Engineering and Technology Journal e-ISSN: 2456-3358

Volume 10 Issue 03 March-2025, Page No.- 3958-3965

DOI: 10.47191/etj/v10i03.02, I.F. – 8.482

Development of an Intelligent Water Pollutant Prediction Robot Assisted by Wireless Transmission Control

Ridwan Siskandar[1], Sesar Husen Santosa[2], Wiyoto Wiyoto[3], Agung Prayudha Hidayat[2], Billi Rifa Kusumah[4], Muhammad Danang Mukti Darmawan[1], Fiqri Nurfadillah[1], Rachel Renengsi Sianipar[5], Azzahra Laila Idfinaya[5], Ade Riyanti[1], Afifah Rodhiyatun Nisa[1], Aura Kharina[1]

[1]Computer Engineering Technology Study Program, College of Vocational Studies, IPB University, Indonesia

[2]Industrial Management Study Program, College of Vocational Studies, IPB University, Indonesia

[3]Production Technology and Management of Aquaculture Study Program, College of Vocational Studies, IPB University, Indonesia

[4]Fishing Technology Study Program, Faculty of Marine and Fisheries Technology, Nahdlatul Ulama University of Cirebon, Indonesia

[5]Department of Mechanical and Biosystem Engineering, Faculty of Agricultural Engineering and Technology, IPB University, Bogor, Indonesia

ABSTRACT: This research aims to develop an intelligent water pollution prediction robot assisted by wireless transmission to address the shortcomings water quality monitoring systems. The robot is designed to operate in micro-waterscapes, particularly freshwater, using a hovercraft model and a radio frequency-based remote-control system. Sensor data is transmitted wirelessly using LoRa Ebyte E32, and the robot employs a 7.5-volt 2S LiPo battery for power. The research approach involves literature study, interviews, and observations to organically map solutions to identified problems. Two main methods are implemented: design and performance testing, encompassing motor motion system, fuzzy logic system for predicting water pollution percentage, remote control system, and data transmission communication system. The intelligent robot was successfully constructed with dimensions of 20 cm x 52.3 cm x 20.9 cm and a weight of 5 kg. The robot can operate for 20 minutes, with a remote-control range of up to 500 meters and a sensor data transmission range of up to 2 kilometers. Testing shows the robot has a 2% sensor error tolerance and accurately predicts water pollution levels. This intelligent robot aims to overcome limitations in water quality monitoring and improve pollution prediction accuracy, offering a more reliable solution for environmental monitoring.

KEYWORDS: Control systems, intelligent robots, mamdani fuzzy logic, microcontrollers, water pollutants.

I. INTRODUCTION

Water is a vital natural resource for human life and ecosystems (Wu et al., 2017; Dani et al., 2019; Baghel et al., 2022; Siskandar et al., 2022, 2023; Sugiharto et al., 2023; Wibowo et al., 2023; Yu et al., 2023; Suhaila et al., 2024). Good water quality is essential for maintaining ecosystem health. However, water pollution often occurs, which can degrade water quality. Accurate water quality monitoring is crucial for maintaining the health of aquatic environments (Wang and Yang, 2016; Pule et al., 2017; Gogoi et al., 2018; Kazeminasab et al., 2020; Hong et al., 2021; Dwi Susanti et al., 2022; Makhdoumi Akram et al., 2022; Saalidong et al., 2022; Yusof et al., 2023; Sugiharto et al., 2023; Shete et al., 2024).

Conventional water quality monitoring systems have several drawbacks, such as requiring skilled human resources and lengthy data recording times. IoT-based water quality monitoring systems can address these shortcomings but still have limitations in covering large areas.

This research aims to develop an intelligent water pollutant prediction robot assisted by wireless transmission with a remote-control system for robot movement, a decision-making system for determining water pollution using Mamdani fuzzy logic, a water quality monitoring system using a microcontroller, and a data transmission control system using LoRa. This intelligent robot is equipped with radio wave control using an Fs-iA6 remote control, a sensor data transmission system without internet using LoRa Ebyte E32, and a decision-making system to determine the percentage level of water pollution using Mamdani fuzzy logic.

