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IoT-Based Water Quality Monitoring System for Fish Ponds Using Fuzzy Inference Method

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ABSTRACT This study uses the fuzzy inference method to develop an Internet of Things (IoT) system to monitor fish pond water quality. This system utilizes pH, Total Dissolved Solids (TDS), and temperature sensors to measure water quality parameters for fish health. Although many previous studies have discussed water quality monitoring, there are still limitations in applying IoT technology integrated with fuzzy inference methods for real-time data analysis. Many existing systems cannot provide information easily understood by fish farmers and are less accurate in measuring water quality parameters. Arduino Nano is the main microcontroller that processes sensor data, while the ESP8266 module is used for Wi-Fi connection for real-time monitoring through the thinger.io web-based application. Before testing, the sensors have been calibrated to ensure measurement accuracy. The test results on three water samples, namely tap water, tilapia pond water, and mujaer pond water, showed high accuracy and consistent results. The fuzzification results from the IoT device are close to the Simulink Fuzzy test results on each sample, with minor differences in tilapia pond water, likely caused by environmental factors such as aeration or sensor precision. This study aims to provide a system that is not only accurate but also presents data in a more understandable format so that it can help fish farmers make better pond management decisions. Thus, this study is expected to increase fish farming productivity through better and technology-based water quality management.

KEYWORDS: IoT, water quality, fuzzy inference, pH sensors, TDS.

I.INTRODUCTION

Water quality is a key factor in the success of freshwater fish farming. The health and optimal growth of fish depends heavily on clean and balanced water conditions. Parameters such as Total Dissolved Solids (TDS), pH, and temperature play a crucial role. Too high a TDS can disrupt the osmotic balance of the fish, while an unideal pH can inhibit physiological processes. Extreme water temperatures can cause stress and death in fish. To ensure that water quality is maintained, cultivators need to refer to the national standards that have been set.[1], [2], [3].

The importance of controlling TDS, pH, and water temperature is not only for fish health, but also for environmental sustainability. National standards such as National Standardization Agency Regulation Number 14 of 2019 provide clear guidelines regarding good water quality for fish farming[2], [4]–[6]. By maintaining water quality, cultivators not only increase business productivity, but also contribute to the preservation of the aquatic environment.

This research focuses on the development of an Internet of Things (IoT)-based water quality monitoring system for tarpaulin fish ponds, using the fuzzy inference method. The system is designed to monitor three important parameters, namely pH, Total Dissolved Solids (TDS), and temperature, which are key factors in maintaining fish health. In this study, the hardware used includes Arduino Nano[7] and ESP8266, as well as IoT platforms Thinger.io [8] for real-time data collection and analysis [4], [6], [9]–[18].

Water quality is a critical factor in fish farming, as these parameters can affect the growth and survival of fish. Previous research has shown that fluctuations in water quality, such as changes in pH and temperature, can cause stress in fish, potentially resulting in death[14], [17]

Therefore, an effective monitoring system is needed to provide early warning to fish farmers about sub-ideal water conditions. By using the fuzzy method [5], [19]–[21], The system can process data from sensors to provide a more accurate assessment of water quality based on expert experience and knowledge.

The system test was carried out by measuring the water quality in tilapia, mujaer, and groundwater ponds in the research area. Prior to testing, the sensor is calibrated using an existing tool on the market to ensure measurement accuracy [10], [12], [13], [17]. Furthermore, fuzzy testing is carried out using Simulink MATLAB to evaluate the error rate and accuracy of the fuzzyification process carried out by IoT tools[22]. The results of this test are expected to provide a solution to minimize fish mortality by providing the right information about the quality of pond water.

In literature reviews, there are similarities in the use of IoT technology and fuzzy methods in water quality monitoring in various studies. Most studies emphasize the importance of water quality parameters such as pH, temperature, and TDS dissolved in water. However, the difference lies in the approach and the device used. For example, some studies use different sensors or varying IoT platforms, as well as analysis methods that do not necessarily involve fuzzy inference.

Thus, this research contributes to the development of a more integrated and efficient system for monitoring water quality in fish ponds, as well as providing new insights in the application of IoT technology in the field of aquaculture.

The research journals that have been conducted show that there is a strong focus on the application of Internet of Things (IoT) technology, fuzzy algorithms, and water quality monitoring, especially in the context of fish farming. Much of this research explores how IoT-based systems can be used to monitor water quality parameters such as pH, temperature, and dissolved oxygen, which are important factors in fish health. Multiple journals.

