**Innovation in Research of Informatics (INNOVATICS)**

| ISSN (Online) 2656-8993 |

# IoT-based Water Quality Control in Tilapia Aquaculture Using Fuzzy Logic

*Anton Prafanto[1], Anindita Septiarini[2], Novianti Puspitasari[3], Medi Taruk[4], Dicky Alvian Mahendra[5]*

*[1,2,3,4,5]Department of Informatics, Mulawarman University, Jl. Kuaro Gn. Kelua, Samarinda 75119, Indonesia*

*[1]antonprafanto@unmul.ac.id, [2]anindita@unmul.ac.id, [3] novipuspitasari@unmul.ac.id, [4] meditaruk@unmul.ac.id, [5]dickyalvian1502@gmail.com*

ARTICLE INFORMATION

*Article History:*
Received: June 3, 2024
Last Revision: September 22, 2024
Published *Online*: September 30, 2024

KEYWORDS

Internet of Things,
Sugeno Fuzzy Method,
Water Quality Control,
Tilapia Aquaculture,
Real-time Monitoring

CORRESPONDENCE

Phone: +62811553393

E-mail: antonprafanto@unmul.ac.id

## ABSTRACT

Tilapia (Oreochromis Niloticus) represents a pivotal species within the domain of freshwater aquaculture, necessitating meticulous water quality management to guarantee its optimal growth and health. A deviation in water pH that is either too acidic or too alkaline can result in a reduction in appetite and an increased mortality rate in tilapia. The objective of this research is to develop an intelligent control system for monitoring and regulating the pH and temperature of tilapia culture ponds, employing the Sugeno Fuzzy method integrated with the Internet of Things (IoT) technology. The system demonstrates how Internet of Things (IoT) technology and Sugeno Fuzzy logic can be integrated to provide a robust solution for water quality management, which significantly improves the sustainability and productivity of tilapia farming. The findings indicate that the proposed system is effective in maintaining water quality, ensuring that pH and temperature remain within ideal ranges, which has a direct impact on reducing mortality and improving feeding efficiency. This marks an important advancement in the application of IoT technology for the improvement of sustainable aquaculture practices.

## 1. INTRODUCTION

Tilapia (Oreochromis Niloticus) is one of the most widely cultivated freshwater fish species globally due to its high protein content and significant economic value. According to the Food and Agriculture Organization (FAO), the global production of tilapia reached approximately 6.4 million tones in 2020, making it one of the top aquaculture species in terms of volume and value. However, maintaining optimal water quality is crucial for the health and growth of tilapia, particularly in terms of pH levels. Deviations in pH, whether too acidic or too alkaline, can lead to decreased appetite and increased mortality rates in tilapia [1], [2]. The advancement of information and communication technologies, particularly the Internet of Things (IoT), offers opportunities to enhance the effectiveness and efficiency of managing pond water quality in aquaculture [3], [4], [5]. The IoT enables the integration of various sensors and devices to collect real-time data, process it, and perform corrective actions automatically. This technological approach addresses the core challenges faced by tilapia farmers by providing a system that not only continuously monitors water conditions but also implements necessary adjustments in a timely and precise manner. This allows for the maintenance of water parameters within ideal limits and significantly reduces the risk of loss. The Sugeno Fuzzy method represents an effective fuzzy logic technique for decision-making based on uncertain and complex data, such as water pH regulation [6], [7], [8].

The selection of the Sugeno fuzzy method in this research is based on its superiority in handling data variability and uncertainty, particularly in applications that require rapid and precise decision-making. In comparison to alternative fuzzy methods, such as the Mamdani approach, Sugeno Fuzzy can generate a more quantifiable output (i.e., a crisp output) using linear or constant functions. This characteristic renders it particularly well-suited to the control of automated systems, such as those employed in the regulation of pH levels in Internet of Things (IoT)-based tilapia aquaculture. In this context, the fluctuating variability of temperature and pH sensor data necessitates an approach that can produce a rapid and precise output response. Sugeno Fuzzy offers a distinct advantage in this processing as it does not require complex defuzzification, thus minimizing delays in the execution of corrective actions [9].

Furthermore, Sugeno Fuzzy is more advantageous in IoT-based applications due to its superior computational efficiency. In the context of IoT systems that involve hardware with limited resources, such as the ESP32, the utilization of methodologies that necessitate less computationally demanding operations is of paramount importance. Sugeno Fuzzy enables the execution of more straightforward calculations in comparison to the Mamdani method, which typically entails the implementation of intricate logical operations. This enhanced efficiency enables the IoT system to effectively manage sensors in real-time with optimized performance, as well as to maintain water quality stability with accurate responses based on sensor data [10]. Recent advancements in IoT-based water quality management systems have shown promising results in enhancing aquaculture practices. For instance, IoT frameworks have been developed to monitor critical water parameters such as temperature, pH, and dissolved oxygen, which are essential for maintaining fish health and growth [11], [12]. These systems use various sensors to collect data and cloud-based platforms for real-time monitoring and analysis, enabling timely interventions and improved resource management. Moreover, integrating fuzzy logic with IoT technology has proven effective in handling the variability and uncertainty inherent in water quality management. Fuzzy logic controllers have been successfully applied to manage parameters such as ammonia and dissolved oxygen levels in aquaculture, offering a robust solution for maintaining optimal conditions [11], [12]. This approach allows for more adaptive and precise control strategies, which are critical for the sustainable growth of aquaculture operations.