In an era of continuous technological advancement, innovations in water quality monitoring systems, such as the use of robots, offer practical solutions for understanding and improving aquatic environments. Through proper monitoring and maintenance, we can reduce the negative impact on aquatic ecosystems and protect this precious natural resource. As part of global efforts to ensure the availability of sufficient and quality water for all living things, water quality monitoring is an essential step in ensuring the survival and well-being of humans and ecosystems in the future.

II. MATERIAL AND METHODS

A research project titled "Development of an Intelligent Water Pollution Prediction Robot with Wireless Transmission" was conducted between August 2023 and December 2023. The research was carried out in the Hardware Lab and Electromechanical Workshop, Fisheries Laboratory of IPB University Vocational School, and Bogorian Aquatics. The research was conducted using three analytical approaches.

The first analytical approach was a literature study, which involved reviewing recent research and track records related to water quality inspection, sensor technology, fuzzy logic, and robotics (Adhipramana et al., 2020; Prabowohendhi et al., 2020; Gupta et al., 2021; Suárez Sanmiguel and Escobar Posada, 2021). This literature review helped in the design of the robot. Additionally, the research employed design and performance testing methodologies.

The equipment required for the construction of the robot is listed in Table 1, while the materials are listed in Table 2.

Table 1. Tools Functionality Requirements

No.	Tools	Function	Vol
1	Arduino Mega	Electronic devices that function as data processors	1
2	Arduino Uno	Electronic devices that function as data processors	1
3	DF Robot Sensor pH	Measure the acidity of water	1
4	DF Robot Module Sensor pH	as module sensor pH	1
5	DF Robot Sensor TDS	Measure the level of solid particles	1
6	DF Robot Module Sensor TDS	as module sensor TDS	1
7	Sensor DS18B20	Measure water temperature	1
8	Module DS18B20	as module sensor DS18B20	1
9	ESC *Driver* 30A	Electric motor pulse width modulation (PWM) regulator.	1
10	A2212 2200 kV BLDC	The trasmitter signals the data back and forth, which is then received by the receiver. The data is processed by Arduino Mega to then command the output	1
11	*LCD Display* I2C 16x2	Display sensor reading measurement results	1
12	*FlySky Fs-iA6*	Trasmitter-Receiver as turbine and servo remote control communication	1
13	*E-Byte LoRa E32*	Trasmitter-Receiver as remote control communication of DS18B20 sensor reading, pH sensor, TDS sensor and 16x2 I2C LCD	2
14	Motor Servo MG90 180 deg	Drive the robot fin turning system	1

Table 2. Material Functionality Requirements

No.	Materials	Function
1	Fritzing	To create an electronic circuit
2	Fusion 360	Used to create 3D designs
3	Arduino IDE	Used to sketch the program on the microcontroller
4	Visual Studio Code	Used to sketch programs on the web
5	MatLab	It is used to analyze data, design algorithms, generate models, and develop applications because it is a matrix-based programming language.
6	Ultimate Cura	Used to slicing *design* 3D

Based on the analytical approach, the appropriate method for mapping the process and achieving the goals is through Design and Performance Testing. Here is a more in-depth explanation of the two methods:

Design

This intelligent water robot boasts a compact design with dimensions of 20 cm (width), 52.3 cm (length), and 20.9 cm (height), weighing approximately 5 kg. Capable of operating for 20 minutes, the robot has demonstrated exceptional performance during testing. The robot's control system connection range extends up to an impressive 500 meters, while sensor data transmission can reach a remarkable distance of 2 kilometers. To ensure accurate water pollution percentage data, the robot employs Mamdani fuzzy logic in its prediction algorithm. Sensor data is processed using fuzzy logic technology, enhancing the accuracy of interpretation by accounting for measurement uncertainties and variabilities.

The processed results are then presented in a user-friendly format by mapping water conditions into categories such as "good," "moderate," or "poor." Furthermore, the analyzed data is wirelessly transmitted using LoRa (Long Range) technology, ensuring seamless data dissemination.

