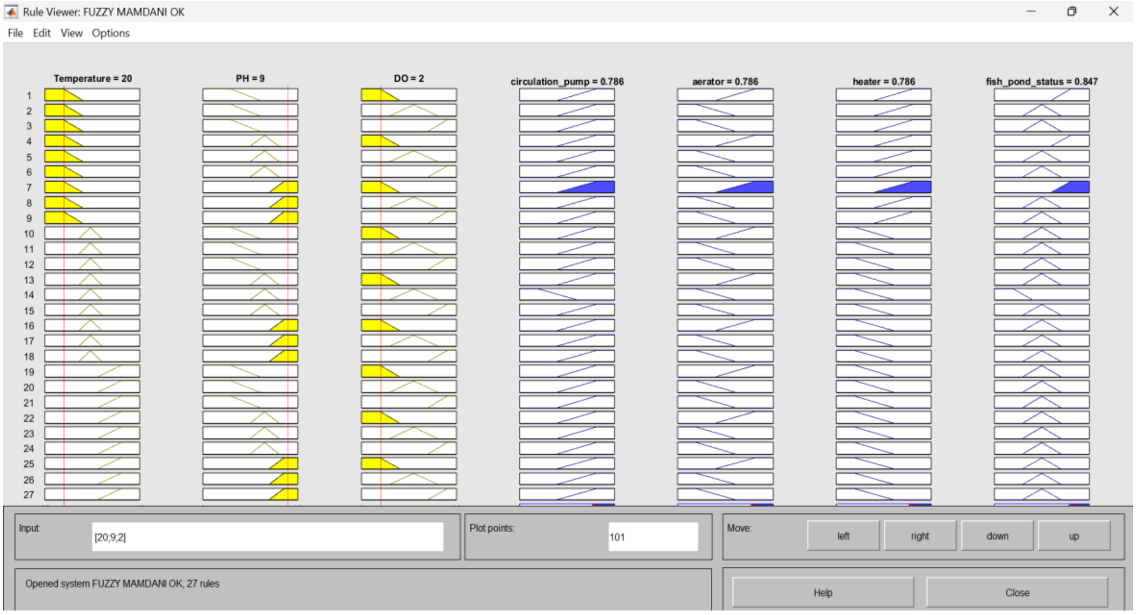

Gambar 8. Fuzzy rule viewer window

3. RESULTS AND DISCUSSION

The result of the hardware design of the Detection system for fluctuation patterns of temperature and pH of fish pond water using Fuzzy Logic Controller (FLC) is a wiring diagram scheme for hardware implementation and physical connection of components. The wiring diagram is shown in Figure 9 below.

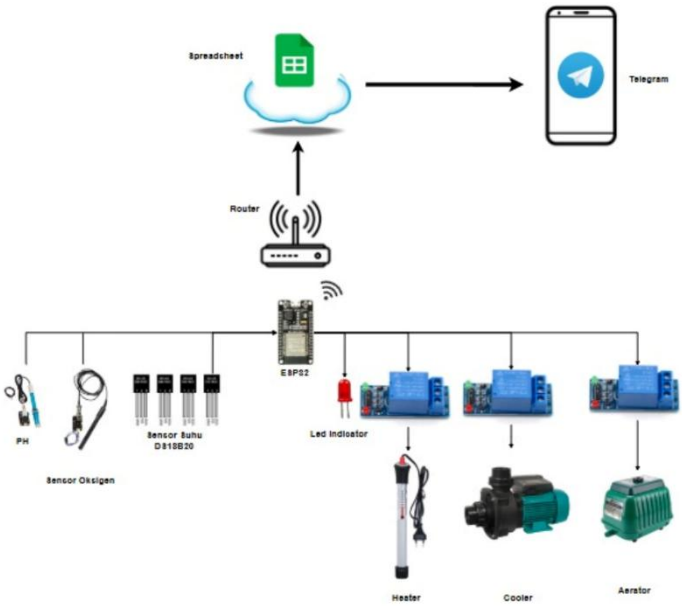

Figure 9. Wiring Diagram

In software design, it includes program design using Arduino IDE software, Fuzzy Logic Controller design using Matlab, database compilation on Google Spreadsheet, IoT integration with Fuzzy Logic Controller, time control programming. The system assembly stages used to control the aeration, heater, and cooler work patterns that are adjusted to water quality fluctuations. The results of the design of Water Quality Fluctuation Pattern Detection using Fuzzy Logic Controller (FLC) are shown in Figure 10 below.

