DEVELOPMENT OF FUZZY LOGIC AUTOMATIC FISH FEEDING SYSTEM AND IOT-BASED WATER QUALITY CONTROL

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ABSTRACT

Rapidly developing technological advances make it easier for fish farmers to manage fish farming systems in an intelligent, structured, and modern way. This study discusses how IoT and fuzzy logic can be used to improve fish farming in an intelligent and modern way, which includes discussing important issues in managing water quality and optimizing fish feeding. The purpose of this study is to develop an IoT-based water quality control system and an automatic fish feeder based on a fuzzy logic controller. The method used in this study is the research and development (R n D) method. The input parameters in this study are temperature, pH, and water clarity, while the outputs in this study are: aerator working duration, heater working duration, cooler working duration, motor working duration, and the amount of fish feed. The results of the study showed an average error percentage of <5% so that the sensor can work accurately in determining water quality and determining the amount of feed; 2) the water quality control system can work well, where the heater, cooler, and aerator can work according to the quality of the pond; 3) the automatic fish feeding system has an average percentage of <5% so that it can work well and precisely in determining the duration of the motor and the amount of fish feed.

Keywords: Aerator; cooler; fish feed; fuzzy, heater, IoT

1. INTRODUCTION

The quality of pond water greatly affects the success of fish farming. The use of aerators, heaters, and coolers is one of the efforts of fish farmers to maintain the quality of pond water so that environmental parameters in the form of temperature, oxygen, clarity level, and ph of pond water are in accordance with the needs of fish (Arini et al., 2023; Reza Habib et al., 2021). One of the things that determines the level of dissolved oxygen content in the water is temperature, this is because the temperature of the pond water that is too high will cause the oxygen content in the water to decrease and the pond water temperature that is too low will cause the metabolism of the fish to decrease and the need for oxygen is reduced, the optimal temperature of gourami fish is around 25^0C-30^0C. The ideal dissolved oxygen level in water for the environmental needs of gourami fish is 3-6 mg/L while the ideal ph scale of pond water in fish farming is 5-8 (Patmawati et al., 2022; Pitowarno et al., 2023). Good fish farming is by implementing a system that can control water quality and fish feed needs in accordance with fish needs and environmental conditions. This is because pond water quality parameters that are not in accordance with the needs of fish will cause fish stress, susceptibility to disease, decreased fish appetite, and feed poisoning due to the amount of feed that settles at the bottom of the pond water as a result of decreasing fish feed capacity due to non-ideal pond conditions (Khaerudin & Kurniawan, 2021; Luthfan Ihtisyamuddin & Zakaria, 2023).

Technological advances have a major impact on the fisheries cultivation system where currently technology has developed a lot of fisheries cultivation equipment that can work intelligently, precisely, and efficiently so as to improve the quality of fisheries cultivation in Indonesia. One of the technological developments in the fisheries sector is aeration, the importance of aeration in fisheries cultivation is to maintain stable and dynamic pond conditions with temperature levels, water clarity and water pH according to fish needs (Abhijith et al., 2024; Bachri, 2023; Leal Junior et al., 2019). Based on observations of 10 gourami fish ponds in Gurami Village, Singkalanyar Village, Nganjuk Regency, it was found that the aeration system in gourami fish ponds uses a water pump, where the water pump will flow air through a pipe that will produce small air bubbles along the flow of the pond. The disadvantages of using an aeration system in gourami fish farming are that the aeration system currently used requires high electrical power and the aeration system does not work based on the actual needs of gourami fish. Currently, aeration equipment sold on the market is not equipped with a remote monitoring system and the intelligent aeration system works according to the actual needs of the fish. Another problem is related to fish poisoning due to feed that settles at the bottom of the pond, based on the results of observations, the automatic fish feeding system sold on the market only schedules feed by providing 100% feed on each schedule without considering environmental conditions such as temperature, oxygen, turbidity and pH of the water which can affect the appetite of fish in consuming food.

The development of smart fisheries cultivation systems related to improving water quality and automatic feeding continues to be developed, several previous studies have discussed the design and development of monitoring and aeration systems used to stabilize and maintain pond conditions so that they can be used to control pond conditions including pond temperature and water level parameters (Pitowarno et al., 2023). In other studies to stabilize pond water conditions according to fish needs, namely by adjusting the duration of water pump operation, cooling, and water heating based on the results of temperature, pH, and turbidity sensor input values (Alfanz et al., 2023). The level of oxygen dissolved in water can be used to determine the quality of pond water and the results of fish farming, the aeration system is designed to control the rise and fall of dissolved oxygen content in water and the incoming load on different time scales (Lv, 2023; T. et al., 2020; Zeng et al., 2021). The weakness of using the aeration system is the high electricity consumption, so to minimize the consumption of electricity in the aeration system, namely with a pressure-based control strategy using several control loops using fuzzy by operating the aeration system at minimum pressure (Ribes et al., 2023). The use of ESP32 in the aeration system is to enable a remote control system where the aeration system is controlled by the ESP 32 micro controller and the reading values will be stored in the cloud using the Internet of Things (IoT) and the blink application (Rao et al., 2021). In fish farming, IoT plays a role in monitoring and controlling fish farming effectively, an IoT-based automatic fish feeder can regulate the amount of feed and feeding time automatically according to the time and input that has been determined on the idea arduino (Hambali Hambali et al., 2023; Wigati et al., 2023).