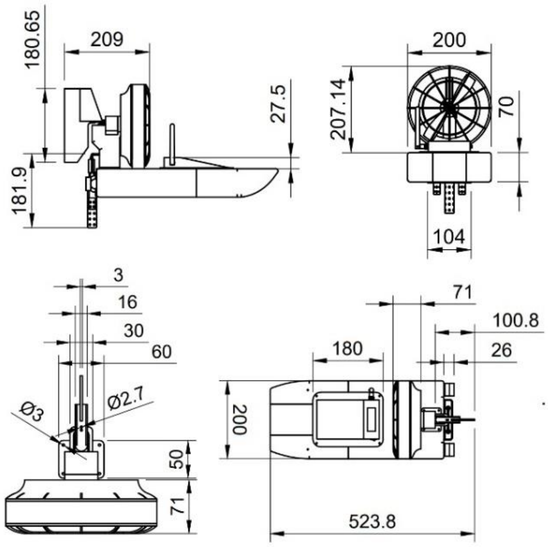

Figure 1. Technical Architecture Robot

Mechanical design of robots is an intricate process that encompasses various stages to establish a robust and functional physical structure and working system for the robot (Adhipramana et al., 2020). This process commences with the conceptualization phase, where the robot's requirements and objectives are meticulously defined. During this stage, technical specifications such as size, weight, payload capacity, and operational environment of the robot are identified. Subsequently, the conceptual design is transformed into a detailed design using Computer-Aided Design (CAD) software. This detailed design encompasses all mechanical components, including the frame, joints, and transmission systems.

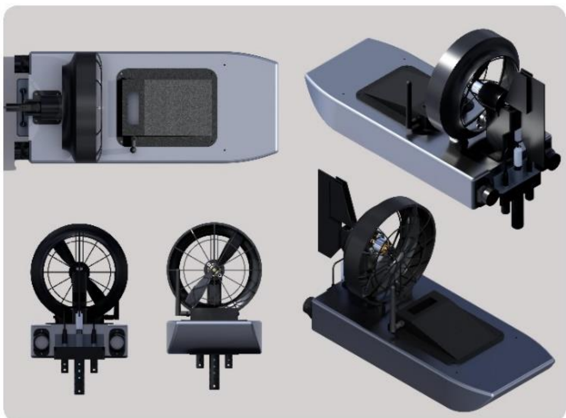

Figure 2. Design 3D Robot ***Performance Testing***

The performance testing method is divided into four main parts, namely: (1) the test method of the motor motion system including the speed test of the drive motor and the test of the length of time of the robot turning system to maximize time and power consumption; (2) the test method of the remote control system; (3) the analysis of mamdani fuzzy logic on the robot and (4) the test method of the sensor data communication system including the sensor data transmission test and the sensor reading comparison test.

Testing motor movement system

This test is carried out to determine the speed of the drive motor motion system. The speed of the motor drive system is important to determine the robot's performance in moving and completing its tasks. The type of test is the time and distance test.

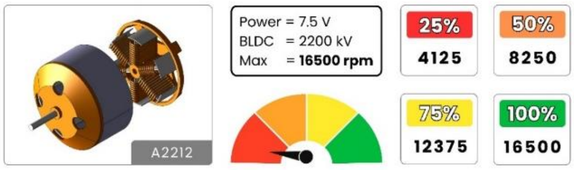

Figure 3. Speed Level And Motor Rpm Partittion

Testing of remote control system

This test was conducted to determine the transmission range of the robot control Fs-iA6. This transmission range is important to know how far the robot can be controlled wirelessly. The type of test used is the distance and signal strength test. This test will measure the maximum distance that the robot can reach to receive control commands from the Fs-iA6 transmitter (Von Borstel Luna et al., 2017; Shahrani et al., 2021). The testing mechanism is to place the robot at various distances from the Fs-iA6 transmitter and observe the robot's ability to receive control commands. This test can be done in an open room or outdoors. The instruments used are ossiloscope, meter, and Fs-iA6 transmitter - receiver.