TABLE 2. Units for Magnetic Properties

Researcher's Name/Year	Research Title	IoT	Algorithm	Research Results	Equation	Difference
Nuradin Mohamed Abdikadir et al., 2024	Smart Aquaculture: IoT-Enabled Monitoring and Management of Water Quality for Mahseer Fish Farming	Yes	IoT-based System (C/C++)	Monitoring water quality parameters such as pH, temperature, and dissolved oxygen using ESP32 and the Blynk 2.0 platform for real-time data visualization.	This research and the research of Nuradin Mohamed Abdikadir et al., (2024), both use IoT with Arduino IDE for sensor management, but the research of Abdikadir et al., (2024), uses ESP32 and the Blynk 2.0 platform.	This study focuses on TDS, temperature, and pH parameters for fish ponds, while the research research of Nuradin Mohamed Abdikadir et al., (2024), is more specific to Mahseer fish cultivation with the Blynk 2.0 platform.
Le Phuong Truong et al., 2021	Cost-effective Evaluation, Monitoring, and Warning System for Water Quality based on Internet of Things	Yes	IoT-based System	Monitoring pH, temperature, and dissolved oxygen (DO) using Arduino Mega2560, ESP8266, and SIM800A with SMS/web-based notification features.	This study uses IoT and Arduino like the research of Le Phuong Truong et al., (2021), but focuses more on SIM800A and ESP8266-based communication.	This study focuses on monitoring water quality to support fish health, while the research of Le Phuong Truong et al., (2021), is simpler with a warning feature.
Lean Karlo S. Tolentino et al., 2021	Development of an IoT-based Intensive Aquaculture Monitoring System with Automatic Water Correction	Yes	IoT and LoRaWAN	Monitoring water parameters (pH, temperature, salinity, dissolved oxygen, turbidity, ORP) with automatic correction features to improve water and fish quality.	This study and the Lean study of Karlo S. Tolentino et al., (2021), both use IoT and Arduino, but this study adds Raspberry Pi and LoRaWAN for long-distance communication.	This study is simpler, focusing on water quality monitoring, while the Lean study of Karlo S. Tolentino et al., (2021), includes automatic correction and more parameters.
Achmad Firman Choiri et al., 2022	Sistem IoT Berbasis Fuzzy Inference Engine untuk Penilaian Kualitas Udara dalam Ruangan	Yes	Fuzzy Inference (Mamdani)	Air quality monitoring uses parameters such as Ozone, PM2.5, CO, CO2, VOC, with an MAE of 0.2667 in the second test.	This research and the research of Achmad Firman Choiri et al., (2022), both use IoT, the Fuzzy Mamdani algorithm, and NodeMCU, but the focus of the parameters is different.	This research focuses on monitoring water quality for fish ponds (TDS, pH, temperature), while the research of Achmad Firman Choiri et al., (2022), focuses on indoor air quality.
Rupali P. Shete et al., 2024	IoT-enabled Effective Real-Time Water Quality Monitoring	Yes	IoT-Based System	Monitoring water parameters such as temperature, pH, and dissolved oxygen using Arduino and a dedicated PCB for	This study and the research of Rupali P. Shete et al., (2024), both use IoT and Arduino for water quality monitoring, but added a	This study focuses on monitoring pond water with TDS, temperature, and pH parameters, while the research of Rupali P. Shete et al., (2024), focuses on