In previous studies related to IoT-based automatic fish feeders. In the study of automatic feeders equipped with NodeMCU8266, RTC, Arduino Uno, and drive motors, this fish feeder has been scheduled for fish feeding and can be monitored using telegrams or can be displayed using the blynk application, so that users can easily monitor the feeding time so that users can find out the water temperature, the fish feeding time has been set (Jadhav et al., 2020; Nurhadi et al., 2023; Somantri et al., 2023). In other studies, automatic fish feeder technology can also be applied using solar panels that can generate electricity for the drive motor, automatic fish feeders are also equipped with a solar energy tracking system that will rotate according to light intensity and can work all the time (Deepthi et al., 2023; Yuniarti et al., 2022).

Based on the problems and research that have been done previously, so in this study the researcher developed an IoT-based water quality control system tool and an automatic fish feeding system based on a fuzzy logic controller. The use of fuzzy can improve the accuracy, precision of the tool, and efficiency (Barzegar et al., 2023; Junaedi & Usino, 2021; Ma, 2022). The purpose of this study is to develop a water quality control system by regulating the performance of the heater, cooler, and aeration based on IoT as well as an automatic fish feeding tool based on a fuzzy logic controller that can work according to pond conditions.

2. METHODOLOGY

This study uses the Research and Development (R n D) method with a development model using 4 main stages, namely: analysis and identification, design planning, assembly and development, testing and evaluation. The Research and Development (R n D) model is used to produce new products by developing and revitalizing previous research. This study focuses on continuous improvement that is important in developing an IoT-based water quality control system and an automatic fish feeding system based on a fuzzy logic controller

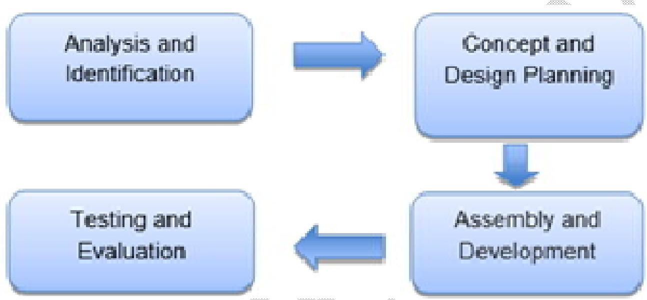

Figure 1. Research Method

The first stage is analysis and identification by conducting a literature study of previous studies, this analysis and identification focuses on innovative methods and solutions to overcome problems in gourami fish cultivation which include a water quality control system and automatic fish feeder (Kustija et al., 2024). The data requirements needed based on the analysis results to cover the water quality control system and automatic fish feeder, namely: 1) the tool has the ability to monitor temperature, pH, water clarity, motor working duration, and the amount of fish feed accurately; 2) the tool is equipped with an aerator, cooler, heater and automatic fish feeder that can work according to pond conditions; 3) the results of input and execution will be read using the user's telegram application. The main components of the system include an IoT-based water quality control system and an automatic fish feeder based on a Fuzzy Logic Controller, namely an oxygen sensor, DHT 11 sensor, PH 45O2C sensor, servo motor, Node MCU ESP 32, heater, and cooler. The software design uses an Arduino application with C language and then the program is uploaded to the ESP32 microcontroller.

The second stage is the concept and design planning stage by creating a hardware software design used to build a physical and logical system so that the system can work according to the desired goals, to create a measurable and innovative intelligent system, the design includes the design of block diagrams, flowchart, and wearing diagrams on the water quality control system and automatic fish feeding system. The block diagram of the IoT-based water quality control system and the IoT and Fuzzy-based fish feeding system are shown in Figure 2 and Figure 3 below.