Analysis of mamdani fuzzy logic

The system receives three input parameters in the form of sensor values to determine the percentage of water pollution. The first input parameter is the pH of the water, which is categorized as acidic, neutral, or alkaline. Next, the second input parameter is the water temperature, which is categorized as cold, medium, or hot. Finally, the third input parameter is TDS, which is categorized as either loose or tight. Based on these three input categories, the system will determine the output in the form of water pollution percentage, which is categorized as lightly polluted, heavily polluted and heavily polluted.

The membership function is determined to express the overall system function with a trapezoidal shape (Adhipramana et al., 2020; Prabowohendhi et al., 2020. The pH membership function is divided into three categories: pH values less than 5.8 are acidic, 6 to 8 are neutral and more than 8.2 are alkaline.

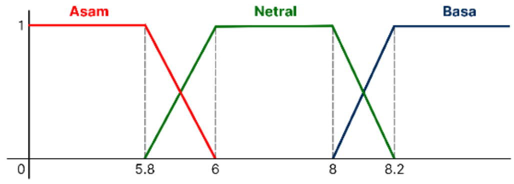

Figure 4. pH Membership Function

The temperature membership function is divided into three categories: temperature values less than 25.8 are cold, 26 to 32 are medium and more than 32.2 are hot.

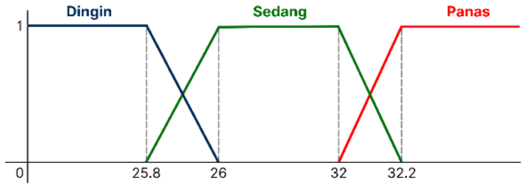

Figure 5. Temp Membership Function

The TDS membership function is divided into 2, namely TDS values less than 250 are good and more than 300 are bad (Athira, 2018; Nowshin et al., 2018).

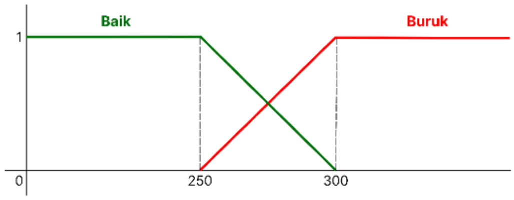

Figure 6. TDS Membership Function

The last is to set a range for the percentage of water pollution with a membership function that is divided into three, namely lightly polluted 0 to 40%, moderately polluted 30 to 60% and heavily polluted 60 to 100%.

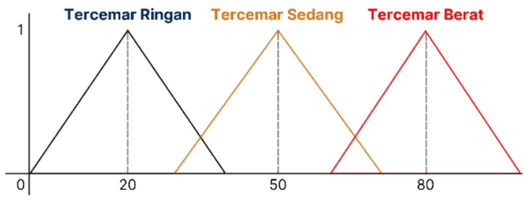

Figure 7. Membership function water pollutant percentage

Then, sets 18 rules to form the conditions that determine the percentage level of pollution.

Table 3. Fuzzy Logic Rules

pH	**Temp**	**TDS**	
		Tenous	**Tight**
Acid	Cold	Polluted Middle	Polluted Severe
Acid	Middle	Polluted Lightly	Polluted Middle
Acid	Hot	Polluted Middle	Polluted Severe
Neutral	Cold	Polluted Lightly	Polluted Middle
Neutral	Middle	No Polluted	Polluted Lightly
Neutral	Hot	Polluted Lightly	Polluted Middle
Alkaline	Cold	Polluted Middle	Polluted Severe
Alkaline	Middle	Polluted Lightly	Polluted Middle
Alkaline	Hot	Polluted Middle	Polluted Severe

In determining the implication function of this fuzzy logic is to take the minimum value of each input parameter. The following is the implication of fuzzy logic found in Figure 8.

