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Development of a Water Quality Control System for Catfish Cultivation Using the Fuzzy Logic Method with IoT-Based Monitoring

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Abstract

Catfish (Clarias spp.) is a freshwater species known for its resilience to murky water conditions. However, when the water quality deteriorates excessively, it can become a breeding ground for diseases that hinder fish growth and even lead to mortality. Consequently, regular water changes are crucial to maintaining optimal conditions for fish cultivation. In response to this issue, this study proposes the development of an automated monitoring and control system to help manage water quality in aquaculture systems. The system integrates various sensors, including pH, DS18B20 temperature, HC-SR04 distance, turbidity, and MQ-135 air quality sensors, along with a Wemos D1 R32 microcontroller, water pump, servo motor, and an ESP-32 camera for real-time monitoring. An Android application is used to facilitate manual or automatic control of the system. The fuzzy logic method is employed to maintain optimal water quality parameters, with target values for temperature between 27-29°C, pH between 6.5-8.5, and turbidity below 32 NTU. System tests revealed that reducing the water temperature from 34°C to the target range of 27-29°C took 180 minutes, while stabilizing the pH from 9 to the optimal range (6.5-8) also took 180 minutes. Similarly, it took 187 minutes to reduce turbidity from 40.3 NTU to below 32 NTU. The results from Android-based monitoring and control tests showed that nearly all trials were successfully conducted. This research contributes significantly to the development of IoT-based automation in aquaculture, particularly in water quality control, offering a reliable and efficient solution to enhance the sustainability of catfish farming practices..

Keywords: Water Quality, Fuzzy Logic, Temperature, Turbidity

1. Introduction

Catfish farming is a rapidly growing sector within the aquaculture industry, with significant potential for economic growth. However, poor water quality is often a major constraint that negatively impacts fish growth and harvest yields (Ammari, Wildian, & Harmadi, 2019). Therefore, effective water quality control is essential to ensure optimal environmental conditions for the development of catfish. This research aims to design and develop a prototype for an automated water quality control system using the Fuzzy Logic method, integrated with an Internet of Things (IoT) based monitoring system (Aritonang & Bangsa, 2021). The application of this system is expected to enable real-time, automated monitoring and control of water quality in catfish ponds, leading to enhanced efficiency and improved harvest outcomes.

The primary objective of this study is to evaluate the performance of a microcontroller-based system in automating water quality control, while also assessing the impact of this system on maintaining the cleanliness of catfish ponds. Furthermore, this research seeks to measure the efficiency of the system in addressing poor water quality conditions and analyze the extent to which it contributes to the enhancement of catfish farming productivity (Barus, Pingak, & Louk, 2018).

The anticipated benefits of this study include the development of an effective tool for controlling water quality in catfish ponds, reducing the time required for water exchange processes, and solving issues related to poor water quality. In addition, this research has the potential to make a significant impact on improving the productivity and sustainability of catfish farming, ultimately providing greater profitability for farmers.

2. Material and methods

2.1. Fuzzy logic

Fuzzy Logic is a branch of artificial intelligence that uses linguistic values to operate intelligent systems (Dandi & Hidayat, 2020). Unlike classical logic, which only recognizes two absolute values true or false fuzzy logic allows truth values to exist on a continuum between true and false (Deswar & Pradana, 2021). In fuzzy logic, the concept of membership is used to describe the degree to which an element meets a particular criterion. This membership is typically represented by a value between 0 and 1, indicating the level of certainty or uncertainty regarding a statement or condition.

One of the primary advantages of fuzzy logic is its ability to handle problems involving uncertainty, imprecision, and noise, which are often present in real-world scenarios (Dewi, Rohmah, & Zahara, 2019). For example, in water quality control, fluctuating conditions such as temperature or pH levels can be analyzed using linguistic terms like "high," "medium," or "low," without relying on precise or exact data. This allows fuzzy systems to make decisions or provide responses even when the available data is imperfect or uncertain.

Additionally, fuzzy logic offers an advantage in terms of ease of design and implementation. Fuzzy-based control systems can be designed using rules based on natural language, such as "If the water temperature is high, then pump more cold water." This makes it more intuitive and easier to understand for system designers, compared to conventional mathematical methods that require more complex modeling (Hilal & Manan, 2015). Therefore, fuzzy logic is well-suited for various automation control applications that do not require complex mathematical models, such as temperature, humidity, and water quality control systems.