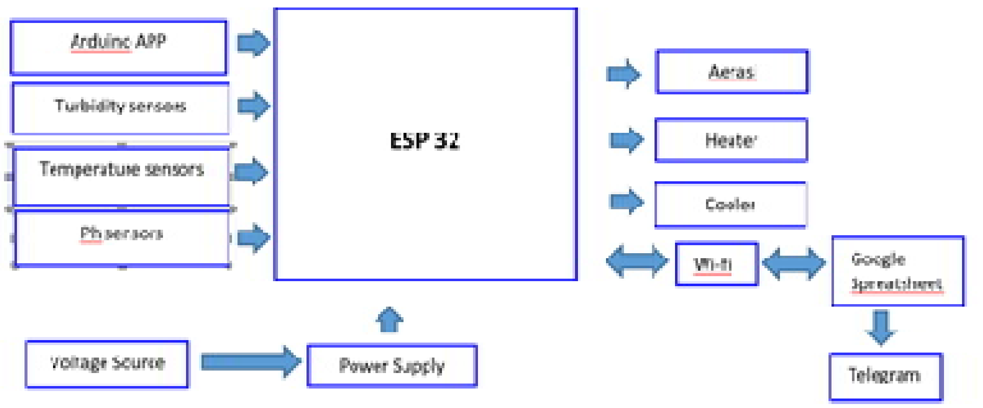

Figure 2. Block Diagram of IoT-Based Water Quality Control System

Figure 2. shows the hardware block diagram of the IoT-based water quality control system. ESP32 is the main component of the IoT-based water quality control system. This water quality control tool can determine the decision-making of the aerator, heater and cooler working time according to needs, so that it is more energy efficient and effective in use. IoT communication is by using a google spreadsheet which functions to monitor the historical reading of sensors and telegrams which function to provide notifications to users or gourami fish farmers containing sensor readings, aerator, heater and cooler working time.

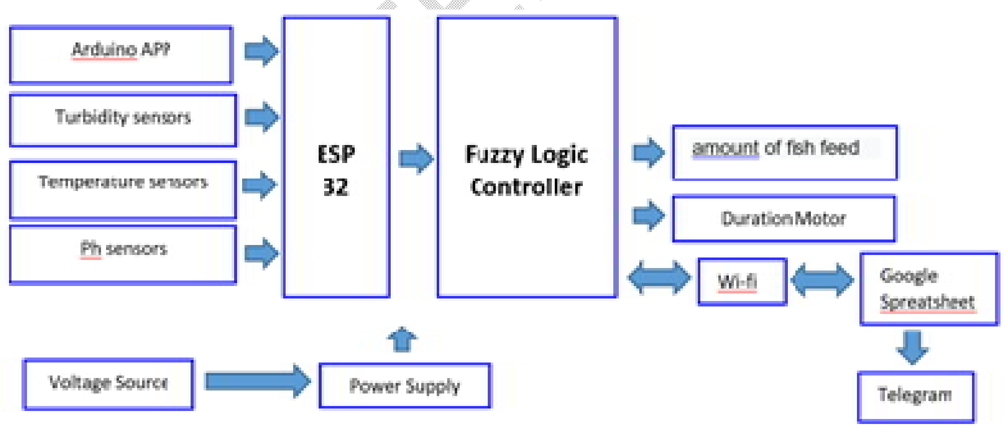

Figure 3. Diagram of IoT and Fuzzy Based Fish Feeding System

Figure 3 shows the hardware block diagram where ESP32 is used as the main controller that will process input from 3 connected sensors, the temperature sensor is used to measure the temperature in the gourami pond, the ph sensor is used to measure the ph content in the pond water, the turbidity sensor is used to measure the turbidity level in the gourami pond, and the servo motor is used as an actuator that will drive the fish feeding mechanism. ESP32 is the main component of the fish feeding system that combines the ability of a fuzzy logic controller-based decision-making to be able to determine decision-making in the form of the amount of feed and the duration of the motor rotation. The flowchart image of the IoT-based water quality control system and the IoT and Fuzzy-based fish feeding system is shown in Figure 4 and Figure 5 below.