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Figure 10. Design of a tool for detecting fluctuation patterns in temperature and pH of fish pond water using a Fuzzy Logic Controller (FLC).

The weaknesses of the designed system are: 1) the system does not have the ability to analyze long-term data trends; and 2) the accuracy of the system is highly dependent on the temperature and pH sensors, so that the sensors experience drift, noise, or damage, then the input data to the FLC is invalid, causing incorrect detection results.

Initial water quality testing was initially carried out manually with the aim of determining water quality fluctuations in the same place but at different angles of instrument placement. Data collection was carried out 3 times, namely in the morning, afternoon, and evening. The results of testing water conditions in the right corner pool and the left corner pool are shown in Figure 11 below.

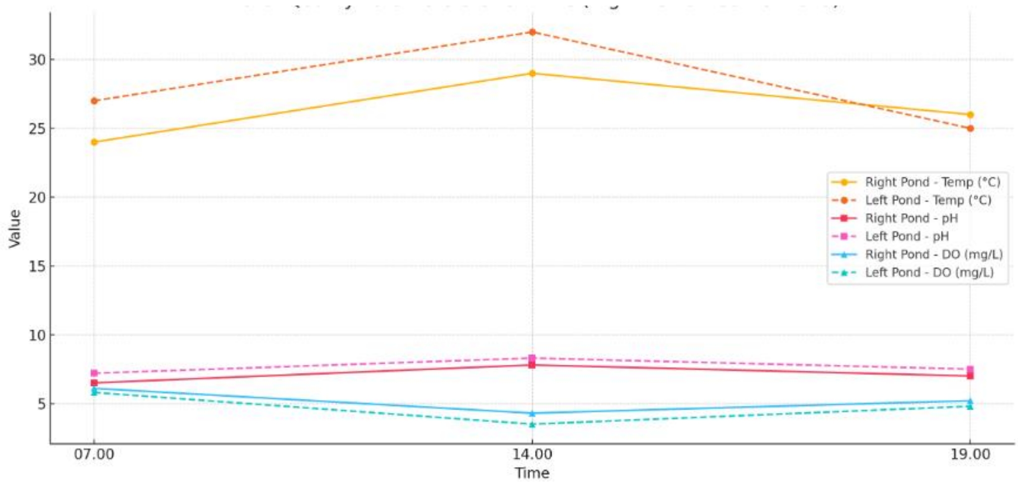

Figure 11. Differences in water quality (temperature, pH, and DO) in the right and left corner pools.

The results show that, in one pool has different water quality this is because the corner of the pool on the right receives direct sunlight so that it affects the amount of oxygen dissolved in the water and the pH content of the water. So the use of fuzzy is expected to be able to regulate the performance of the circulation pump, heater performance, cooler performance according to the value of water quality fluctuations based on sensor readings.

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Further testing with a water quality fluctuation pattern detection tool with a fuzzy logic controller was carried out for 24 hours at different times to determine the water quality in one day. The test results are shown in Figure 12 below.