This study aims to design an intelligent control system capable of monitoring and regulating the pH and temperature of tilapia aquaculture ponds in real-time using IoT technology and the Sugeno Fuzzy method. The system employs DS18B20 temperature sensors and E-201-C pH sensors to collect data on pond conditions, which is then processed by an ESP32 microcontroller. The obtained data is mapped to corrective actions involving the addition of pH buffers to maintain the water within the optimal range. Furthermore, this data is transmitted to a web server to enable real-time monitoring. It is anticipated that this research will make a significant contribution to the field of aquaculture, particularly in improving the quality and productivity of tilapia farming through the application of Internet of Things (IoT) technology and the Sugeno Fuzzy method[13], [14].

## 2. RELATED WORK

Several related studies have been conducted with the objective of monitoring and controlling water quality in aquaculture using Internet of Things (IoT) technology and fuzzy logic methods [5]. Research conducted by Martins A et al. developed an automated fish feeding system utilizing temperature and pH sensors and employed a fuzzy method to adjust the feed dosage based on inputs from both sensors. This system successfully provided fish feed according to a schedule with high accuracy [3]. In a further study, Mashaii N et al. monitored pH levels and water height in an aquaponic system using IoT. This system employed a microcontroller and sensors to automatically measure pH levels and water height, applying the Tsukamoto fuzzy concept to regulate water balance. Test results indicated that the system accurately measured pH levels and water height [1]. Liu L and Deng H developed an automatic control system to regulate the acidity (pH) of water in gourami fishponds using the Mamdani fuzzy method [7]. This study employed an Arduino Uno microcontroller, a pH sensor, and an ultrasonic sensor to measure water height. The Mamdani fuzzy method was applied to determine the corrective actions necessary to maintain optimal pH levels in the water. Kambalimath S and Deka P employed the Sugeno Fuzzy method to regulate water quality in tilapia fishponds. This research utilized pH and temperature sensors, and an ESP32 microcontroller to process sensor data. The results demonstrated that the Sugeno Fuzzy method was effective in regulating water quality by considering complex input variables [2].

The selection of an appropriate fuzzy logic method, namely Sugeno, Mamdani or Tsukamoto, is largely dependent on the specific requirements of the application in question. Although the Mamdani method is widely acknowledged for its intuitive approach and extensive utilization in commercial applications, it necessitates intricate defuzzification processes that may not be optimal for systems with constrained computational resources, such as IoT devices employed in aquaculture. Conversely, the Tsukamoto method, while offering a direct crisp output, may lack flexibility in handling the dynamic range of water quality parameters observed in aquaculture environments. The Sugeno method, employed in the present study, represents an optimal compromise, offering computational efficiency, which is vital for real-time applications, while maintaining the capacity to handle non-linearities in data through its piecewise linear or constant output functions. This method's reduced computational demand renders it particularly well-suited to the embedded systems within IoT applications, thereby enhancing the system's responsiveness and accuracy in water quality management.

In a study by Tolentino L et al., the Internet of Things (IoT) was employed to enhance the effectiveness of water quality management in aquaculture [8]. Their developed system utilized various sensors to monitor water conditions in real-time, and data was sent to a server for further analysis. The research indicated that the use of IoT could significantly improve the efficiency of water quality management. The studies demonstrate the efficacy of IoT technology and fuzzy logic methods, including the Sugeno method, in controlling and monitoring water quality in aquaculture [14]. Recent advancements in IoT-based water quality management systems have shown promising results in enhancing aquaculture practices. For instance, a study by Syeda et al. presented an IoT framework for real-time monitoring of water quality parameters such as temperature, pH, and dissolved oxygen using smart sensors and cloud-based platforms. This approach allowed for timely interventions and improved resource management

[15]. Another study by Zheng et al. implemented an IoT-based intelligent water quality management system that integrated fuzzy logic controllers to handle the variability and uncertainty in water quality data, resulting in more adaptive and precise control strategies [15]. Furthermore, the integration of fuzzy logic with IoT technology has proven effective in handling the variability and uncertainty inherent in water quality management. Fuzzy logic controllers have been successfully applied to manage parameters such as ammonia and dissolved oxygen levels in aquaculture, offering a robust solution for maintaining optimal conditions [15]. This approach allows for more adaptive and precise control strategies, which are critical for the sustainable growth of aquaculture operations.

This research builds upon these findings by focusing on the application of the Sugeno Fuzzy method and IoT technology to regulate the pH and temperature of water in tilapia aquaculture ponds.

## 3. METHODOLOGY

The objective of this study is to develop an intelligent control system capable of monitoring and regulating the pH and temperature of tilapia aquaculture ponds in real-time using IoT technology and the Sugeno Fuzzy method. The pH value of tilapia pond water can fluctuate due to various activities such as rain, leftover food, and fish waste, which can affect the health of tilapia. To maintain the pH stability of the pond water, an effective control system is essential. This research project aims to develop a system that accurately controls the pH level using Internet of Things (IoT) technology in conjunction with the Sugeno fuzzy method. The system integrates an ESP32 microcontroller as the data processing center, E-201-C pH sensors for measuring water acidity, DS18B20 temperature sensors for monitoring water temperature, and 12V DC pumps for dispensing pH Buffer Up and pH Buffer Down. Furthermore, a two-channel relay module controls the pumps, an ADS1115 serves as an analog-to-digital converter, and a 16×4 LCD provides local display of information. The integration of these components into a cohesive IoT system is intended to ensure optimal water conditions for tilapia, thereby enhancing their overall health and growth.