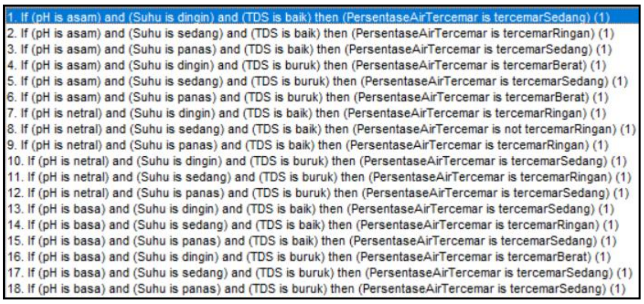
1. If (pH is asam) and (Suhu is dingin) and (TDS is baik) then (PersentaseAirTercemar is tercemarSedang) (1)
2. If (pH is asam) and (Suhu is sedang) and (TDS is baik) then (PersentaseAirTercemar is tercemarRingan) (1)
3. If (pH is asam) and (Suhu is panas) and (TDS is baik) then (PersentaseAirTercemar is tercemarSedang) (1)
4. If (pH is asam) and (Suhu is dingin) and (TDS is buruk) then (PersentaseAirTercemar is tercemarBerat) (1)
5. If (pH is asam) and (Suhu is sedang) and (TDS is buruk) then (PersentaseAirTercemar is tercemarSedang) (1)
6. If (pH is asam) and (Suhu is panas) and (TDS is buruk) then (PersentaseAirTercemar is tercemarBerat) (1)
7. If (pH is netral) and (Suhu is dingin) and (TDS is baik) then (PersentaseAirTercemar is tercemarRingan) (1)
8. If (pH is netral) and (Suhu is sedang) and (TDS is baik) then (PersentaseAirTercemar is not tercemarRingan) (1)
9. If (pH is netral) and (Suhu is panas) and (TDS is baik) then (PersentaseAirTercemar is tercemarRingan) (1)
10. If (pH is netral) and (Suhu is dingin) and (TDS is buruk) then (PersentaseAirTercemar is tercemarSedang) (1)
11. If (pH is netral) and (Suhu is sedang) and (TDS is buruk) then (PersentaseAirTercemar is tercemarRingan) (1)
12. If (pH is netral) and (Suhu is panas) and (TDS is buruk) then (PersentaseAirTercemar is tercemarSedang) (1)
13. If (pH is basa) and (Suhu is dingin) and (TDS is baik) then (PersentaseAirTercemar is tercemarSedang) (1)
14. If (pH is basa) and (Suhu is sedang) and (TDS is baik) then (PersentaseAirTercemar is tercemarRingan) (1)
15. If (pH is basa) and (Suhu is panas) and (TDS is baik) then (PersentaseAirTercemar is tercemarSedang) (1)
16. If (pH is basa) and (Suhu is dingin) and (TDS is buruk) then (PersentaseAirTercemar is tercemarBerat) (1)
17. If (pH is basa) and (Suhu is sedang) and (TDS is buruk) then (PersentaseAirTercemar is tercemarSedang) (1)
18. If (pH is basa) and (Suhu is panas) and (TDS is buruk) then (PersentaseAirTercemar is tercemarSedang) (1)

Figure 8. Implication Function

Testing of data communication systems

Wireless sensor data transmission communication using LoRa. Data is sent through the transmitter and then forwarded to the receiver. After that, the data that has been received will be displayed on the LCD. The data displayed are ph sensor readings, TDS sensor readings, DS18B20 sensor readings, and predictions of the percentage of water pollutants. This test will verify the ability of the LoRa Ebyte E32 module to send and receive sensor data and determine the maximum distance at which the LoRa Ebyte E32 module can send and receive sensor data.

III. RESULTS AND DISCUSSION

Robot Prototype

The application of the wireless transmission-assisted water pollutant prediction intelligent robot prototype is shown in Figure 40. Figure 40 shows that the water pollutant prediction intelligent robot can run and operate in the fishery basin to sample water pollution data.

Figure 9. Robot Model

The working principle of the tool on this robot is processed with various multi-parameter sensors that are able to measure several aspects of water quality, such as:

1. pH, measures the acidity or basicity of water.
2. Temperature, measures the temperature of the water which is important for the aquatic ecosystem (Santosa et al., 2021).
3. Total particle solids, measures solid particles suspended in water.