Due to its flexibility and ability to handle uncertainty, fuzzy logic has been widely applied in numerous fields, from automotive and electronics industries to agriculture and aquaculture. One relevant example of fuzzy logic application is in the control of water quality in catfish farming, where the water quality can be automatically monitored and controlled by considering various dynamic parameters that are difficult to measure accurately.

2.2. Internet of things

The Internet of Things (IoT) is a concept aimed at expanding the benefits of continuous internet connectivity (Imran & Rasul, 2020). Essentially, IoT refers to physical objects or "things" that can be uniquely identified and act as virtual representations within an internet-based structure. These objects are equipped with sensors, software, and other technologies that enable them to collect and exchange data over the internet without requiring direct human intervention. The IoT ecosystem connects devices to the internet, allowing them to communicate with each other, share data, and be controlled remotely (Mahendra Widyartono & K.T., 2020).

The main advantage of IoT lies in its ability to enhance the functionality and efficiency of systems by providing real-time data monitoring, analysis, and automated control (Noor, 2020). For example, in agriculture or aquaculture, IoT devices can monitor environmental conditions such as soil moisture, temperature, or water quality and send this data to a centralized platform for further analysis or action. This enables better decision-making, more efficient resource management, and improved operational outcomes. IoT is increasingly being integrated into various industries, including healthcare, manufacturing, transportation, and home automation, to create smarter, more interconnected environments (Novianti, Pribadi, & Saputra, 2018).

2.3. Sensor

- **pH Sensor**

A pH sensor is an electronic device used to measure the acidity or alkalinity (pH level) of a liquid. It consists of a measurement probe that is connected to an electronic device (Qalit & Rahman, 2017). The basic principle of the pH sensor is based on the electrochemical potential between a known solution inside the glass electrode and an unknown external solution. The potential is measured between a reference electrode (typically HgCl) and a KCl solution inside the glass electrode, as well as between the sample and a silver electrode.

The potential difference between the sample and the glass electrode changes according to the chemical properties of the sample (Kartika W, Farasi, & I., 2019). This change in potential is directly related to the concentration of hydrogen ions (H^+) in the solution, which determines the pH level. The sensor works by detecting these changes in electrochemical potential and converting them into an electrical signal that can be measured and displayed as the pH value.

pH sensors are commonly used in various fields, such as environmental monitoring, water treatment, food processing, and aquaculture, to ensure the proper pH levels for optimal conditions. In aquaculture, for example, maintaining the right pH level in fish ponds is crucial for the health and growth of aquatic organisms, as extreme pH levels can harm the ecosystem.

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- **DS18B20**

The DS18B20 is a waterproof temperature sensor with a digital data output. It is widely used in applications that require accurate temperature measurement in harsh or submerged environments. This sensor operates with a voltage range of 3-5V and has an accuracy of ±0.5°C. The temperature measurement range of the DS18B20 spans from -10°C to 85°C, making it suitable for a variety of applications, including monitoring temperature in environments such as fish ponds, water tanks, and outdoor systems.

- **HC-SR04**

The HC-SR04 is an ultrasonic sensor that converts sound waves into electrical signals to measure distance (Rosa, Simon, & Lieanto, 2020). It operates by emitting ultrasonic waves, typically at a frequency of around 20 kHz, and then measuring the time it takes for the waves to bounce back after hitting an object. This principle of sound wave reflection is used to calculate the distance between the sensor and the object.

The ultrasonic waves emitted by the HC-SR04 are inaudible to humans but can be detected by certain animals, such as bats, which use similar high-frequency sounds for echolocation. The sensor works by sending out a pulse (a burst of ultrasonic waves) and waiting for the echo to return (Siegers, Prayitno, & Sari, 2019). The time taken for the echo to return is used to calculate the distance based on the speed of sound in air.

The HC-SR04 can measure distances to objects in various mediums, including liquids, solids, and gases. However, it is important to note that ultrasonic waves can be absorbed by some materials, such as foam or textiles, which may reduce the effectiveness of the sensor in certain conditions. The sensor is commonly used in applications such as obstacle avoidance systems, distance measurement, robotics, and water level detection in tanks or ponds (Siswanto, Rojikin, & Gata, 2019) (Nugraha, 2022). The simplicity and affordability of the HC-SR04 make it a popular choice for DIY projects and educational purposes.