### 3.1 Data Collection

Data collection is conducted using advanced IoT sensors to obtain real-time measurements of water temperature and pH levels. The DS18B20 temperature sensor operates within a range of -55°C to +125°C with an accuracy of ±0.5°C, ensuring precise monitoring of the pond's environmental conditions [15]. The E-201-C pH sensor, with a measurement range of 0 to 14 pH and an accuracy of ±0.1 pH, provides accurate readings of the water's acidity. These sensors are strategically placed in the pond to continuously capture data, which is then transmitted to the ESP32 microcontroller for processing.

Recent advancements in IoT technology have facilitated the development of smart aquaculture systems that integrate multiple sensors for comprehensive water quality monitoring. For example, systems that incorporate turbidity, dissolved oxygen, and ammonia sensors in addition to temperature and pH sensors have been shown to provide a more holistic view of the aquaculture environment. These integrated systems enable real-time monitoring and timely interventions to maintain optimal water conditions for fish health and growth [16].

The temperature variable is categorized into three fuzzy sets: "Cold," "Normal," and "Hot," while the pH variable is divided into five fuzzy sets: "Very Acidic," "Acidic," "Normal," "Basic," and "Very Basic." The classification of these variables into fuzzy sets is detailed in Table 1, which illustrates the specific ranges and membership functions used for each set. Figures 1 and 2 visually represent the membership functions for temperature and pH, respectively [17].

TABLE 1. FUZZY SETS FOR TEMPERATURE AND PH VARIABLES

| Function | Variable | Set | Universe of Discourse |
|---|---|---|---|
| Input | Temperature | Cold | 0 - 25 °C |
| | | Normal | 20 - 35 °C |
| | | Hot | 30 - 45 °C |
| | pH | Very Acidic | 0 - 4.5 pH |
| | | Acidic | 4 - 7 pH |
| | | Normal | 6.5 - 8.0 pH |
| | | Basic | 7.5 - 9 pH |
| | | Very Basic | 8.5 - 14 pH |
| Output | pH Up | Empty | 0 ml |
| | | Slight | 50 ml |
| | | Normal | 100 ml |
| | | Much | 150 ml |
| | | Very Much | 200 ml |
| | pH Down | Empty | 0 ml |
| | | Slight | 50 ml |
| | | Normal | 100 ml |
| | | Much | 150 ml |
| | | Very Much | 200 ml |

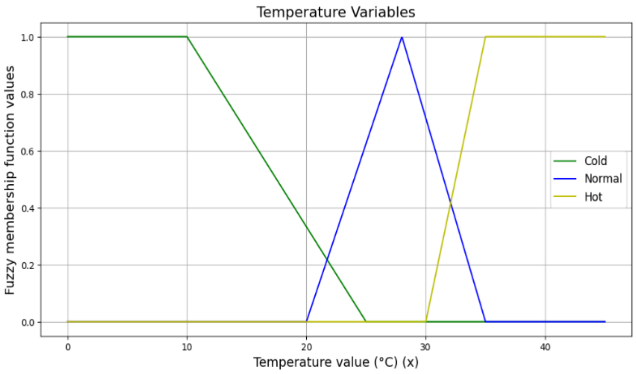

FIGURE 1. MEMBERSHIP FUNCTIONS FOR TEMPERATURE VARIABLE

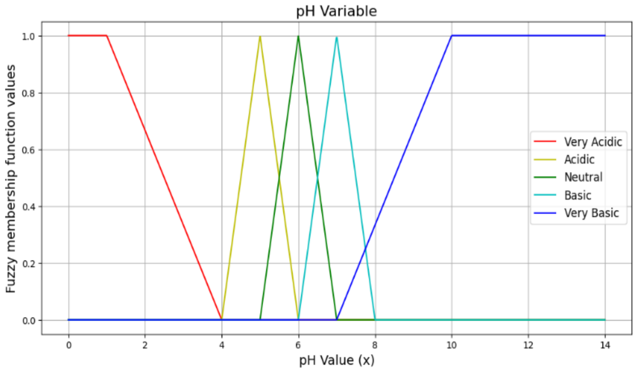

FIGURE 2. MEMBERSHIP FUNCTIONS FOR PH VARIABLE

To provide further illustration of the fuzzy logic control system, the triangular membership functions for temperature and the trapezoidal membership functions for pH are defined as follows. These membership functions are of critical importance in the fuzzyfication process, whereby real-world measurements are converted into degrees of membership that the system can utilise for decision-making.

The triangular membership function is defined mathematically as follows:

$$\mu(x; a, b, c) = \begin{cases} 0 & if\ x \leq a\ or\ x \geq c \\ {x-a}/{b-a} & if\ a < x \leq b \\ {c-x}/{c-b} & if\ b < x < c \end{cases} \tag{1}$$

The trapezoidal membership function is defined mathematically as follows:

$$\mu(x; a, b, c, d) = \begin{cases} 0 & if\ x \leq a\ or\ x \geq d \\ {x-a}/{b-a} & if\ a < x \leq b \\ 1 & if\ b < x \leq c \\ {d-x}/{d-c} & if\ c < x < d \end{cases} \tag{2}$$

## 3.2 Rule Formation

The Sugeno Fuzzy method is employed to process the collected data and determine the appropriate corrective actions. The fuzzy logic control system includes the fuzzification of input variables, rule evaluation, and defuzzification. The temperature variable is categorized into three fuzzy sets: "Cold," "Normal," and "Hot," while the pH variable is divided into five fuzzy sets: "Very Acidic," "Acidic," "Normal," "Basic," and "Very Basic." The membership functions for these variables are depicted in Figures 1 and 2. The fuzzy rules are formulated based on expert knowledge and previous research, as outlined in Table 2.