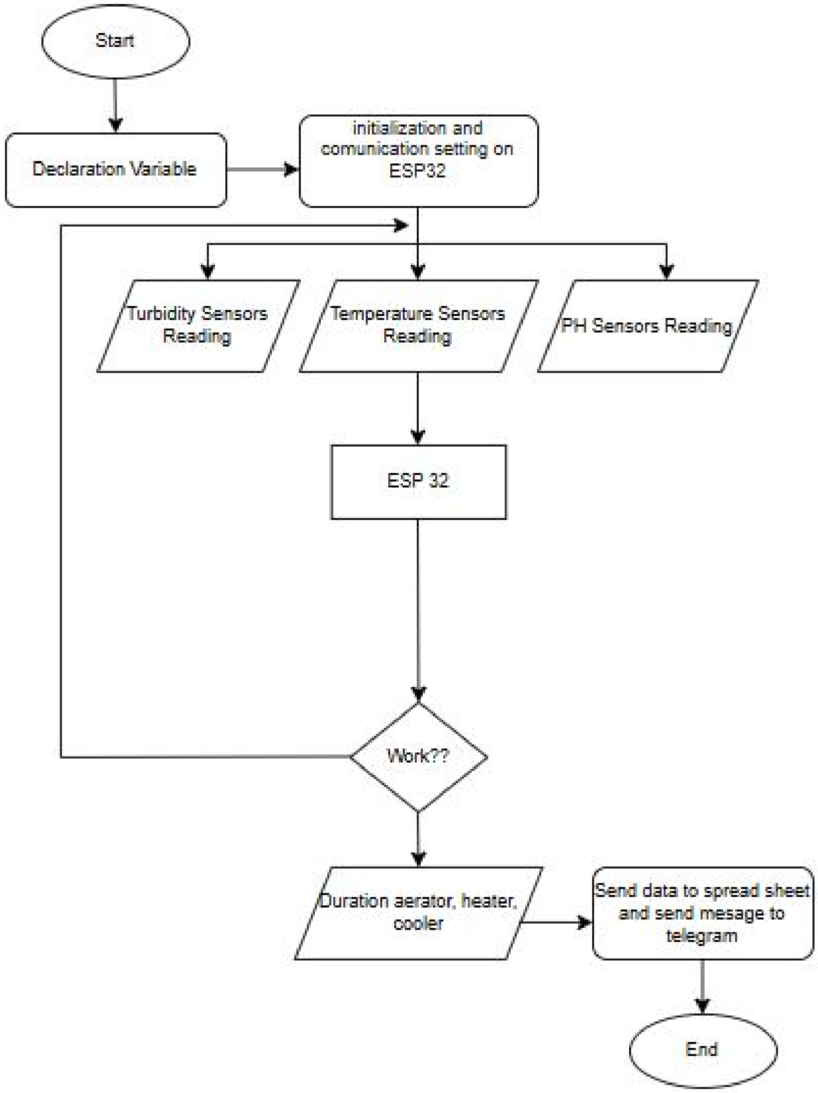

Figure 4. Flowchart of IoT-Based Water Quality Control System

Figure 4 shows that the process of the IoT-based water quality control system begins with the system declaring the required variables. ESP32 is used to read data from three main sensors, namely turbidity sensor, temperature sensor, and PH sensor. Data from these three sensors are collected by ESP32 via Analog/Digital Input communication, then the sensor data obtained will be by ESP32 using serial communication to send the reading results of the turbidity sensor, temperature sensor, and PH sensor and the data is stored in Google Spreadsheet, then the ESP sends an email to the address configured by the user which will automatically be forwarded to the telegram. The results of the sensor readings will determine the duration of the aerator, heater, and cooler to control the water quality in the fish pond.

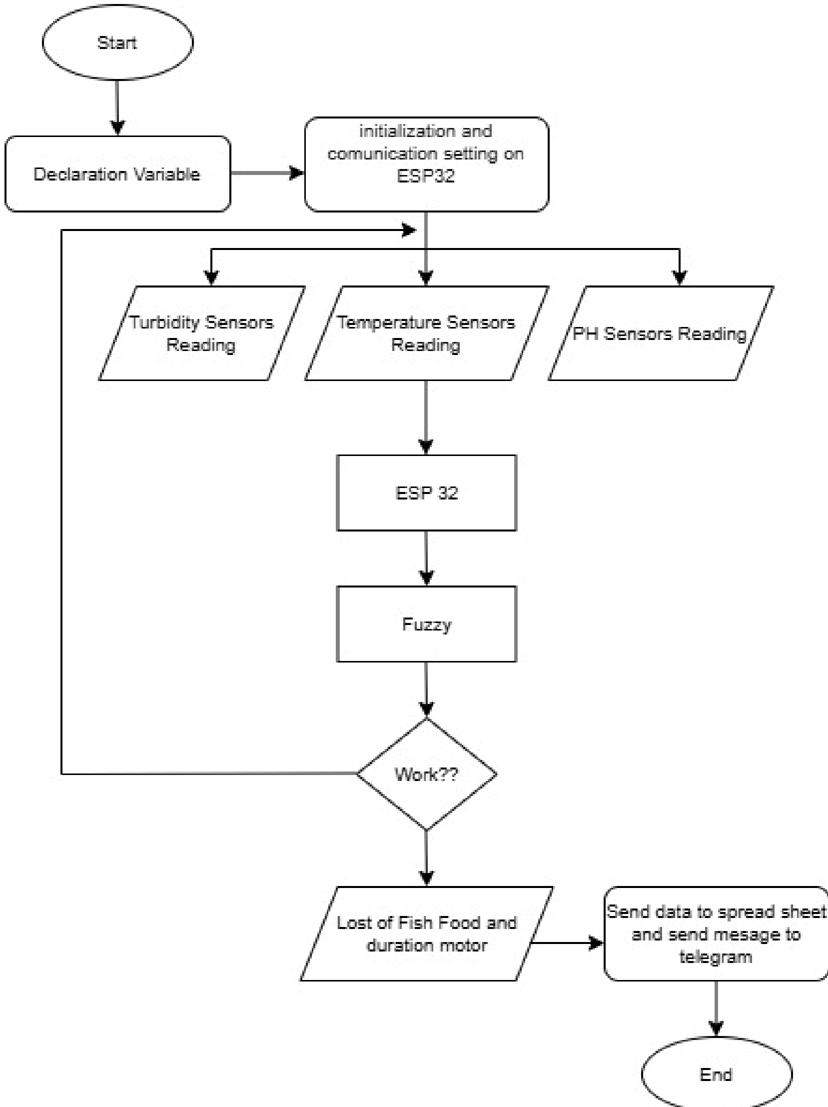

Figure 5. Flowchart of IoT and Fuzzy Based Fish Feeding System

Figure 5 shows that the IoT and Fuzzy Fish Feeding System declares the required variables. ESP32 is used to read data from three main sensors, namely turbidity sensor, temperature sensor, and PH sensor. Data from these three sensors are collected by ESP32 via Analog/Digital Input communication, then the sensor data obtained will be processed using the Fuzzy Logic Controller (FLC) method after that ESP32 uses serial communication to send the reading results of the turbidity sensor, temperature sensor, and PH sensor. Fuzzy decisions to the Arduino IDE serial monitor To save data to Google Spreadsheet, then the ESP sends an email to the address configured by the user which will automatically be forwarded to the telegram. The results of the sensor readings will determine the duration of the motor and the amount of fish feed.