	Method for Aquaculture			high accuracy. The data is manually calibrated and validated.	special PCB to improve sensor accuracy.	temperature, pH, and dissolved oxygen with data-driven integration for fish disease prevention.
Jaime Cesar Prieto-Luna et al., 2023	IoT-Based System for Monitoring Dissolved Oxygen and Temperature in Fish Larviculture	Yes	IoT-Based System	Monitoring dissolved oxygen dan suhu air menggunakan Arduino dalam budidaya larva ikan Piaractus brachypomus, dengan data real-time yang tetap dalam toleransi.	This research and the research of Jaime Cesar Prieto-Luna et al., (2023), both use IoT and Arduino, but focus on two main parameters: dissolved oxygen and temperature.	This study involves more parameters (TDS, pH, temperature) for monitoring fish pond water quality, while the research of Jaime Cesar Prieto-Luna et al., (2023), focuses on the larviculture of Amazon fish.
M. Manoj et al., 2022	State of the Art Techniques for Water Quality Monitoring Systems for Fish Ponds Using IoT and Underwater Sensors: A Review	Yes	IoT and WSN	Review of IoT-based water quality monitoring systems, highlighting advancements in sensors and methodologies from 2011–2020, with emphasis on qualitative and quantitative measures.	The research of M. Manoj et al., (2022), focuses on literature analysis, does not involve direct experiments. Comparisons are more relevant in the framework of IoT and sensor development.	This study is more specific with direct experiments on water parameters (TDS, pH, temperature) for fish ponds, while the research of M. Manoj et al., (2022), is a literature review that provides an overview of technological advances.
Konstantinos Tatas et al., 2022	Reliable IoT-Based Monitoring and Control of Hydroponic Systems	Yes	Fuzzy Inference Engine	Implementation of iPONICS for hydroponic control and monitoring using IoT. The system includes water quality, temperature, humidity, and irrigation control measurements.	The research of Konstantinos Tatas et al., (2022), used a fuzzy algorithm for the duration of plant irrigation, in contrast to this study which used fuzzy for the pond water quality index.	This study focuses on monitoring water quality for fish ponds with parameters such as TDS, temperature, and pH, while the research of Konstantinos Tatas et al., (2022), for hydroponic systems.
Kun-Lin Tsai et al., 2022	IoT-Based Smart Aquaculture System with Automatic Aerating and Water Quality Monitoring	Yes	Fuzzy Inference Rules	Monitoring water parameters (temperature, pH, dissolved oxygen, water hardness) with IoT to increase the survival rate of shrimp up to 33.3% compared to conventional methods.	The research of Kun-Lin Tsai et al., (2022), used fuzzy inference for automatic control of aerators and feeders, in contrast to this research that used fuzzy for pool water quality.	This study focuses on TDS, pH, and temperature for pool water quality monitoring, while the research of Kun-Lin Tsai et al., (2022), includes automatic control of aerators and feeders with additional parameters such as water hardness.
Rizky Maulana et al., 2021	Sistem Monitoring dan Controlling Kualitas Air Serta Pemberian Pakan Pada Budidaya Ikan Lele Menggunakan Metode Fuzzy, NodeMCU dan Telegram	Yes	Fuzzy Inference Method	Monitoring water quality (pH, temperature) with IoT using NodeMCU and Telegram Bot. The system controls the pump to change the pool water automatically.	This study and the research of Rizky Maulana et al., (2021), both use fuzzy inference and NodeMCU for data processing. However, the study uses Telegram Bot for the control interface.	This study involves additional parameters such as TDS for fish pond water quality, while the research of Rizky Maulana et al., (2021), focuses more on pH and temperature for catfish cultivation in tarpaulin ponds.
Fachrul Rozie et al., 2021	Sistem Akuaponik untuk Peternakan Lele dan Tanaman Kangkung Hidroponik Berbasis IoT dan Sistem Inferensi Fuzzy	Yes	Fuzzy Inference System	Monitoring and controlling water quality in aquaponics systems using IoT, resulting in an accuracy of 83.33% for water circulation speed and 90.97% for automatic feeding.	The research of Fachrul Rozie et al., (2021), used the Fuzzy Inference algorithm to regulate water circulation and automatic feeding, in contrast to this study which focused on the water quality index.	This study focuses on monitoring pond water (TDS, pH, temperature) for aquaculture, while the research of Fachrul Rozie et al., (2021), combines aquaculture and hydroponics with additional features such as biofilters.
Herryawan Pujiharsono & Danny Kurnianto, 2020	Sistem Inferensi Fuzzy Mamdani untuk Menentukan Tingkat Kualitas Air pada Kolam	No	Mamdani Fuzzy Inference	Using Mamdani FIS to map the water quality level of biofloc ponds in catfish farming based on pH, temperature, and DO with an accuracy of 89.92%.	This study also discusses FIS Mamdani to determine the level of water quality, but based on pH, temperature, and DO.	This study focuses more on monitoring the water quality of fish ponds with TDS, pH, temperature, and the application of fuzzy parameters for water quality output, while the research of Herryawan Pujiharsono &