TABLE 1. Fuzzy Rule Formation

| No | Code | Condition |
|---|---|---|
| **1** | R1 | If the temperature is COLD and the pH is VERY ACIDIC, then pH UP is VERY MUCH, and pH DOWN is EMPTY |
| **2** | R2 | If the temperature is COLD and the pH is ACIDIC, then pH UP is MUCH, and pH DOWN is EMPTY |
| **3** | R3 | If the temperature is COLD and the pH is NORMAL, then pH UP is EMPTY, and pH DOWN is EMPTY |
| **4** | R4 | If the temperature is COLD and the pH is BASIC, then pH UP is EMPTY, and pH DOWN is LITTLE |
| **5** | R5 | If the temperature is COLD and the pH is VERY BASIC, then pH UP is EMPTY, and pH DOWN is MUCH |
| **6** | R6 | If the temperature is NORMAL and the pH is VERY ACIDIC, then pH UP is MUCH, and pH DOWN is EMPTY |
| **7** | R7 | If the temperature is NORMAL and the pH is ACIDIC, then pH UP is LITTLE, and pH DOWN is EMPTY |
| **8** | R8 | If the temperature is NORMAL and the pH is NORMAL, then pH UP is EMPTY, and pH DOWN is EMPTY |
| **9** | R9 | If the temperature is NORMAL and the pH is BASIC, then pH UP is EMPTY, and pH DOWN is LITTLE |
| **10** | R10 | If the temperature is NORMAL and the pH is VERY BASIC, then pH UP is EMPTY, and pH DOWN is MUCH |
| **11** | R11 | If the temperature is HOT and the pH is VERY ACIDIC, then pH UP is MUCH, and pH DOWN is EMPTY |
| **12** | R12 | If the temperature is HOT and the pH is ACIDIC, then pH UP is LITTLE, and pH DOWN is EMPTY |
| **13** | R13 | If the temperature is HOT and the pH is NORMAL, then pH UP is EMPTY, and pH DOWN is EMPTY |
| **14** | R14 | If the temperature is HOT and the pH is BASIC, then pH UP is EMPTY, and pH DOWN is LITTLE |
| **15** | R15 | If the temperature is HOT and the pH is VERY BASIC, then pH UP is EMPTY, and pH DOWN is VERY MUCH |

The codes are employed to facilitate referencing or calling during the inference engine stage of each rule. The conditions produced are based on the statement, If the temperature is (temperature variable) and the pH is (pH variable), then pH UP is (pH Up variable) and pH DOWN is (pH Down variable). Recent advancements have highlighted the effectiveness of fuzzy logic in managing water quality parameters in aquaculture systems. For instance, a study developed an IoT-based intelligent water quality management system that utilized fuzzy logic to manage temperature, pH, and turbidity levels. This system employed an ESP32 microcontroller to receive data from sensors and communicate with a cloud database, demonstrating the practical application of fuzzy logic in real-time water quality management [18].

Furthermore, another study implemented fuzzy logic to optimize the control of aerators and water pumps in aquaculture, showing significant improvements in maintaining stable water quality conditions. This research utilized trapezoidal membership functions for input parameters such as temperature, dissolved oxygen, and salinity, demonstrating how fuzzy logic can effectively handle the variability and uncertainty in water quality data [18]. The rule formation process is crucial in fuzzy logic systems as it directly impacts the decision-making process. The fuzzy rules are formulated by combining different input conditions to determine the appropriate actions. For example, if the water temperature is low and the pH is highly acidic, the system will add a significant quantity of pH Buffer Up to balance the water conditions. These rules are based on expert knowledge and empirical data from previous studies, ensuring that the system's responses are both accurate and effective.

The codes are employed to facilitate referencing or calling during the inference engine stage of each rule. The conditions produced are based on the statement, "If the temperature is (temperature variable) and the pH is (pH variable), then pH UP is (pH Up variable) and pH DOWN is (pH Down variable)." The rule formation table (Table 2) outlines the fuzzy rules employed in the pH control system. Each rule consists of temperature and pH conditions as inputs and the corresponding actions as outputs. For example, if the water temperature is low and the pH is highly acidic, the system will add a significant quantity of pH Buffer Up to balance the water conditions.

## 3.3 Inference Engine & Defuzzification

The inference engine is a critical component of the fuzzy logic control system where it processes the fuzzy input sets according to predefined rules to generate appropriate outputs. The inference process involves several steps, including rule evaluation, aggregation and defuzzification. The rules in the fuzzy rule base are evaluated using the minimum operator (AND) to determine the degree to which the antecedent conditions are satisfied. This degree is referred to as the firing strength (α-predicate) of the rule. The output of each rule is then calculated based on its firing strength and the corresponding output values.

Table 3 shows the evaluation of the fuzzy rules. Each rule is evaluated by calculating the minimum membership values (μ) of the input variables. The firing strength (α-predicate) for each rule is determined and the corresponding output values for pH Up (PHUP) and pH Down (pHDown) are assigned based on these strengths.