The third stage is the assembly and development of an IoT-based water quality control system and a Fuzzy-based fish feeding system, which includes electronic circuit assembly, mechanical integration, and installation of electronic components. Software assembly includes the creation of programming designs using Arduino IDE, Fuzzy Logic Controller design using Matlab, database compilation on Google Spreadsheet, IoT integration with fuzzy logic controller, and time control programming. The assembly stage of the IoT-based water quality control system is used to control the performance of the aerator, heater, and cooler according to the conditions of the fish pond, while the assembly stage of the IoT-based fish feeding system and fuzzy logic controller used to control the amount of fish feed according to environmental conditions is made using the Sugeno type Fuzzy Logic Controller (FLC) method where with this method at the input stage it will map the temperature sensor, pH sensor, and turbidity sensor and will change the input from all sensors into a fuzzy set which ultimately becomes the basis for the decision of the output. The Fuzzy Set Table for input variables is shown in Table 1 below.

Table 1. Fuzzy Sets on Input Variables (Temperature, pH, and turbidity sensors)

No	Input Variable	Fuzzy	Domain
1.	Turbidity	Too Clear	0 NTU-30 NTU
		Ideal	29 NTU-60 NTU
		Turbid	59 NTU-100 NTU
2.	Temperature	Low	15^0C -25^0C
		Ideal	24^0C -30^0C
		Hot	29^0C -35^0C
3.	pH	Low (Acidic)	3-6
		Ideal (Neutral)	5-8
		High (Alkali)	7-9

Determination of input variable values in the form of temperature sensor values, pH sensors, and turbidity sensors is based on the linguistic variable function. Based on the fuzzy set formed, the membership function used in presenting the data is the triangle membership function.

In fish ponds, the level of water clarity is an important factor in supporting fish health, pond water that is too clear is not good for fish because the nutritional content contained in the pond water and the amount of plankton which is a natural food source for fish is small, besides that it also reduces fish appetite due to high environmental visibility. The level of water turbidity that is too high will also result in a lack of oxygen in the water, fish are susceptible to disease, high levels of stress in fish due to contamination of the pond water, thus reducing the fish's immune system and appetite. In gourami fish, the level of clarity in pond water is around 30 NTU-60 NTU. In this study, the sensor used to measure the level of pond clarity is the Turbidity Sensor SEN0189 which works by detecting the amount of light reflected by particles in the water, namely the more particles in the water, the more light will be reflected. The SEN0189 Turbidity Sensor has a measurement range of 0 to 1000 NTU (Nephelometric Turbidity Units) with an accuracy of ± 5% of the full measurement range.

The temperature level in the pond water affects the behavior and appetite of the fish. The optimal temperature requirement in a gourami pond is 25^0C -30^0C where at this temperature the fish's metabolic process increases, the fish will be more active so that the fish's appetite increases, at the optimal temperature the daily feed requirement for gourami fish is 3% of its body weight. Temperatures below standard or temperatures that are too low the daily feed requirement for gourami fish is 2% of its body weight, which will cause the fish's appetite to decrease because the metabolic process slows down, this is in line with if the temperature is too high, it will cause a decrease in the oxygen content in the water, causing death before harvest time. At high temperatures the feed requirement for gourami fish decreases drastically, namely 1.5% of the fish's body weight.

The ideal range of PH content requirements in water in gourami fish farming ponds is 5-8 if the pH is too low or too acidic it will cause irritation to the fish, reduce the amount of oxygen in the water, fish metabolism becomes unbalanced, fish are stressed, and susceptible to disease, but if the pH content is too high or alkaline it will cause an increase in ionized ammonia levels into free ammonia (NH_3) which is very toxic to fish so that fish are more susceptible to bacterial infections or diseases which ultimately increase fish deaths before harvest time, so based on these conditions this tool works by controlling the quality of fish by maintaining the temperature, pH, and clarity of the pond water and automatically feeding fish according to the needs of the fish and pond conditions.

