Journal of Mechatronics, Electrical Power, and Vehicular Technology 14 (2023) 198-207

Journal of Mechatronics, Electrical Power, and Vehicular Technology

e-ISSN: 2088-6985
p-ISSN: 2087-3379

mev.brin.go.id

Water quality assessment monitoring system using fuzzy logic and the internet of things

Hanif Fakhrurroja [a, c, *], Edi Triono Nuryatno [b], Aris Munandar [c], Muhammad Fahmi [d], Novan Agung Mahardiono [c]

[a] *School of Industrial Engineering, Telkom University*
Jalan Telekomunikasi Terusan Buah Batu, Bandung, 40257, Indonesia
[b] *UWA Centre for Medical Research, University of Western Australia*
35 Stirling Highway, Perth, 6009, Australia
[c] *Research Center for Smart Mechatronics, National Research and Innovation Agency (BRIN)*
Kawasan Sains dan Teknologi (KST) Samaun Samadikun, Jalan Sangkuriang, Bandung, 40135, Indonesia
[d] *Faculty of Digital and Information Technology, Institute of Digital Economics LPKIA*
Jalan Soekarno Hatta no. 456, Bandung, 40266, Indonesia

Received 25 May 2023; 1st revision 1 November 2023; 2nd revision 10 November 2023;
Accepted 13 November 2023; Published online 29 December 2023

Abstract

Water utilization has recently been at its highest level of demand. The water needed to be clean, healthy, and determined to be suitable for consumption. Therefore, it is necessary to have a system that can monitor the water quality so that information related to water suitability can be received regularly and in real-time. This paper addresses the critical need for real-time water quality monitoring systems. This study proposed a novel approach integrating the Tsukamoto fuzzy algorithm into an internet of things (IoT)-based framework, forming part of the Fuzzy Inference System. Our system serves as a decision support tool, enabling continuous assessment of water quality. The method categorizes water quality into three levels: good, moderate, and unhealthy, providing timely and precise suitability information. The results demonstrate the effectiveness of the fuzzy logic method in delivering accurate output. Through remotely deployed IoT devices, water suitability and status can be monitored and analyzed in real-time over the internet. This research bridges the gap between traditional water quality assessment methods and the demands of our modern, technology-driven society, ensuring a reliable supply of safe and consumable water.

Keywords: assessment monitoring; fuzzy logic; internet of things (IoT); real-time; water quality.

I. Introduction

Water is one of the most important basic needs, whether used for drinking, cooking, washing, or other purposes. Water that is good for use is water that is not polluted by anything. Pollution itself is a change in a condition from its initial form to a worse one [1]. Water that is fit for human consumption must meet physical standards. It must be crystal clear, not turbid. Water turbidity is typically brought on by the presence of very small clay particles [2]. Water that is colored indicates the presence of potentially dangerous substances [3]. Water that tastes sour or salty indicates that the quality of the water is not good [4]. A salty taste is due to the presence of certain salts that dissolve in water. The presence of both organic and inorganic acids contributes to the sour flavor, while the pH level is neutral between 6.5 and 8.5. Organic components are being digested (decomposed) by water microorganisms in the foul-smelling water, which has a low pH and tastes sour yet feels bitter when the pH is high [5]. As a result of the rise of these issues, this paper argues that it is vital to have a system that can monitor the appropriateness of water in water storage sources so that information on water suitability may be obtained on a frequent, accurate, and real-time basis.

* Corresponding Author. Tel: +62-818647004
E-mail address: haniff@telkomuniversity.ac.id

doi: https://dx.doi.org/10.14203/j.mev.2023.v14.198-207
2088-6985 / 2087-3379 ©2023 National Research and Innovation Agency

How to Cite: H. Fakhrurroja, E. T. Nuryatno, A. Munandar, M. Fahmi, N. A. Mahardiono, "Water quality assessment monitoring system using fuzzy logic and the internet of things," *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, vol. 14, no. 2, pp. 198-207, Dec. 2023.

Table 1.
Existing water quality assessment monitoring system using IoT

Sensors	Microcontroller	Method	System	IoT Cloud Services	Reference
Temperature, pH, turbidity	Raspberry Pi	Fuzzy logic	Monitoring and assessment	Webserver®	[12]
Temperature, pH, turbidity	ESP8266, Arduino Uno	–	Monitoring only	ThingSpeak®	[13]
Temperature, pH, turbidity, humidity	ESP8266	Fuzzy logic	Monitoring and automatic draining	Blynk®	[14]
pH, turbidity, TDS	ESP32	Fuzzy logic	Monitoring, assessment, and notification	Webserver®	This research

With today's rapid technological advancements, the process of monitoring water appropriateness can be automated by utilizing an internet of things (IoT)-based microcontroller [6][7]. The ESP32 microcontroller is a single-board microcontroller that is open source [8][9]. This microcontroller can be useful for running tasks from sensors commonly referred to as embedded systems [10]. This sensor can provide information related to eligibility, which will then be displayed directly on the web [11]. Through the technology that is described, the goal is to conduct further research by developing a monitoring tool design to check the condition of microcontroller-based water using fuzzy logic, which can identify the suitability of water and meet the pH standards that are safe for daily use. It is expected to be able to overcome the current water problems, namely the difficulty of managing clean water that is suitable for use from water sources and meets good water standards for daily needs.