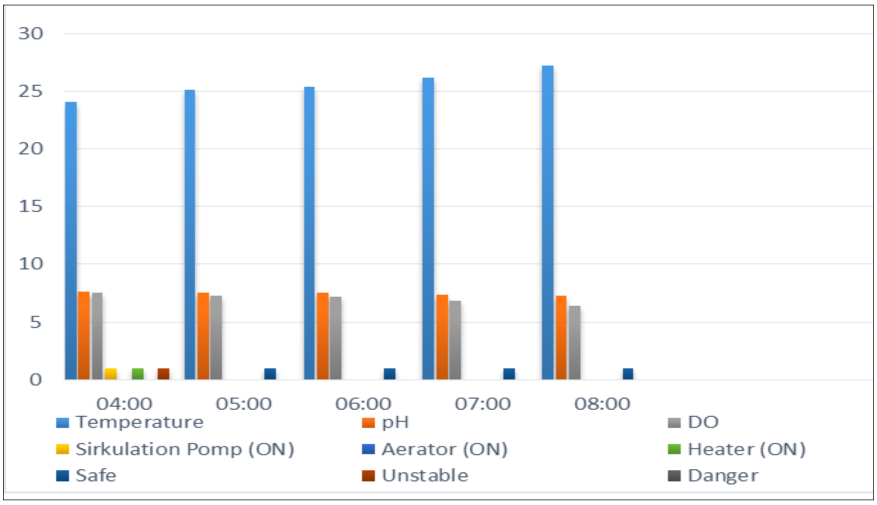

Figure 12. Results of water quality testing at 4:00 AM - 8:00 AM

Figure 12 shows that the water quality is unstable at 4:00 AM, namely the temperature is below the safe threshold so that the water quality shows an unstable status so that the heater automatically turns on and the circulation pump turns on and the message shows that the pool water quality is in condition, the circulation pump also turns on with the aim of distributing heat from the heater flame evenly in the pool. At 5:00 AM-8:00 AM after the temperature, pH, and oxygen are stable and show a safe status, the circulation pump, heater, and cooler are off.

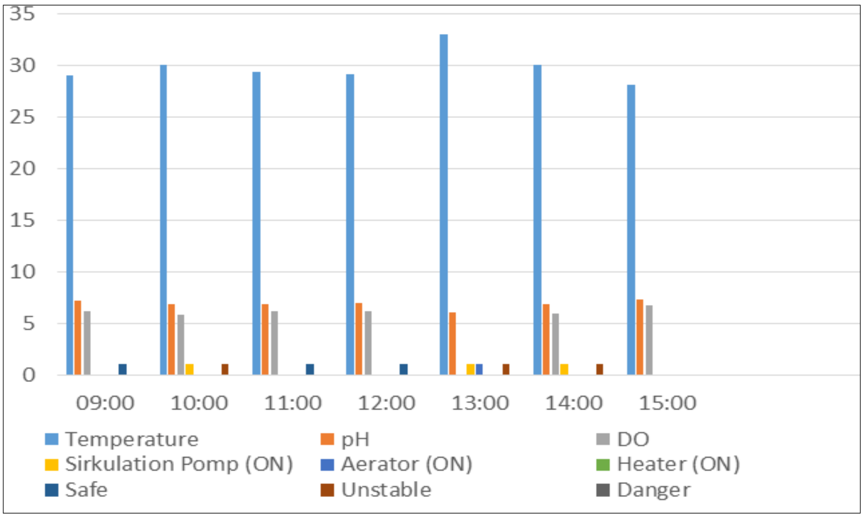

Figure 13. Results of water quality testing at 9:00 AM - 3:00 PM

Figure 13 shows that the water quality shows a safe status at 9:00 AM and at 10:00 AM the status decreases to unstable due to an increase in temperature above the safe limit so that the circulation pump turns on at 11:00 AM the water quality shows a safe status but at 01:00 PM the status changes to unstable due to a spike in temperature and a drastic decrease in DO, so that at 01:00 PM the circulation pump and aerator turn on simultaneously in order to reduce heat and help mix the water so that the temperature is even, increase DO levels by bringing water to the surface for contact with air, at 2:00 PM the condition still shows an unstable status

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but there has been an increase in oxygen so that the aerator turns off and the circulation pump is still on until the water quality condition shows a safe status. At 3:00 PM the water quality status shows a safe status so that the circulation pump, heater, and cooler are off.