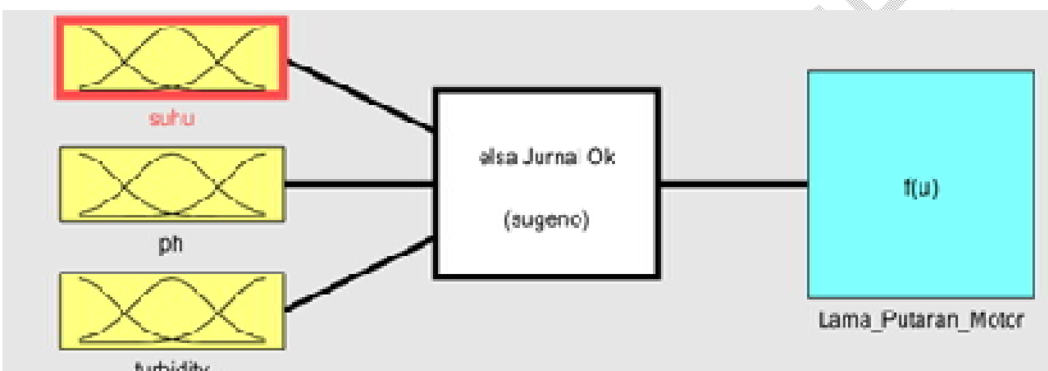

Figure 6. Fuzzy Logic Toolbox

Figure 6 shows the Fuzzy Logic Toolbox of an automatic fish feeding system with 3 inputs consisting of temperature, pH, and turbidity and 1 output, which is the duration of the motor rotation which will determine the amount of feed. The rule base consists of 27 rules consisting of 3 inputs and 1 output, namely the rule base produces a fast motor rotation output of 7, medium of 13, and long of 7.

The fourth stage includes testing the sensor work system, testing the IoT-based water quality control system, and the automatic fish feeding system based on the fuzzy logic controller. The testing stages were carried out five times with different testing times with the aim of making the test results precise and accurate.

3. RESULTS AND DISCUSSION

This research was conducted on a gourami fish pond, the input is in the form of temperature value, turbidity value, while the output is in the form of motor duration, aeration duration, heater duration, cooler duration, and amount of feed. The research includes solving fish farming problems which include controlling the quality of fish pond water and providing fish feed precisely according to fish needs, these two systems complement each other in the process of smart and modern fish farming because all systems are running automatically according to the program that has been made.

The water quality controller works based on temperature sensor readings. The results of the temperature sensor readings on the water quality control system are shown in Figure 7 below.


id: 32219 - Temp 01: 27.00 - Temp 02: 26.96 - Temp 03: 26.79 - Temp 04: 26.57
17:04

Figure 7. Results of Reading Four Temperature Sensors on Telegram

The temperature sensor in the pool is placed at 4 different locations to determine the condition of each corner of the pool. Notifications on Telegram only show readings on the temperature sensor while data values from the pH sensor, turbidity sensor, heater on time, cooler (circulation pump), and aerator will appear in the Google spreadsheet database.

Initial testing is by testing the three inputs, namely the temperature sensor, pH sensor, and turbidity sensor which are used to determine the level of sensor precision which will later determine the output of the pond water quality control system tool circuit and automatic fish feeding system. The results of the error presentation calculation are used to measure and determine the level of difference between the values measured by the sensor and the reference value or the correct value. The results of testing the DS18B20 temperature sensor with a thermometer are shown in Figure 8 below.

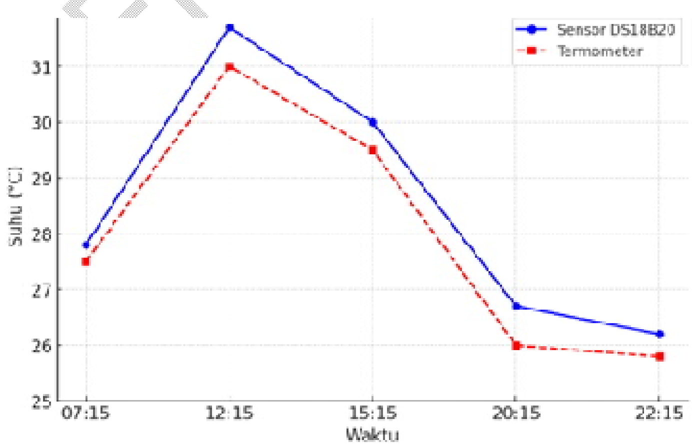

Figure 8. Results of testing the DS18B20 temperature sensor with a thermometer.

Figure 8 shows the measurement results of the DS18B20 sensor and thermometer with a bar chart showing the percentage of error at any time. The test results of the DS18B20 temperature sensor with a thermometer were carried out 5 times at different times, namely the first test at 07:15 obtained a percentage error of 1.09, the second test at 12:25 with a percentage error of 2.25, the third test at 15:15 with a percentage error of 1.70, the fourth test at 20:15 with a percentage error of 2.69, and the fifth test at 22:15 with a percentage of 1.55. The average percentage error result is 1.85 or <5% so that the measurement results of the DS18B20 temperature sensor get precise and accurate results. The test results of the PH-4502C sensor with a PH meter are shown in Figure 9 below.