	Bioflok dalam Budidaya Ikan Lele					Danny Kurnianto, (2020), specializes in biofloc and only uses pH, temperature, and DO.
Adani Bimasakti Wibisono & Riyanto Jayadi, 2024	Experimental IoT System to Maintain Water Quality in Catfish Pond	Yes	Fuzzy Logic	IoT system with NodeMCU, pH, temperature, and water level sensors for real-time monitoring and automatic control, reduces catfish mortality through water quality stabilization.	The research of Adani Bimasakti Wibisono & Riyanto Jayadi, (2024), uses fuzzy logic for automatic control of water pumps and pH regulators based on water parameters, similar to this research.	This study includes TDS as an additional parameter, while the research of Adani Bimasakti Wibisono & Riyanto Jayadi, (2024), focuses on pH, temperature, and water level to support catfish health.
Azimbek Khudoyberdiev et al., 2022	Enhanced Water Quality Control Based on Predictive Optimization for Smart Fish Farming	Yes	Predictive Optimization & Fuzzy Logic	IoT-based systems use predictive optimization to control water quality (pH, temperature, water level) with energy efficiency of up to 30%. The system uses fuzzy logic to control parameters based on optimal predictions.	The research of Azimbek Khudoyberdiev et al., (2022), added predictive optimization and objective functions to determine the best water quality parameters, while this research only uses fuzzy logic without prediction.	This study focuses on monitoring TDS, pH, and temperature for fish ponds, while the research of Azimbek Khudoyberdiev et al., (2022), adds data-driven predictions for optimal energy efficiency and control.
Nor Salwa Damanhuri et al., 2024	Automated System of Water Quality Monitoring for Prawn Industry via LabVIEW and Internet of Things	Yes	Fuzzy Logic	Monitoring pH and temperature of saltwater for prawn industry using LabVIEW and IoT, with real-time data transfer via ThingSpeak. The system maintains water temperature between 30.6°C and 33.86°C, within the optimal range for prawn farming.	Temperature measurement between 30.6°C and 33.86°C for shrimp farming, using fuzzy control to regulate pH via submersible pump.	This research focuses on monitoring water quality for fish ponds using TDS, pH, and temperature, while Nor Salwa Damanhuri et al., (2024), focus more on the shrimp industry with the use of LabVIEW and IoT-based alarm systems.
Hanif Fakhrurroja et al., 2023	Water Quality Assessment Monitoring System Using Fuzzy Logic and the Internet of Things	Yes	Tsukamoto Fuzzy Logic	The system monitors water quality in real-time using IoT devices, categorizing the quality into good, moderate, and unhealthy levels. It effectively assesses water suitability, providing timely information.	Fuzzy Inference System with Tsukamoto Fuzzy Algorithm for real-time water quality assessment.	The research of Hanif Fakhrurroja et al., (2023), integrates the Tsukamoto fuzzy algorithm to monitor water quality in real-time using IoT, in contrast to the approach of this research which uses fuzzy logic for the control system in fish ponds.

Some studies have similarities in the use of fuzzy algorithms and IoT technologies, but each has a different focus. Although all previous studies used fuzzy and IoT algorithms, these differences in focus point to a wide range of applications and approaches to improving sustainability and efficiency in the fisheries and agriculture sectors.

II.METHOD

This research has several stages in the process carried out, namely:

A. Problems

Analyze the known problems, then look for relevant sources as supporting arguments from various sources that can be used as basic references in determining known problem points and finding the right solution in the research case being carried out. So that an effective solution can be found as the right case study for the research to be taken.

B. Observation Data Collection

Collect datasheets and main components of each topic to support the system work process. This is intended, for example, to find the standard value owned by each variable so that on the basis of this reference it can facilitate further data collection. As well as looking for various research sources and other sources to support research such as literature reviews and theories.

C. Fuzzy and IoT System Analysis

Analyze and simulate the fuzzy system from the research to be carried out and look for several papers or reference sources that will be used as decision support in this research by comparing it with each previous trial. and also observe the IoT concept used whether the system can be applied to the system or not so that the results can be applied as expected.

D. Fuzzy System Design

Designing fuzzification components in the formation of variables and fuzzy sets for each variabe as shown in table 2.

TABLE 2. FUZZY VARIABLES AND SETS

Variables	Set Label	Domain
Sensor TDS	Baik	[0, 1200]
	Buruk	[800, 2000, 3000]
Sensor Temp	Dingin	[0, 18, 24]
	SSSedang	[20, 26, 32]
	Panas	[29, 35, 100]
Sensor PH	Acid	[0, 4.5, 6.5]
	Netral	[5.5, 7.5, 9.5]
	Alkaline	[8.5, 10.5, 14]
Water Quality	Sangat Baik	[0, 4]
	Kurang Baik	[2, 5, 8]
	Buruk	[6, 10, 14]

From table 2, It is known that the input membership function has 3 input variables in the form of sensors, namely TDS, Temp and PH, while for the output fuzzy membership variable, namely Water Quality. The TDS Sensor input variable has a fuzzy set "Baik" which can be interpreted as Good and "Buruk" which means bad, the Temp Sensor input has a variable "Dingin" which means Cold, "Sedang" is interpreted as medium and "Panas" is interpreted as Hot while the PH Sensor input has a set "Acid" which means Acid, "Neutral" is interpreted as Neutral and "Alkaline" is interpreted as Alkaline. The Water Quality output variable has a set of "Sangat Baik" which means very good, "Kurang Baik" is interpreted as Less Good and "Buruk" which means bad. The following is the form of the fuzzy input and output variables:

- TDS Sensor

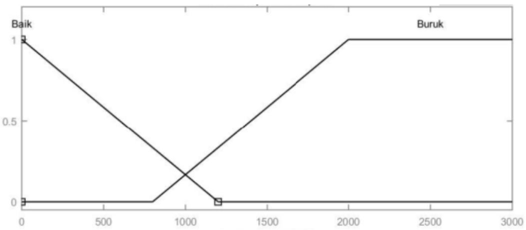

FIGURE 1. TDS SENSOR MEMBERSHIP FUNCTION

So the formation of the TDS sensor membership function as shown in table 3 is t:

TABLE 3. TDS SENSOR MEMBERSHIP FUNCTION

Himpunan	Fungsi Keanggotaan	
µBaik(x)	**{(1;(1200 - x)/(1200 - 0);0;)}** $x \le 0,\ 0 \le x \le 1200,\ x \ge 1200$	**(1)**
µBuruk(x)	**{(0; (x-800)/(2000 - 800); 1;)}** $x \le 800,\ 800 \le x \le 2000,\ x \ge 2000$	**(2)**

- Temperature Sensor

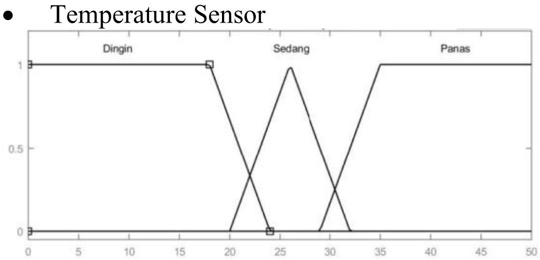

FIGURE 2. TEMPERATURE SENSOR MEMBERSHIP FUNCTION

So the formation of the Temperature sensor membership function as shown in the following table 4:

TABLE 4. TEMPERATURE SENSOR MEMBERSHIP FUNCTION

Himpunan	Fungsi Keanggotaan	
µDingin(x)	**{(1;(24 - x)/(24 - 18);0;)}** $x \le 18,\ 18 \le x \le 24,\ x \ge 24$	**(3)**
µSedang(x)	**{(0; (x-20)/(26- 20); (32-x)/(32 - 26);)}** $x \le 20$ atau $x \ge 32,\ 20 \le x \le 26,\ 26 \le x \le 32$	**(4)**
µPanas(x)	**{(0; (x-29)/(35 - 29); 1;)}** $x \le 29,\ 29 \le x \le 35,\ x \ge 35$	**(5)**

- PH Sensor

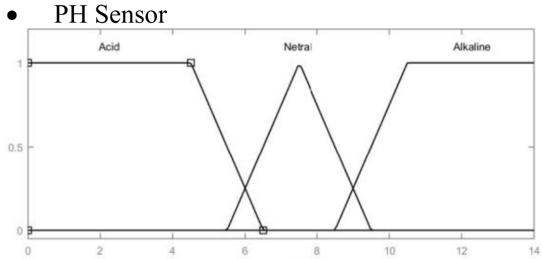

FIGURE 3. PH SENSOR MEMBERSHIP FUNCTION

So the formation of the PH sensor membership function as shown in the following table 5:

TABLE 5. PH SENSOR MEMBERSHIP FUNCTION

Himpunan	Fungsi Keanggotaan	
µAcid(x)	**{(1;(4.5 - x)/(6.5 – 4.5);0;)}** $x \le 4.5,\ 4.5 \le x \le 6.5,\ x \ge 6.5$	**(6)**
µNetral(x)	**{(0; (x-5.5)/(7.5- 5.5); (9.5-x)/(9.5 – 5.5);)}** $x \le 5.5$ atau $x \ge 9.5,\ 5.5 \le x \le 7.5,\ 7.5 \le x \le 9.5$	**(7)**
µAlkaline(x)	**{(0; (x-8.5)/(10.5 – 8.5); 1;)}** $x \le 8.5,\ 8.5 \le x \le 14,\ x \ge 14$	**(8)**

- Output Water Quality

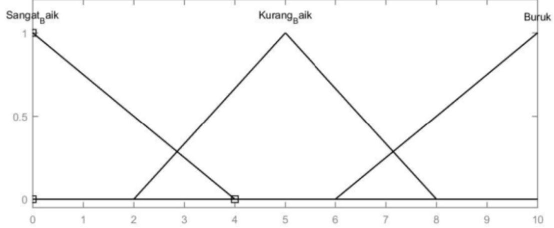

FIGURE 4. OUTPUT WATER QUALITY MEMBERSHIP FUNCTION

So the establishment of the Output Water Quality membership function as shown in the following table 6:

TABLE 6. WATER QUALITY MEMBERSHIP FUNCTION

Himpunan	Fungsi Keanggotaan	
µSangatBaik(x)	**{(1;(0 - x)/(4 – 0);0;)** x ≤ 0, 0 ≤ 𝑥 ≤ 4, 𝑥 ≥ 4	**(9)**
µKurangBaik(x)	**{(0; (x-2)/(5- 2); (8-x)/(8 - 5);)}** x ≤ 2 atau x ≥ 8, 2 ≤ x ≤ 5, 5 ≤ x ≤ 8	**(10)**
µBuruk(x)	**{(0; (x-6)/(10 - 6); 1;)}** x ≤ 6, 6 ≤ x ≤ 14, x ≥ 14	**(11)**

The next process is the formation of a fuzzy design as in "Fig. 5" according to the specifications described in Table 2. The fuzzy design consists of 3 inputs and 1 output. Then the fuzzy output results are forwarded to the NodeMcu 8266 as an IoT module which will later send fuzzyfication data to the IoT thingger.io website to display sensor reading data and results.

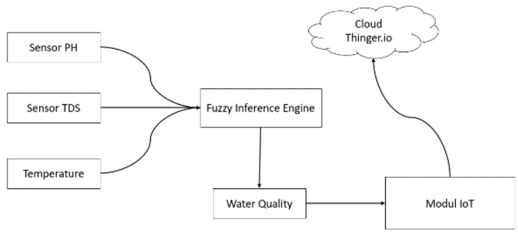

FIGURE 5. FUZZY DESIGN

So based on the design of the system that is made, it can produce an assessment model to determine Water Quality for fish pond water, then rules can be formed in the form of rules that will be applied to the following system:

R[1]	*IF (TDS is Baik) AND (Temp is Dingin) AND (PH is Acid) THEN (WaterQuality is Buruk)*
R[2]	*IF (TDS is Baik) AND (Temp is Sedang) AND (PH is Acid) THEN (WaterQuality is Buruk)*
R[3]	*IF (TDS is Baik) AND (Temp is Panas) AND (PH is Acid) THEN (WaterQuality is Buruk)*
R[4]	*IF (TDS is Baik) AND (Temp is Dingin) AND (PH is Netral) THEN (WaterQuality is Kurang Baik)*
R[5]	*IF (TDS is Baik) AND (Temp is Sedang) AND (PH is Netral) THEN (WaterQuality is Sangat Baik)*
R[6]	*IF (TDS is Baik) AND (Temp is Panas) AND (PH is Netral) THEN (WaterQuality is Kurang Baik)*
R[7]	*IF (TDS is Baik) AND (Temp is Dingin) AND (PH is Alkaline) THEN (WaterQuality is Buruk)*
R[8]	*IF (TDS is Baik) AND (Temp is Sedang) AND (PH is Alkaline) THEN (WaterQuality is Buruk)*
R[9]	*IF (TDS is Baik) AND (Temp is Panas) AND (PH is Alkaline) THEN (WaterQuality is Buruk)*
R[10]	*IF (TDS is Buruk) AND (Temp is Sedang) AND (PH is Netral) THEN (WaterQuality is Kurang Baik)*
R[11]	*IF (TDS is Buruk) AND (Temp is Sedang) AND (PH is **not** Netral) THEN (WaterQuality is Buruk)*

E. Fuzzy and IoT System Design

Designing IoT modules starting from hardware and software design, in "Fig. 6" the following is a general overview that can be applied with the Fuzzy Inference Engine method to IoT systems that have been built.

Overview of the IoT system there are 3 input sensors and 1 fuzzy output and uses Arduino nano as the Master IoT module that handles input sensors and fuzzyification data processing and for the Slave module in the form of NodeMCU 8266 as an IoT system control to be able to connect to the internet network and is in charge of sending data to the IoT cloud website thinger.io can be connected to the internet via wifi network [4], [10], [11], [13].

This IoT system can be accessed through other devices by monitoring the real-time dashboard of sensor values that can be monitored as long as the device can be connected to the internet.

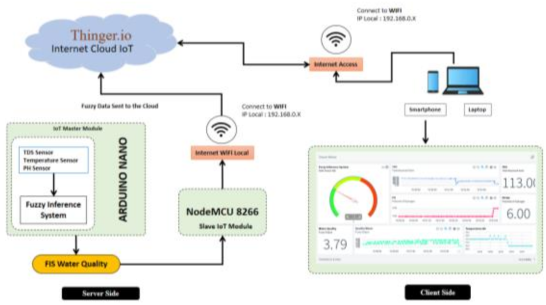

FIGURE 6. FUZZY AND IOT SYSTEM DESIGN

And with this simple system, it is hoped that it will make it easier for pond fish farmers to monitor water quality regularly.