TABLE 3. RULE EVALUATION

| Rule | $\alpha$**predicate** | Output Values |
|---|---|---|
| R1 | $\alpha$predicate1=min($\mu$COLD[$x$],$\mu$VERY ACIDIC[$y$]) | $z$1PHUP=200, $z$1PHDOWN=0 |
| R2 | $\alpha$predicate2=min($\mu$COLD[$x$],$\mu$ACIDIC[$y$]) | $z$2PHUP=150, $z$2PHDOWN=0 |
| R3 | $\alpha$predicate3=min($\mu$COLD[$x$],$\mu$NORMAL[$y$]) | $z$3PHUP=0, $z$3PHDOWN=0 |
| R4 | $\alpha$predicate4=min($\mu$COLD[$x$],$\mu$BASIC[$y$]) | $z$4PHUP=0, $z$4PHDOWN=50 |
| R5 | $\alpha$predicate5=min($\mu$COLD[$x$],$\mu$VERY BASIC[$y$]) | $z$5PHUP=0, $z$5PHDOWN=150 |
| R6 | $\alpha$predicate6=min($\mu$NORMAL[$x$],$\mu$VERY ACIDIC[$y$]) | $z$6PHUP=150, $z$6PHDOWN=0 |
| R7 | $\alpha$predicate7=min($\mu$NORMAL[$x$],$\mu$ACIDIC[$y$]) | $z$7PHUP=50, $z$7PHDOWN=0 |
| R8 | $\alpha$predicate8=min($\mu$NORMAL[$x$],$\mu$NORMAL[$y$]) | $z$8PHUP=0, $z$8PHDOWN=0 |
| R9 | $\alpha$predicate9=min($\mu$NORMAL[$x$],$\mu$BASIC[$y$]) | $z$9PHUP=0, $z$9PHDOWN=50 |
| R10 | $\alpha$predicate10=min($\mu$NORMAL[$x$],$\mu$VERY BASIC[$y$]) | $z$10PHUP=0, $z$10PHDOWN=150 |
| R11 | $\alpha$predicate11=min($\mu$HOT[$x$],$\mu$VERY ACIDIC[$y$]) | $z$11PHUP=150, $z$11PHDOWN=0 |
| R12 | $\alpha$predicate12=min($\mu$HOT[$x$],$\mu$ACIDIC[$y$]) | $z$12PHUP=50, $z$12PHDOWN=0 |
| R13 | $\alpha$predicate13=min($\mu$HOT[$x$],$\mu$NORMAL[$y$]) | $z$13PHUP=0, $z$13PHDOWN=0 |
| R14 | $\alpha$predicate14=min($\mu$HOT[$x$],$\mu$BASIC[$y$]) | $z$14PHUP=0, $z$14PHDOWN=50 |
| R15 | $\alpha$predicate15=min($\mu$HOT[$x$],$\mu$VERY BASIC[$y$]) | $z$15PHUP=0, $z$15PHDOWN=200 |

The evaluation of these rules is based on the calculation of the minimum membership values (μ) of the input variables. The firing strength (α-predicate) for each rule is determined, and the corresponding output values (PHUP and PHDOWN) are assigned based on these strengths. The aggregation of the outputs from all the rules is performed to obtain a single fuzzy output. The defuzzification process involves converting this aggregated fuzzy output into a crisp value. This is typically accomplished through the weighted average method, wherein the weights are the firing strengths of the rules. The aggregated fuzzy output is then defuzzied to obtain a crisp value. In the Sugeno method, this is typically accomplished through the weighted average of the rule outputs.

The defuzzification process is formulated as follows:

$$Z *= \frac{\sum_{i=i}^{n} \alpha_i \, z_i}{\sum_{i=i}^{n} \alpha_i} \qquad (3)$$

Where $\alpha i$ represents the firing strength of rule i, and *zi represents the crisp output of rule i.*

## 3.4 Process Design

This section outlines the design process of the water quality control system in tilapia aquaculture ponds, utilizing the Sugeno fuzzy method and the Internet of Things (IoT). The principal components employed include the ESP32, pH sensor, DS18B20 temperature sensor, DC pump, and relay module. The design process encompasses several stages, including the system block diagram, wiring diagram, and system flowchart.

### 3.4.1 IoT System Block Diagram

The IoT-based water quality control system developed in this study consists of several key components, including an ESP32 microcontroller DS18B20 temperature sensors, E-201-C pH sensors, a two-channel relay module, and 12V DC pumps for dispensing pH Buffer Up and pH Buffer Down. The system architecture is illustrated in the block diagram shown in Figure 3. The pH and temperature sensors are connected to the analog and digital pins of the ESP32, respectively, to facilitate data collection and processing.

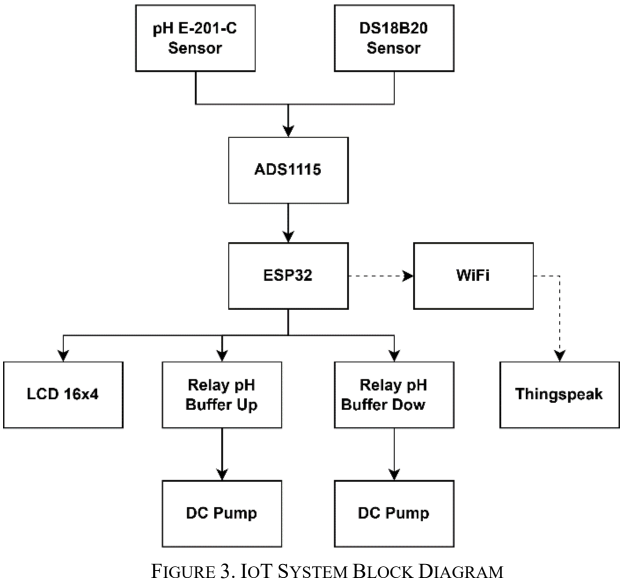

FIGURE 3. IOT SYSTEM BLOCK DIAGRAM

### *3.4.2 Wiring Diagram*

Figure 4 illustrates the system's wiring diagram for water quality control using fuzzy logic. The ESP32 microcontroller serves as the core, interfacing with various sensors and modules via digital and analog pins. Temperature and pH sensors connected to the analog pins provide real-time water condition data. An LCD display, connected through an I2C module, shows temperature, pH levels, and system status. The relay module, linked to the digital pins, controls the DC pumps based on ESP32's instructions. Multiple 12V, 2A power supplies ensure sufficient power distribution to all components. DC pumps regulate water flow to maintain optimal water quality, adjusting circulation and replacement as directed by the ESP32's fuzzy logic-based processing. This system ensures healthy environment for tilapia aquaculture by dynamically adjusting water conditions based on sensor data.