Then the data collected by the sensors is processed using fuzzy logic technology to interpret more accurately the sensor data by considering the uncertainty and variability in the measurements.

Test Motor Movement System

The results of this speed test are used to optimize the robot control algorithm.

Table 4. Testing Speed Motor Movement

Diameter Propeller (mm)	Pitch Propeller (mm)	Voltage (V)	RPM	Speed (m/s)
10	5	6.5	3700	2.61
10	5	7	3700	2.87
10	5	7.5	3700	3.13
12	6	6.5	3700	3.14
12	6	7	3700	3.41
12	6	7.5	3700	3.69
15	7.5	6.5	3700	3.89
15	7.5	7	3700	4.26
15	7.5	7.5	3700	4.64

It can be stated from the speed test that the motor speed is affected by propeller diameter, propeller pitch, and voltage. The larger the propeller diameter, the higher the motor speed. The larger the propeller pitch, the higher the motor speed. The higher the voltage, the higher the motor speed.

Testing Control System Transmission

Transmission tests help optimize signal strength and stability, ensuring smooth and responsive control performance. The following is the data presented during the control transmission test shown in Table 5.

Table 5. Testing Of Remote Control System

Distance (m)	Status	Keterangan
100	Connected	Robot can be controlled by remote control
150	Connected	Robot can be controlled by remote control
200	Connected	Robot can be controlled by remote control
250	Connected	Robot can be controlled by remote control
300	Connected	Robot can be controlled by remote control
350	Connected	Robot can be controlled by remote control
400	Connected	Robot can be controlled by remote control
450	Connected	Robot can be controlled by remote control
>500	Failed	Robot can't be controlled by remote control

The wireless-based sensor value data transmission test through LoRa E-Byte E32 was carried out with an ISM band frequency of 868MHz.The test concluded that the farther the data transmission, the weaker the transmission signal.

Table 6. Testing Data Transmission

Distance (km)	Transmission (dBm)	Status
0.25	20	Connected
0.5	18.3	Connected
0.75	17	Connected
1	16.8	Connected
1.25	14	Connected
1.5	12	Connected
1.75	10	Connected
2	0	Failed

Defuzzyfication

Defuzzyfication is an important process in fuzzy logic systems that converts the numerical values of inference results into fuzzy representations.This process involves the use of membership functions to map the sharp values into fuzzy sets that represent the degree of membership in the output variable. This form allows fuzzy systems to capture uncertainty and gradations in input and output values. The following is one of the sample proofs of the results from the application-based prediction.

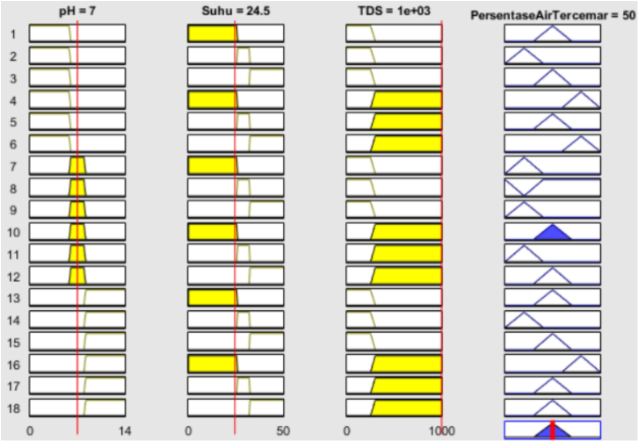

Figure 10. Defuzzyfication Based On Matlab

Figure 10 shows the defuzification results for predicting the percentage of water pollutants through the MatLab application. In this figure, the percentage prediction results for a pH value of 7, a temperature value of 24.5°C, and a TDS value of 1000 show a pollution level of 50%. Figure 11 shows the prediction results through the Arduino IDE application. Both comparisons, through MatLab and Arduino IDE, produce the same prediction of 50%. This shows the consistency and reliability of the fuzzy logic system in predicting water pollution levels.