F. Testing

Before testing, each sensor to be used will be calibrated with PH, TDS, and temperature test tools that are widely available on the market. And then after the sensor output value is the same or close to the tool value indicated by the same water measurement, the next thing to do is to test the fuzzy system by taking the sensor data value and fuzzification of 3 water samples, namely Tap Water, Tilapia pond water and Mujaer fish pond water. And there are other treatments for the water. So to test the fuzzy system by comparing the results of the tool fuzzification with the results of the fuzzy simulink fuzzification as a fuzzy calculation with the same input value. Then from these results can be observed and calculated to determine the level of accuracy of the IoT device that has been made.

FIGURE 7. COMPARISON OF WATER COLORS FOR TESTING

In "Fig 7" is a sample of the water that was tested, it can be seen that the tap water is very clear (left), the water of the Mujaer fish pond is not too cloudy (middle) and the water of the tilapia pond looks brown and more turbid (right).

There are 3 tests carried out, namely:

1. Water Faucet

The water data tester is taken directly from the tap water. And the data was taken with an IoT tool that was placed for 1-3 minutes to see if there were still changes in the sensor parameters with the following test results:

TABLE 7. FAUCET WATER TESTING

TDS	PH	°C	WaterQuality		Simulink	
			value	desc	value	desc
279	5.3	30	8.34	Buruk	8.34	Buruk

2. Tilapia Pond Water

FIGURE 8. TILAPIA POND WATER

Water test data is taken directly from the fish pond. The water condition in tilapia cultivation is in terms of maintenance using the Aerator system, but there are still tilapia that die even though there are fewer than before the use of the aerator. And the data was taken with an IoT tool that was placed for 1-3 minutes to see if there were still changes in the sensor parameters with the following test results:

TABLE 8. TILAPIA POND WATER TESTING

TDS	PH	°C	WaterQuality		Simulink	
			value	desc	value	desc
445	6.2	30	4.56	Baik	4.09	Baik

3. Mujaer Fish Pond Water

FIGURE 9. MUJAER FISH POND WATER

Water test data is taken directly from the fish pond. The water condition in Mujaer fish cultivation in terms of treatment only uses water hyacinth plants, one of which can filter harmful substances in the water and can also purify the water. And the data was taken with an IoT tool that was placed for 1-3 minutes to see if there were still changes in the sensor parameters with the following test results:

TABLE 9. MUJAER POND WATER TESTING

TDS	PH	°C	WaterQuality		Simulink	
			value	desc	value	desc
111	6.5	30	3.19	Sangat Baik	3.19	Sangat Baik

III.RESULT AND DISCUSSION

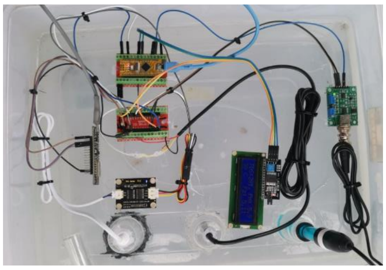

FIGURE 10. FUZZY WATERQUALITY IOT DEVICE

From the results of the IoT system test conducted on three water samples, namely tap water, tilapia pond water, and mujaer pond water, the WaterQuality IoT device shows high accuracy with consistent results. The fuzzification results from IoT devices can be close to or equal to the simulation results for each pond water sample tested, with small differences found only in tilapia pond water, which are likely due to environmental factors such as aeration or sensor precision.

IoT devices are able to measure water quality well in various conditions, from clear water to cloudy water. In the tap water test, the device gives a poor quality value indicated by the "Buruk" set label, according to the low pH level indicating the "Acid" set label. For tilapia pond water, the results show good water quality indicating the "Baik" set label, from the test results there is a slight difference in fuzzy output with fuzzy Simulink. Meanwhile, in tilapia pond water, the results show very good quality with identical values between the device and fuzzy simulink.

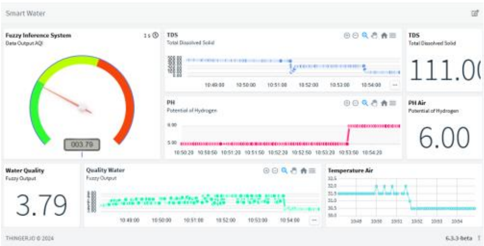

FIGURE 11. DASHBOARD IOT FUZZY WATERQUALITY

Overall, the WaterQuality device has proven to be effective for monitoring water quality in real-time with a high level of accuracy. This makes it a potential solution for use in water quality management in various environments, such as fish farming and environmental monitoring.