### *3.4.3 System Flowchart*

The system flowchart explains the workflow of the water quality control system, as shown in Figure 5. The process begins with the initialization of the ESP32, followed by starting the LCD and establishing a Wi-Fi connection. The ESP32 then reads data from the pH and temperature sensors. This data is processed using the Sugeno fuzzy method to determine the amount of pH buffer solution required. If the pH is less than 7, the system activates the relay and the DC pump to add the pH buffer up solution. If the pH is greater than 7.5, the system activates the relay and the DC pump to add the pH buffer down solution. The decision points ensure the precise activation of the relays and pumps based on real-time sensor data. The result of this process is sent to the relay module, which controls the pump to adjust the pH level in the pond. This automated feedback loop ensures optimal water quality for tilapia aquaculture, dynamically adjusting water conditions based on sensor data processed through fuzzy logic.

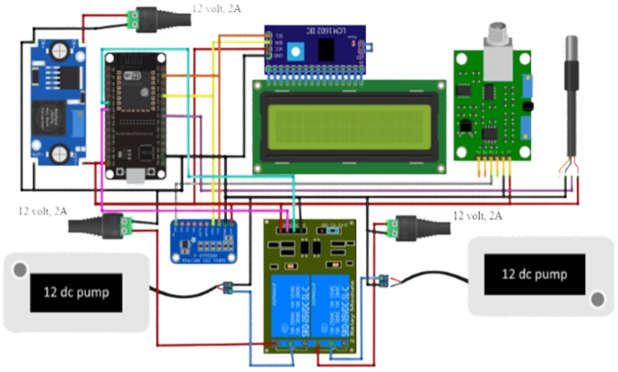

FIGURE 4. WIRING DIAGRAM OF IOT SYSTEM USING FUZZY LOGIC

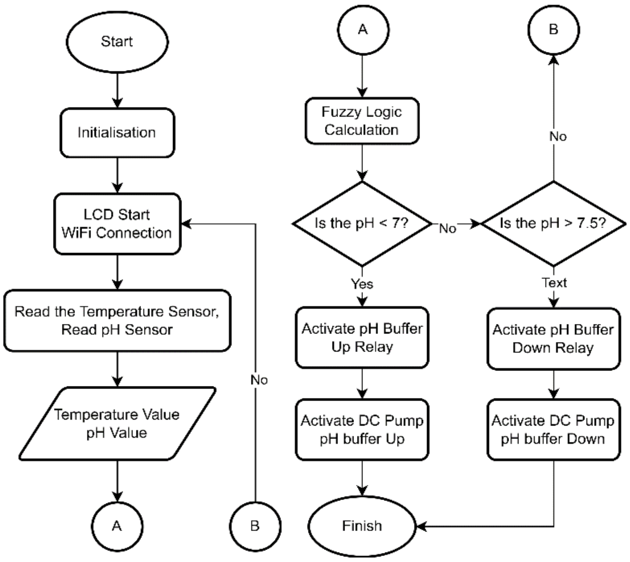

FIGURE 5. SYSTEM FLOWCHART OF IOT SYSTEM USING FUZZY LOGIC

## 4. RESULT AND DISCUSSION

This section will present the results of data acquisition from the sensors used. The acquired data includes pH values and water temperature in the tilapia aquaculture pond. This data is then processed using the Sugeno fuzzy method to produce outputs that will be used to control water quality. The pH and temperature values measured by the sensors are displayed in graphical form for easier analysis. The graphs displayed in Figures 4.1 and 4.2 illustrate the temporal changes in pH and temperature, respectively, and the system's response to these fluctuations.

TABLE 4. RULE EVALUATION

| No | Date | Clock | pH | Temperature |
|---|---|---|---|---|
| **1** | 13-09-2022 | 16.07.53 | 7.30 | **30.50°C** |
| **2** | 13-09-2022 | 16.09.46 | 7.33 | **30.44°C** |
| **3** | 13-09-2022 | 16.11.43 | 7.35 | **30.44°C** |
| **4** | 13-09-2022 | 16.13.43 | 7.76 | **30.44°C** |
| **5** | 13-09-2022 | 16.15.35 | 6.90 | **30.50°C** |
| **6** | 13-09-2022 | 16.17.38 | 7.08 | **30.37°C** |
| **7** | 13-09-2022 | 16.19.31 | 7.52 | **30.37°C** |
| **8** | 13-09-2022 | 16.21.29 | 7.76 | **30.37°C** |
| **9** | 13-09-2022 | 16.23.28 | 6.98 | **30.31°C** |
| **10** | 13-09-2022 | 16.25.23 | 6.81 | **30.37°C** |
| **11** | 13 09 2022 | 16.27.19 | 7.14 | **30.31°C** |
| **12** | 13-09-2022 | 16.29.16 | 7.08 | **30.31°C** |
| **13** | 13-09-2022 | 16.31.10 | 7.05 | **30.31°C** |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| **29** | 13-09-2022 | 17.02.26 | 5.53 | **29.94°C** |
| **30** | 13-09-2022 | 17.04.25 | 7.09 | **29.87°C** |

### 4.1 Test Result

The test results provide an assessment of the effectiveness of the IoT-based water quality control system using the Sugeno fuzzy method. The tests were carried out by comparing the sensor measurements with manual measuring tools to ensure accuracy. The tests focused on pH and temperature measurements, as these are critical parameters for maintaining optimal conditions for tilapia in aquaculture ponds.