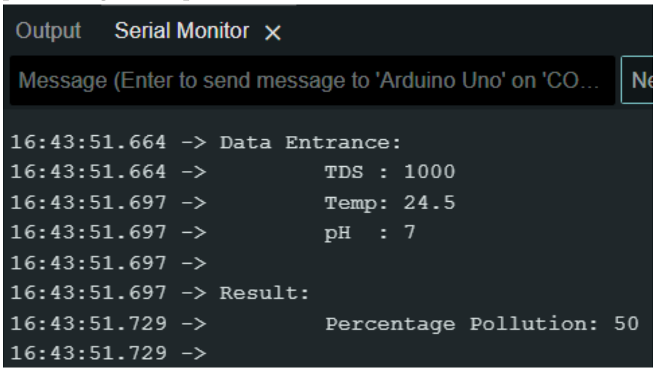

Figure 11. Defuzifikasi via Arduino IDE *Comparison Test of Sensor Readings with Measuring Instruments*

Measurements are taken at several sampling points with respect to sample type and water condition. Then enter the sensor value fuzification and involve the output with MatLab. The following is a table of results from testing sensor values and predicting the percentage of water pollution.

Table 7. Comparative Testing of Sensor and Measuring Instrument Values

No.	Comparison					
	Sensor			Instrument values		
	Temp (C)	pH	TDS (ppm)	Temp (C)	pH	TDS (ppm)
1	24.5	7	1000	23.7	6.8	1000
2	28	6	1000	27.4	5.9	1000
3	23	5	770	22.3	5.3	680
4	24.5	5.85	400	20.8	5.3	295
5	26.2	6.34	288	37.6	11.7	900
6	35.6	8.15	276	34.2	10.8	900
7	37	8	900	36.1	8	900
8	33	3	590	32.5	2.8	500
9	29	4	700	27.7	3.9	680
10	26	4	200	25.6	3.9	150

Measurements are made by taking ten samples of basin water by comparing the value of the sensor read and the results of the measuring instrument. From these water samples, a forecast is carried out to determine the percentage value of water pollution using the library system contained in the Arduino IDE feature. So that the data obtained - the percentage of pollution data in accordance with Table 8.

Table 8. Water pollutant value prediction test

No.	Sample (Water)	Condition	Pollutant (%)	Difference Reading		
				Temp (C)	pH	TDS (ppm)
1	Fish Tank 1	Normal	50	0.8	0.2	0
2	Fish Tank 2	Acid	20	0.6	0.1	0
3	Fish Tank 3	Acid	80	0.7	0.3	90
4	Shrimp Tank 1	Acid	70	0.2	0.3	105
5	Shrimp Tank 2	Alkaline	40.8	0.4	0.3	50
6	Shrimp Tank 3	Alkaline	39.8	0.8	0.2	0
7	Filter Tank 1	Alkaline	50	0	0	0
8	Filter Tank 2	Acid	80	0.2	0.2	90
9	Filter Tank 3	Acid	50	0.1	0.1	20
10	Fish Pool	Acid	20	0.1	0.1	50

CONCLUSIONS

This research develops an intelligent water robot with the ability to autonomously float, maneuver, and take water samples. The robot is designed with a precise hull, lightweight materials, and tightly packed using filaments. A steering system with servo enables maneuvering on water. The LoRa E-Byte E32 connects wireless monitoring and robotics systems for remote control and real-time sensor data. The robot is capable of autonomous movement and taking water samples at a designated location with connected control up to 500 meters away. The robot dimensions are 20 cm x 52 cm x 21 cm and weighs 5 kg. Tests showed motion control range up to 500 meters, sensor data transmission up to 2 km, and operation for 20 minutes. Battery capacity was tested by alternating use at 50%, 75%, and 100% speed for 5 minutes, showing power consumption of 0.74 V, 1.06 V, and 1.27 V, respectively. The error tolerance of the sensor reading against the measuring instrument is 2%. The water pollutant percentage prediction test showed consistent values between Matlab and Arduino IDE.

ACKNOWLEDGEMENT

This research was funded by the Research of Vocational Product Grant Program in 2024 contract number 120/SPK/D.D4/PPK.01.APTV/IV/2024.

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