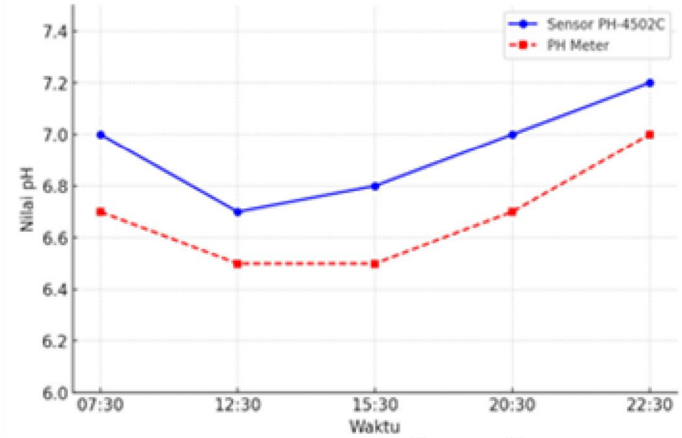

Figure 9 Test results of the PH-4502C sensor with a PH meter

Figure 9 shows the results of testing the PH-4502C sensor with a PH meter, the test was carried out 5 times with different times, namely the first test obtained a percentage error of 4.47, the second test 3.07, the third test 4.61, the fourth test 4.47, and the fifth test 2.85. The average percentage error is 3.8 or <5% so that the measurement results of the PH-4502C sensor get precise and accurate results. The difference in measuring the Turbidity sensor with the Turbidity meter is shown in Figure 10 below.

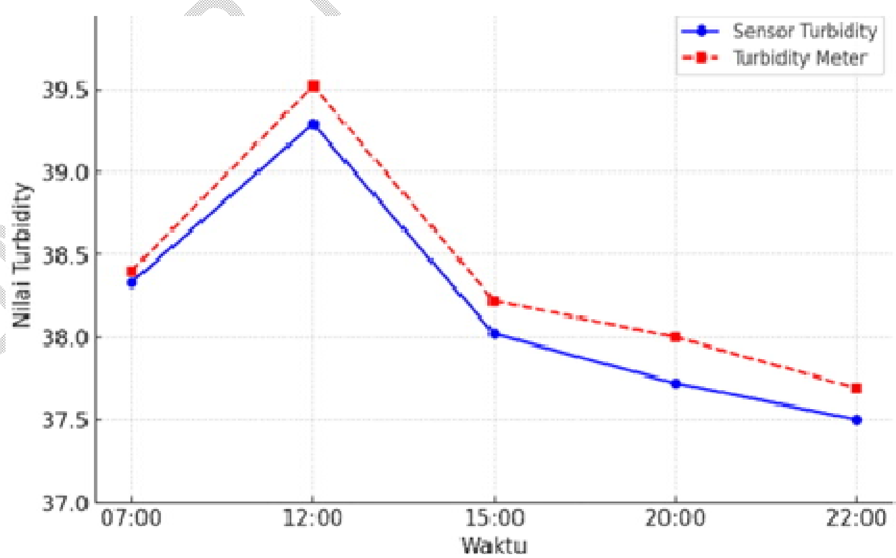

Figure 10. Results of testing turbidity sensors with turbidity meters

Figure 10. shows the results of turbidity sensor testing with a turbidity meter, the test was carried out 5 times with different times, namely the first test at 07:00 got a percentage error of 0.18, the second test at 12:00 got a percentage error of 0.59, the third test at 15:00 got a percentage error of 0.52, the fourth test at 20:00 got a percentage error of 0.74, and the fifth test at 22:00 got a percentage error of 0.50. The average percentage error is 0.5 or <5% so that the measurement results of the Turbidity sensor get precise and accurate results.

The water quality control system testing was conducted with five tests at different times. The test results are shown in Table 2 below.

Table 2. Water Quality Control System Test Results

Time	TS1	TS2	TS3	TS4	PH	TRB	Cooler	Heater	Aerator
04:00	24.03	23.96	23.89	23.90	7.2	35.3	OFF	ON	ON
08:00	26.20	26.18	26.09	26.11	7.0	37.2	OFF	OFF	OFF
12:00	31.02	30.96	30.74	30.57	6.6	39.3	ON	OFF	ON
16:00	28.00	27.86	27.79	27.72	6.8	38.8	OFF	OFF	OFF
20:00	25.31	25.26	25.21	25.13	7.0	38.0	OFF	OFF	OFF

Description:
TS1 : Pool temperature sensor point 1
TS2 : Pool temperature sensor point 2
TS3 : Pool temperature sensor point 3
TS4 : Pool temperature sensor point 4
PH : PH sensor
TRB : Turbidity sensor

In the water quality control system, the temperature sensor is the main parameter that can affect other sensors to determine the duration of the heater, cooler, and aerator. Table 1 shows that when the temperature is stable, the pH and oxygen needed by the fish are relatively stable, when the temperature is high, the pH will decrease and turbidity will increase. The working time of the cooler, heater, and aerator is adjusted to the condition of the pond, so that by implementing the pond water quality control system, the pond water quality is always maintained according to the needs of the fish. The implementation of the water quality control system is shown in Figure 11 below.