### *4.1.1 pH Sensor Testing*

The pH sensor test was carried out using the E-201-C pH sensor and a pH meter for comparison. The results, shown in Table 4.2, indicate the accuracy of the pH sensor readings compared to the pH meter. Error percentages were calculated to evaluate the performance of the sensor.

FIGURE 5. E-201-C PH SENSOR TESTING WITH PH METER

| No | pH Meter | E-201-C pH Sensor | Error (%) |
|---|---|---|---|
| **1** | 7.0 | 7.1 | 1.43 |
| **2** | 6.5 | 6.4 | 1.54 |
| **3** | 8.0 | 7.9 | 1.25 |
| **4** | 5.5 | 5.6 | 1.82 |
| **5** | 7.2 | 7.1 | 1.39 |

The results show that the E-201-C pH sensor provides accurate readings with minimal error, making it suitable for real-time monitoring of pH levels in the aquaculture pond.

### *4.1.2 Temperature Sensor Testing*

The temperature sensor test involved comparing the DS18B20 sensor with a digital thermometer. The results, shown in Table 4.3, show the accuracy of the temperature sensor readings and the associated error percentages.

FIGURE 6. DS18B20 SENSOR TESTING WITH DIGITAL THERMOMETER

| No | Digital Thermometer | DS18B20 Sensor | Error (%) |
|---|---|---|---|
| **1** | 25°C | 24.8°C | 0.80 |
| **2** | 27°C | 27.1°C | 0.37 |
| **3** | 29°C | 28.9°C | 0.34 |
| **4** | 30°C | 29.8°C | 0.67 |
| **5** | 26°C | 26.2°C | 0.77 |

The DS18B20 temperature sensor exhibited exceptional accuracy, maintaining low error margins across various conditions, which underscores its reliability for precise temperature monitoring within the system. Its consistent performance, even in fluctuating environmental factors, makes it an ideal choice for applications requiring long-term stability and dependable data collection for critical thermal management.

### *4.1.3 Fuzzy Logic Testing*

The fuzzy logic control system was tested to evaluate its ability to maintain optimal pH levels in the pond. Table 4.4 presents the results of the fuzzy logic evaluation, showing the input conditions, the corresponding output actions and the effectiveness of the system in maintaining the desired pH range.

Figure 7. Fuzzy Logic Control System Testing

| No | Input Conditions | Output Actions | Result |
|---|---|---|---|
| 1 | Temperature: 25°C, pH: 6.0 | pH Buffer Up: 100 ml | pH Adjusted to 7.0 |
| 2 | Temperature: 28°C, pH: 8.5 | pH Buffer Down: 150 ml | pH Adjusted to 7.5 |
| 3 | Temperature: 30°C, pH: 7.2 | No Action | pH Remained 7.2 |
| 4 | Temperature: 26°C, pH: 5.5 | pH Buffer Up: 150 ml | pH Adjusted to 6.8 |
| 5 | Temperature: 27°C, pH: 9.0 | pH Buffer Down: 200 ml | pH Adjusted to 7.5 |

The fuzzy logic control system proved its effectiveness in adjusting the pH levels to the optimum range, ensuring an environment conducive to tilapia growth.

## 5. CONCLUSIONS

In this study, an IoT-based water quality control system using the Sugeno fuzzy method for tilapia aquaculture was successfully developed and tested. The system is designed to monitor and regulate the pH and temperature of the pond water in real time to maintain optimal conditions for tilapia growth. The test results showed that the E-201-C pH sensor and the DS18B20 temperature sensor have high accuracy with minimal error, ensuring reliable data collection for the control process. The Sugeno fuzzy control system proved effective in adjusting the pH levels of the pond water to the optimum range based on the detected temperature and pH input conditions. In addition, the system is equipped with real-time monitoring capabilities, allowing continuous monitoring and immediate action, if necessary, thus improving responsiveness to changes in water conditions. Overall, this study demonstrates that the integration of IoT technology and fuzzy logic can significantly improve the efficiency and productivity of tilapia aquaculture, reducing the risk of fish mortality due to sub-optimal water conditions. The implementation of this system is expected to make a significant contribution to the field of aquaculture, particularly in improving the quality and productivity of tilapia farming.

## REFERENCES

[1] N. Mashaii *et al.*, “Reproductive Biology of Nile Tilapia, Oreochromis niloticus under the Brackish Water Culture Condition,” *International Journal of Food Science and Agriculture*, vol. 6, no. 1, pp. 4–7, Jan. 2022, doi: 10.26855/ijfsa.2022.03.002.

[2] A. W. S. Martins *et al.*, “Exposure to salinity induces oxidative damage and changes in the expression of genes related to appetite regulation in Nile tilapia (Oreochromis niloticus),” *Front Genet*, vol. 13, Sep. 2022, doi: 10.3389/fgene.2022.948228.

[3] Y. Chang, J. Xu, and Z. Ghafoor, “AN IOT AND BLOCKCHAIN APPROACH FOR THE SMART WATER MANAGEMENT SYSTEM IN AGRICULTURE,” vol. 22, no. 2, pp. 105–116, 2021, doi: 10.12694:/scpe.v22i2.1869.