The results of the study show that this fuzzy-based IoT system is able to monitor water quality in real-time with a high level of accuracy and information that is easy for users to understand. Compared to previous research, such as Le Phuong Truong et al. [10] and Rupali P. Shete et al. [12], The system not only integrates IoT for monitoring, but also uses fuzzy inference methods to provide more accurate data analysis in real-time. Testing shows that the fuzzification results of IoT devices are close to those of MATLAB Simulink simulations, with small differences in inland pool water likely to be affected by environmental factors such as aeration or sensor precision. In addition, the study covers a wider range of parameters, namely pH, TDS, and temperature, which provides a more comprehensive assessment of water quality than studies such as Jaime Cesar Prieto-Luna et al. [13] and Kun-Lin Tsai et al. [17], which only focuses on two parameters. Another advantage is the presentation of data in a simple format, in contrast to the study of Nor Salwa Damanhuri et al. [20], which makes it difficult for users with more complex data formats. Overall, the system not only provides a more comprehensive technology-based solution, but also ensures a high level of accuracy, making it a potential tool for improving fish pond management efficiently and productively.

The discussion of the fuzzification process from the test results can be done using tilapia pond water testing data as an example.

A. Calculating Sets on Input Variables

The calculation process is mathematically carried out using a formula in accordance with the membership function on each input variable that has been determined. Then the result is as shown in the following table.

TABLE 10. VALUE OF FUZZY INPUT MEMBERSHIP DEGREE

Variables	Fuzzy Set	$\mu(x)$
TDS Sensor	µBaik(111)	**0.9075**
Temp Sensor	µSedang(30)	**0.33**
PH Sensor	µNetral(6,5)	**0.5**

B. Fuzzy Operator Implementation

Next, perform the calculation of the MAX method of the function with implications on the rule using the MIN function.

α_5 = min(µBaik(111),µSedang(30),µNetral(6.5))
= min(0.9075,0.3333,0.5)
= 0.333

C. Function Implications

In the linear representation of the up and down should be calculated to find the value x of the Good value of the Water Quality output membership from the formula in table 6 of the medium category.

$$\mu(x) = \frac{4-x}{4} \quad \Rightarrow \quad 0.33 = \frac{4-x}{4} \quad \Rightarrow \quad x = 4 - 1.32 = 2.68$$

D. Deffuzification

The next step is to calculate the moment and area as follows;

$$\mu_{\text{Sangat Baik}}(x) = \begin{cases} 0.33, & 0 \le x \le 2.68 \\ \frac{4-x}{4}, & 2.68 < x \le 4 \\ 0, & \text{lainnya} \end{cases}$$

1. Calculating Area

$$A_1 = \int_0^{2.68} 0.33\,dx = 0.33 \cdot x \Big|_0^{2.68} = 0.33 \cdot 2.68 = 0.8844$$

$$A_2 = \int_{2.68}^{4} \frac{4-x}{4}\,dx \quad = 1089/5000 = 0.2178$$

2. Counting Moments

Perform integral calculations to find the following moments:

$$M_1 = \int_0^{2.68} x \cdot 0.33\,dx = 148137/125000 = 1.185096$$

$$M_2 = \int_{2.68}^{4} x \cdot \frac{4-x}{4}\,dx \quad = 1089/5000 = 0.2178$$

3. Centroid Functions

Then after the area and moment have been calculated, then we can calculate the centroid point can be obtained from the following formula:

Z* = (M1+M2)/(A1+A2)

IV. CONCLUSION

The results of this study provide insight into the application of water quality monitoring which has the potential to be a tool that can be used by fish farmers because in the results of the system test, the fuzzy algorithm was successfully applied and the Testing of the WaterQuality IoT system was carried out on three types of water, namely tap water, tilapia pond water, and mujaer pond water, with results showing a high level of accuracy. From the fuzzification data of IoT devices compared with Simulink fuzzy simulation to measure the consistency and accuracy of the fuzzy system. However, in this study, there are still obstacles in the rules that are not precise because the source of reference data for the water quality index is varied and less specific for freshwater fish. This can affect the rules so that the action after being known from the measurement results can be the optimal solution. This study aims to provide a system that is not only accurate but also presents data in a more understandable format so that it can help fish farmers make better pond management decisions. Thus, this study is expected to increase fish farming productivity through better and technology-based water quality management.

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