Figure 11. Water quality control system (heater, cooler, and aerator)

Based on the results of the water quality control system test, it was found that the temperature in the pond can affect the pH value and turbidity value in the pond water and the working system of the pond water quality control, namely: 1) when the temperature is high, namely > 30^{0}C, the cooler (circulation pump) and aerator will work together, the function of the collaboration of the cooler (circulation pump) and aerator is so that the pond temperature quickly reaches the ideal number, creating bubbles in the water and air fountains that can increase dissolved oxygen in the water, reduce the accumulation of fish waste and food waste in the water, so that water quality is maintained; 2) if the temperature is low, namely <25^{0}C, the heater and aerator will turn on simultaneously, when the heater turns on, the aerator will emit air bubbles under the water which are useful for underwater air circulation so that the heat in the heater is easily spread into the pond, and when it shows ideal conditions, the heater, cooler, and aerator will turn off and will work again when the pond water shows conditions that are not ideal.

The results of the test of the automatic fish feeding system based on fuzzy logic were carried out five times with different times, this was to obtain accurate and precise test results. The test results are shown in Table 3 below.

Table 3. Test Results of Fuzzy-based Automatic Fish Feeding System

Terting To	Input			Output	
	Temperature	PH	Turbidity	Motor Running Time	Fish Feed
1	23.03	7.2	32.3	229	3.893
2	26.08	7.0	37.2	235	3.995
3	31.56	5.9	39.3	232	3.944
4	30.47	6.1	39.0	235	3.995
5	25.59	6.9	38.1	235	3.995

The implementation of the fuzzy-based automatic fish feeder is shown in Figure 12 below.

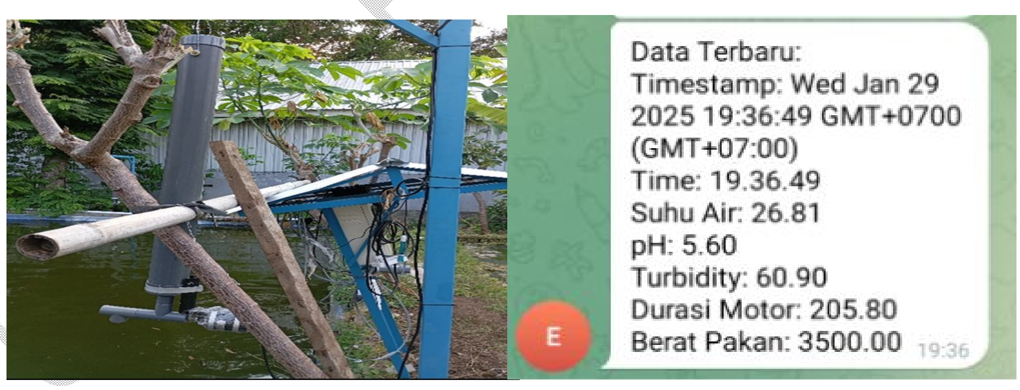

Figure 12. Automatic Fish Feeding System and Notifications on Telegram

The test results in Table 3 on the automatic fish feeding system show that the automatic fish feeding device based on the Fuzzy Logic Controller (FLC) is precise in determining the amount of feed based on the quality of the pond water or based on the readability value of the temperature sensor, pH sensor, and turbidity sensor so that the feed given to the fish is not wasted and poisons the fish. This automatic fish feeding system can be monitored via the telegram application.

The results of the system test show that the amount of working time duration and the amount of feed that changes adjusts to environmental conditions and pond water quality. The average error presentation in five tests was very low, namely 0.19%. In this study, fish feeding was scheduled 2 times using a timer, namely at 06.00 and 18.00 with the duration of the motor on and the amount of fish feed according to the results on the sensor, but for notifications on the telegram in the form of temperature conditions, pH, and turbidity notifications on the telegram every 1 hour.
This research has the advantage of collaboration between 2 systems, namely the water quality control system and the automatic fish feeding system, where this automatic fish feeding system will work according to the water quality based on three input criteria in the form of temperature, pH, and turbity to determine the duration of heater performance, cooler performance duration, aerator performance duration, and the amount of fish feed with precise results and the tool works according to the needs of the fish and the quality of the pond water. The implication of this research can be used in developing further research related to an integrated and modern intelligent fish farming system. The disadvantages of this research are that there is a signal disconnection or if there is no data package or network, the user will not receive a notification on the telegram and there is no draining system in the pond when the turbidity sensor shows high turbidity results so that further research is expected to be able to complement the intelligent fish farming system with an automatic pond draining system.

4. CONCLUSION

Based on the research that has been done, it can be concluded that: 1) The results of the sensor test, the average percentage error on the temperature sensor is 1.85, the average percentage error on the PH-4502C sensor is 3.8 and the average percentage error on the turbidity sensor is 0.5 so that the average measurement result of the sensor is <5% so that accurate results are obtained; 2) The results of the water quality control system test can work well, where the temperature sensor can affect the pH sensor and turbidity sensor, namely when the temperature is high, namely> 30^0C, the cooler (circulation pump) and aerator will work simultaneously, if the temperature is low, namely <25^0C, the heater and aerator will turn on simultaneously, and when it shows ideal conditions, the heater, cooler, and aerator will turn off; 3) The results of the test on the automatic fish feeding system, the average percentage error in five tests is very low, namely 0.19% <5% so that the system can work well and precisely in determining the amount of fish feed.

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Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1. table-to-image generator on image 8, 9 and 10 with gpt chat

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