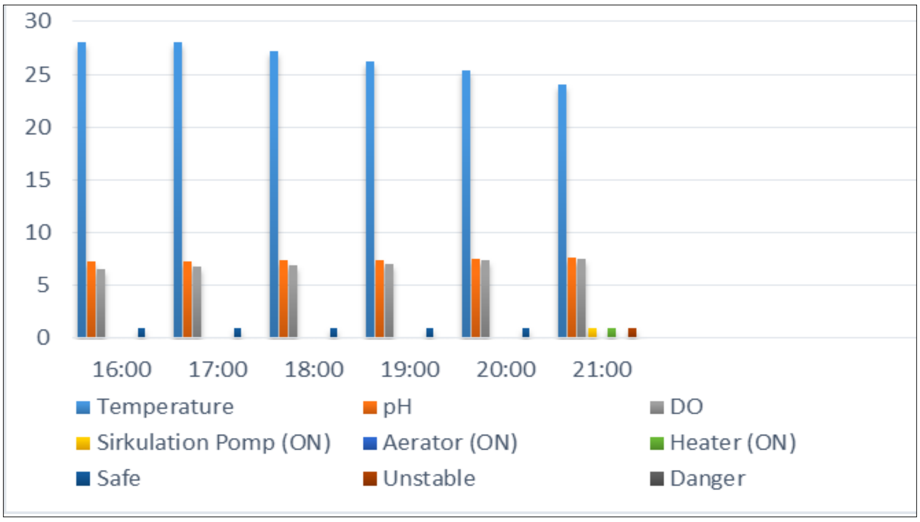

Figure 14. Results of water quality testing at 4:00 PM-9:00 PM

Figure 14 shows that the water quality shows a safe status at 4:00 PM to 8:00 PM but at 9:00 AM the condition changes to become unstable because there is a decrease in temperature so that the circulation pump and heater will turn on simultaneously. This is with the aim that heat can spread faster in the pool so that the pool condition quickly changes to a safe status.

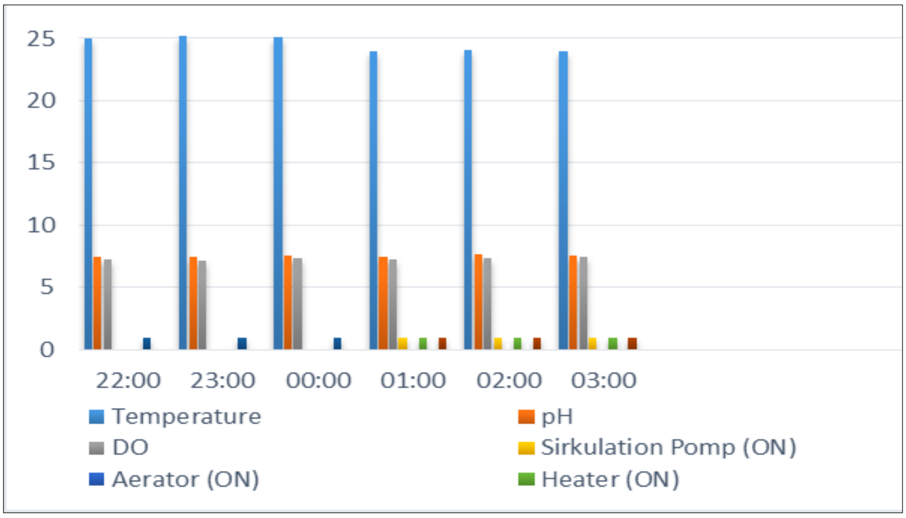

Figure 15. Results of water quality testing at 10:00 PM-3.00 AM

Figure 15 shows that the water quality shows a safe status at 10:00 PM to 12:00 PM and at 1:00 AM there is a decrease in status to become unstable due to an increase in temperature above the safe limit so that the circulation pump turns on at 11:00 AM the water quality shows a safe status but at 01:00 PM the status changes to unstable due to a decrease in temperature, so that at 01:00 PM the circulation pump and heater turn on simultaneously with the aim of accelerating the distribution of heat in the pool and the pool condition changes to a safe status.

Detection of water quality fluctuation patterns with fuzzy logic controller obtained results that the condition of water quality fluctuations changes every hour. In this study, to stabilize water quality, it is assisted by a circulation pump, heater, and aerator. The results of the

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application with a water quality fluctuation pattern detection tool with a fuzzy logic controller are shown in Figure 16 below.