[4] M. M. Islam, M. A. Kashem, and J. Uddin, “An internet of things framework for real-time aquatic environment monitoring using an Arduino and sensors,” *International Journal of Electrical and Computer Engineering*, vol. 12, no. 1, pp. 826–833, Feb. 2022, doi: 10.11591/ijece.v12i1.pp826-833.

[5] F. Lezzar, D. Benmerzoug, and I. Kitouni, “IoT for monitoring and control of water quality parameters,” *International Journal of Interactive Mobile Technologies*, vol. 14, no. 16, pp. 4–19, 2020, doi: 10.3991/ijim.v14i16.15783.

[6] S. Kambalimath and P. C. Deka, “A basic review of fuzzy logic applications in hydrology and water resources,” Aug. 01, 2020, *Springer Science and Business Media Deutschland GmbH*. doi: 10.1007/s13201-020-01276-2.

[7] L. Liu and H. Deng, “A fuzzy approach for ranking discrete multi-attribute alternatives under uncertainty,” *Mathematics*, vol. 8, no. 6, Jun. 2020, doi: 10.3390/MATH8060945.

[8] L. K. Tolentino *et al.*, “IoT-based automated water monitoring and correcting modular device via LoRaWAN for aquaculture,” *International Journal of Computing and Digital Systems*, vol. 10, no. 1, pp. 533–544, 2021, doi: 10.12785/IJCDS/100151.

[9] D. Mukhamedieva, K. Alimbaev, S. Bakhtiyorov, and S. Normirzaev, “Creation of an intelligent irrigation system based on the fuzzy Sugeno model,” *InterConf*, no. 43(193), pp. 487–493, Mar. 2024, doi: 10.51582/interconf.19-20.03.2024.047.

[10] O. O. Olanubi, T. T. Akano, and O. S. Asaolu, “Design and development of an IoT-based intelligent water quality management system for aquaculture,” *Journal of Electrical Systems and Information Technology*, vol. 11, no. 1, Mar. 2024, doi: 10.1186/s43067-024-00139-z.

[11] G. You *et al.*, “Evaluation of aquaculture water quality based on improved fuzzy comprehensive evaluation method,” *Water (Switzerland)*, vol. 13, no. 8, Apr. 2021, doi: 10.3390/w13081019.

[12] C. H. Chen, Y. C. Wu, J. X. Zhang, and Y. H. Chen, “IoT-Based Fish Farm Water Quality Monitoring System,” *Sensors*, vol. 22, no. 17, Sep. 2022, doi: 10.3390/s22176700.

[13] E. Syrmos *et al.*, “An Intelligent Modular Water Monitoring IoT System for Real-Time Quantitative and Qualitative Measurements,” *Sustainability (Switzerland)*, vol. 15, no. 3, Feb. 2023, doi: 10.3390/su15032127.

[14] M. Lowe, R. Qin, and X. Mao, “A Review on Machine Learning, Artificial Intelligence, and Smart Technology in Water Treatment and Monitoring,” *Water (Switzerland)*, vol. 14, no. 9, May 2022, doi: 10.3390/w14091384.

[15] F. Jan, N. Min-Allah, and D. Düştegör, “Iot based smart water quality monitoring: Recent techniques, trends and challenges for domestic applications,” Jul. 01, 2021, *MDPI AG*. doi: 10.3390/w13131729.

[16] W. M. Sanya, M. A. Alawi, and I. Eugenio, “Design and development of Smart Water Quality Monitoring System Using IoT,” *International Journal of Advances in Scientific Research and Engineering*, vol. 08, no. 03, pp. 01–13, 2022, doi: 10.31695/ijasre.2022.8.3.1.

[17] A. A. Bracino *et al.*, “Fuzzy Logic-Based Automated pH and Temperature Control System for Biofilter in Smart Aquaponics,” 2020.

[18] O. O. Olanubi, T. T. Akano, and O. S. Asaolu, “Design and development of an IoT-based intelligent water quality management system for aquaculture,” *Journal of Electrical Systems and Information Technology*, vol. 11, no. 1, Mar. 2024, doi: 10.1186/s43067-024-00139-z.

## AUTHORS

**Anton Prafanto**

A lecturer in the Department of Informatics at the Faculty of Engineering, Mulawarman University, Samarinda. His current research interests encompass Wireless Sensor Networks, the Internet of Things (IoT), and embedded systems. Additionally, he explores innovative applications of these technologies in various domains, including smart cities, environmental monitoring, and industrial automation. Through his work, he aims to enhance connectivity, efficiency, and automation in modern technological ecosystems, contributing to advancements in both academic research and real-world solutions.

**Anindita Septiarini**

Lecturer in the Department of Informatics, Faculty of Engineering, Mulawarman University, Samarinda. Research interests include Artificial Intelligence, Image Processing, Computer Vision, Machine Learning, Data Science, Deep Learning, and Pattern Recognition, with a focus on developing innovative computational techniques.

**Novianti Puspitasari**

Received the B.Sc. degree in informatics engineering from the Universitas Islam Indonesia, and the M.Eng. degree in information technology from the Gadjah Mada University, Indonesia. She is currently a lecturer at the Department of Informatics, Mulawarman University. Her research interest is in data science and analytics, artificial intelligence, and machine learning areas.

**Medi Taruk**

Lecturer in the Department of Informatics, Faculty of Engineering, Mulawarman University, Samarinda. Current research focuses on Network Centric Computing, Security, Cryptography, Distributed Systems, Cloud Computing, and Data Privacy, with an emphasis on developing secure and scalable solutions.

**Dicky Alvian Mahendra**

Graduated from the Department of Informatics, Faculty of Engineering, Mulawarman University, Samarinda, Indonesia, focus on Software Engineering, Data Analysis, and System Design.