- **Turbidity**

A turbidity sensor is used to detect the cloudiness or turbidity of water by measuring its optical properties. This sensor works by comparing the amount of light that is reflected off the particles in the water with the amount of light that is transmitted through the water (Sugiono, Indriyani, & Ruswiansari, 2017). The turbidity level is determined based on this comparison, which provides an indication of how clear or murky the water is.

Turbidity in water is caused by individual particles, such as dirt, algae, or suspended solids, that are too small to be seen with the naked eye. These particles scatter and absorb light, which in turn affects the intensity of light reflected or transmitted through the water. The higher the turbidity, the more suspended particles are present, leading to a greater change in the sensor's output voltage.

- **MQ-135**

The MQ-135 is a chemical sensor sensitive to various compounds such as ammonia (NH_3), nitrogen oxides (NOx), alcohol, benzene, carbon monoxide (CO), carbon dioxide (CO_2), and others. This sensor detects gases by measuring changes in resistance, which is correlated with the concentration of the target gas in the air (Widodo, Irawan, Prastowo, & Surahman, 2020). As the concentration of a particular gas increases, the sensor's resistance changes, and this change can be detected and processed to estimate the concentration of the gas.

The MQ-135 is known for its good durability and high energy efficiency, making it a suitable choice for continuous monitoring of air quality. The sensitivity of the sensor can be adjusted based on different resistance values that correspond to various gas concentrations. This feature makes the sensor versatile for detecting different gases in different concentrations.

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2.4. Servo motor

A servo motor is a motor with a closed-loop feedback system that provides information about the motor's position to the control circuit (Yana, Dantes, & Wigraha, 2017). It consists of a motor, gears, a potentiometer, and a control circuit. The motor's angular position is regulated by the width of the pulse sent through the signal. A larger OFF pulse width moves the shaft in the clockwise direction, while a smaller pulse width moves it in the counterclockwise direction.

Servo motors are typically DC motors with built-in control mechanisms and internal gears that allow precise control over the movement and angular position of the motor. The potentiometer, which is connected to the motor, continuously measures the position of the motor shaft and provides feedback to the control circuit. This feedback ensures that the motor adjusts its movement to reach and maintain the desired angle.

3. Results and discussion

3.1. System design

Table 1. Performance

No	Temperature	Turbidity	pH	Water quality	
				Arduino	Toolbox Matlab
1	35,8	21,3	8,3	22,38	24,1
2	16,7	32,9	5,5	19,5	20,3
3	29,6	31,4	7,9	34,43	34,53
4	22,6	30,3	6,7	32,03	32,7

This study collects water quality datasheet data from the catfish farming pond owned by Pak Ryan. The data collection process is carried out through testing sensors connected to an Arduino. The gathered data includes water turbidity, water temperature, and pH levels. This data will serve as input for the system and will be compared with fuzzy logic results using Matlab. Four data points are used for the fuzzy logic comparison between Arduino and Matlab. The inputs involve five sensors: temperature, turbidity, pH, distance, and ammonia. These sensors will be connected to a microcontroller using fuzzy logic methods.

The sensor data will be processed by the microcontroller using fuzzy logic and subsequently sent to an Android application linked to a Google Firebase database. The application can be accessed via smartphones or laptops. Within the application, there are commands to control actuators that perform manual or automatic water draining and refilling of the pond. This system aims to improve the management and quality control of the pond's water, ensuring optimal conditions for the fish farming operation.

3.2. Testing Fuzzy

The fuzzy testing was conducted by comparing the fuzzy results obtained using Matlab and those derived from Arduino programming, as well as through manual calculations. Table 3.2 presents a comparison between the fuzzy results from Matlab and Arduino. The fuzzy logic testing results on Arduino, compared with Matlab, show an error of 3.35% for the water quality output, 2.8% for the incoming water output, 1.13% for the outgoing water output, and 0.52% for the aerator output, when compared to the Matlab toolbox.

This indicates that the use of fuzzy logic in the program created for Arduino aligns well with the Matlab toolbox, as evidenced by the small error values produced. The low error percentages demonstrate that the fuzzy logic implementation in the Arduino-based system is effective and accurate in controlling and monitoring the pond's water quality, confirming its reliability in comparison with the established Matlab toolbox.