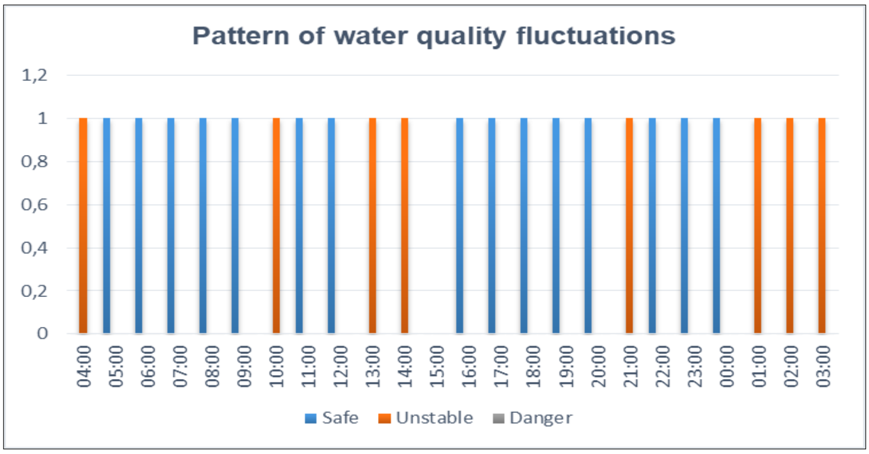

Figure 16. Pond Water Quality Fluctuation Pattern

The results showed that the water quality of the gourami pond was mostly in a safe condition and status throughout the day, with some unstable fluctuation periods that appeared periodically, especially at 04:00, 12:00–14:00, 21:00, and 01:00–03:00. This pattern indicates the influence of daily rhythms on water quality, such as an increase in daytime temperature or a decrease in dissolved oxygen levels at night. The absence of any hazardous conditions indicates that the water quality control system is working effectively, although optimization is still needed at critical hours to maintain the stability of the gourami pond water environment.

Figure 17. Application of water quality fluctuation pattern detection tool with *Fuzzy Logic Controller*

The application of a water quality fluctuation pattern detection tool with a fuzzy logic controller can help gourami fish in monitoring and regulating water quality fluctuation patterns according to the needs of gourami fish. If the measurement results are more unstable, the system will provide a warning to the user via notification on Telegram and the tool will work according to the conditions of the fish pond, so that by implementing this tool, fish can grow optimally and make it easier for gourami fish farmers to run a modern and economical fisheries system.

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4. CONCLUSION

Based on research related to the detection of water quality fluctuation patterns, it can be concluded that: 1) the device works every hour to monitor environmental fluctuations efficiently in order to detect changes that can affect fish health early, the results show that there are changes in water quality at critical hours, namely 04:00, 12:00–14:00, 21:00, and 01:00–03:00 which are influenced by temperature, pH, and oxygen conditions, 2) The status of water quality conditions is divided into three statuses, namely safe, unstable, and dangerous; and 3) The circulation pump, aerator, and heater turn on when the status is unstable and dangerous and will turn off when the pond condition is in a safe status.

5. ACKNOWLEDGMENT

Thanks to the Gurami Village fisheries group, Prambon District, Nganjuk Regency, who have agreed to be the place for conducting research and implementing a water quality fluctuation pattern detection tool with a fuzzy logic controller.

6. AUTHORS' NOTE

The authors declare no conflict of interest regarding the publication of this article. In addition, the authors confirm that the contents of this article are original work and free from plagiarism.

7. AUTHORS' CONTRIBUTION

The division of tasks in this study is: 1) Elsanda Merita Indrawati is responsible for Conceptualization, Methodology, Writing Original Drafts, Investigation, Supervision, Data Curation, Software, Review & Editing; 2) Cucun Andrianto and Adam Kurniawan are responsible for testing tools and analysis. The previous author's contribution is to provide an important contribution to the development of this research, especially in terms of the application of fuzzy inference systems to handle complex and uncertain data. Although the context of application is different, the structure of the fuzzy model, the use of IF-THEN rules, and the selection and processing of linguistic variables in this study are references in designing an air quality detection system based on the Fuzzy Logic Controller (FLC). The approach in the previous study also shows how the fuzzy method can be implemented periodically and validated through real case studies, which is in line with the testing strategy applied in this study.

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