Table 2. Error fuzzy Arduino and Matlab

No	Error(%)			
	Water quality	Water in	Water out	Aerator
1	7,14	7,44	0,00	0,00
2	3,94	1,49	0,99	0,57
3	0,29	0,00	2,15	1,50
4	2,05	2,28	1,38	0,00
Averang	3,35	2,80	1,13	0,52

e				

Fuzzy testing was conducted by comparing the fuzzy results obtained using Matlab with those derived from Arduino programming, as well as manual calculations. Table 2 presents the comparison between the fuzzy results from Matlab and Arduino. The results of the fuzzy logic testing on Arduino, compared to Matlab, show an average error of 2.25% for the water quality output, 4.05% for the incoming water output, 2.05% for the outgoing water output, and 1.36% for the aerator output, when compared to the Matlab toolbox.

This indicates that the use of fuzzy logic in the designed system aligns well with the Matlab toolbox. The small error values suggest that the fuzzy logic implementation in the system works effectively and accurately, achieving results that are consistent with the established Matlab toolbox. The low error percentages reflect the reliability and accuracy of the fuzzy logic system designed for controlling and monitoring water quality.

Table 3. Error fuzzy Arduino and Matlab

No	Error(%)			
	Water quality	Water in	Water out	Aerator
1	0	0	0	0
2	3,94	1,49	0,99	0,57
3	29,8	12,51	5,84	4,86
4	2,10	2,19	1,37	0
Averang e	2,25	4,05	2,05	1,36

3.3. Implementation

Table 4. Error fuzzy Arduino and Matlab

Day	Control Pool			Non Control Pool		
	Tem p	pH	Turbidity	Tem p	pH	Turbidity
1	27,8	7,9	31,9	29,4	9	47,3
2	27,3	7,3	31,9	27,4	7,7	47,9
3	28,6	7,9	32	27,7	8,8	45,3
4	27,7	8	30,7	28,3	7,8	49,4
5	28,6	7,7	31,3	29,5	8,2	46,2
6	28,5	6,9	31,9	29,5	7,9	46,3
7	27,2	7,6	30,7	29,8	8,8	46,7
8	28,1	7,2	31,7	27,6	8,8	49,8
9	27,7	7,7	31,1	28,5	8,8	49,4
10	27,2	7,5	31,6	27,7	8,2	48,9
11	27	7,6	30,5	27,4	8,6	31
12	28,9	7,2	31,7	28,1	7,7	31,3
13	27,8	7,1	31,3	29,1	7,8	33,6
14	27,7	7,3	30,5	30,2	7,7	30,7

. It can be concluded that the automatic water quality control system is effective in maintaining water quality at predefined values. Compared to ponds that are not controlled, the parameters obtained in the controlled system are more stable, ensuring that the water quality is consistently maintained. This stability in water quality is crucial for the health and growth of the fish, as it helps create optimal environmental conditions and minimizes the risk of water quality fluctuations that could harm the aquatic ecosystem.

4. Conclusion

Based on the findings of this study, several conclusions can be drawn. First, the design successfully demonstrates that key water quality parameters, such as temperature, pH, and turbidity, can be maintained within desired ranges. The application used for monitoring water quality parameters has also been successfully implemented and operated, providing real-time feedback and control.

Second, the implementation of manual monitoring and control via the Android application for the cultivation of red tilapia proved to be effective, yielding satisfactory results. While some tests experienced failures, the overall testing process was conducted with positive outcomes, showcasing the potential of this system for real-world applications in aquaculture.

Third, the application of the fuzzy logic method as an automatic controller for regulating temperature, pH, and turbidity through the process of water drainage and refilling was successful, though the time required to achieve the desired values was relatively long. This delay was primarily due to the use of a pump with a low flow rate, which impacted the efficiency of the system in controlling water quality parameters.

Based on these conclusions, several recommendations for further improvement can be made. First, it is suggested to add sensors at multiple points within the system to obtain more precise and measurable results during the monitoring process, enhancing the overall accuracy and reliability of the data. Second, integrating a cloud server for camera streaming would allow the system to continue streaming even when the laptop is turned off, improving the flexibility of the monitoring system. Additionally, it is recommended to use a higher-quality camera for better image clarity. Third, optimizing the water drainage system by selecting a pump with a higher flow rate would significantly reduce the time required to control water quality parameters, improving the overall efficiency of the system. If using a DC pump, it is important to match the battery capacity with the required power demand to ensure stable operation. Lastly, during sensor calibration, it is recommended to use a larger number of test samples to obtain more accurate calibration results, further enhancing the precision of the system..

Credit authorship contribution statement
Author Name: Conceptualization, Writing – review & editing. **Author Name**: Supervision, Writing – review & editing. **Author Name**: Conceptualization, Supervision, Writing – review & editing.

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