Table 1 shows the current research in water quality assessment. They are focused on the development of an innovative monitoring system that combines the power of fuzzy logic and the IoT. This system aims to provide real-time and accurate information about water quality parameters, enabling proactive management and effective decision-making to ensure safe and sustainable water resources. By employing fuzzy logic, the system can handle the inherent uncertainties and imprecise nature of water quality data, allowing for more reliable and robust assessments. The integration of IoT technology enables the collection of data from various sensors deployed in different water bodies, facilitating continuous monitoring and remote access to information. This research not only improves the efficiency of water quality assessment but also enhances the early detection of unhealthy water, thus enabling prompt remedial actions and minimizing the risks to public health.

Table 2.
Drinking water quality requirements [23]

No.	Physical Parameter	Unit	Maximum Allowable Levels
1.	Smell	–	–
2.	Total marine solids (TDS)	mg/l	500
3.	Turbidity	NTU scale	5
4.	Taste	–	–
5.	Temperature	°C	Air temperature ±3
6.	Color	TCU	15
7.	pH	–	6.5 – 8.5

II. Materials and Methods

A. Water quality monitoring systems

The system is a collection of several components or pieces that work together to achieve specific goals, while detection is a process of examining or conducting an examination with the goal of solving an issue in many different approaches that are used to provide a solution [15]. Sensors are used to detect things as needed. The sensor is a tool for detecting signs or symptoms caused by energy changes, such as electrical energy, mechanical energy, physical energy, chemical energy, biological energy, and so on [16][17]. The monitoring system is the process of collecting and analyzing information about activities or programs based on indicators that are determined systematically and continuously so that corrective action can be taken to improve the program or activity until it meets the objectives to be achieved [15].

Water quality is a quality characteristic required as a reference for the usage of various water sources, including water qualities, the content of living organisms, energy molecules, or components in water [18]. Water quality is expressed in several parameters, including physical parameters such as turbidity, temperature, and dissolved solids, chemical parameters such as metal levels, pH, and dissolved oxygen, and biological parameters such as the presence of plankton, bacteria, and so on [19][20]. Water needs are determined by the community and are influenced by the environment and behavior. Water that is safe to drink is clear, odorless, tasteless, at an acceptable temperature, free of bacteria, and contains a trace amount of minerals [21][22]. Meanwhile, according to the Regulation of the Minister of Health of the Republic of Indonesia No: 492/MENKES/PER/IV/2010 about drinking water quality regulations, it must meet the physical conditions outlined in Table 2.

B. Fuzzy logic

A type of deterministic uncertainty is fuzziness [24]. It describes the ambiguity of the event class; hence fuzziness measures the degree to which an event occurs. A linguistic variable might be considered a value variable, a fuzzy number, or a variable. The fuzzy logic of fuzzy set theory serves as a foundation for mathematical modeling and language, allowing for the accurate expression of highly advanced algorithms [25]. Fuzzy means blurred or unclear. So, fuzzy logic is logic which is fuzzy for the systems and contains elements of uncertainty [26][27][28]. In ordinary logic, namely strict logic, we only recognize two values: false or true (0 or 1). While fuzzy logic can determine between true and false values. The degrees of truth in fuzzy logic, whose values range from 0 to 1, can be used to express truth. One element of soft computing is fuzzy logic. Fuzzy set theory serves as fuzzy logic's foundation. In fuzzy set theory, membership degrees are crucial in establishing whether or not items of a set exist [29]. The primary feature of fuzzy logic reasoning is membership value, membership degree, or membership function [30]. From some of the experts above, it can be concluded that fuzzy logic is logic used to explain ambiguity, set logic that resolves ambiguity, and converts linguistic statements into numeric. There are two characteristics of the fuzzy set: linguistic and numerical [31]. While the numeric attribute is a value that specifies the magnitude of a variable, the linguistic attribute is used to mention a group that reflects a particular condition or condition using natural language, such as youthful, middle-aged, or old.

III. Results and Discussions

A. Hardware implementation

Figure 1 shows the design of a water quality assessment monitoring system. The sensors used are turbidity sensors, pH sensors, and total dissolved solids (TDS) sensors, which function to read and send content values in the water. The ESP32 microcontroller receives data from sensors, processes the data using fuzzy logic, and then sends the results to the web server and other devices such as buzzers and OLEDs using mobile Wi-Fi hotspots (MiFi). A web server is a service provider for clients, where clients request information in the form of a website. Clients on this system can be computers or mobile phones. Figure 2 shows the prototype of a water quality assessment monitoring system. The prototype consists of an electronics panel and a water box for testing. The electronics panel consists of an ESP32 module, three water quality sensors, an OLED module, and a buzzer. The water box is used to test water samples.

B. System structure and data modeling

Figure 3 shows the identification of actors and use cases. Each use case has an explanation, which is specified in a use case scenario, which contains the use case's name, actions, actors, and system responses. Each sensor measures the water quality and sends the data to the ESP32 microcontroller. The device converts the sensor value to each water quality unit, which is then analyzed using a fuzzy algorithm to determine water quality and displayed on a web page.

A class diagram is a visual representation that depicts the structure and relationships of classes within a system. It is one of the key components of unified modeling language (UML) and serves as a blueprint for designing and understanding the organization of objects in an object-oriented system. In a class diagram, classes are represented as boxes, with the class name written inside the box. The attributes (properties or variables) of a class are

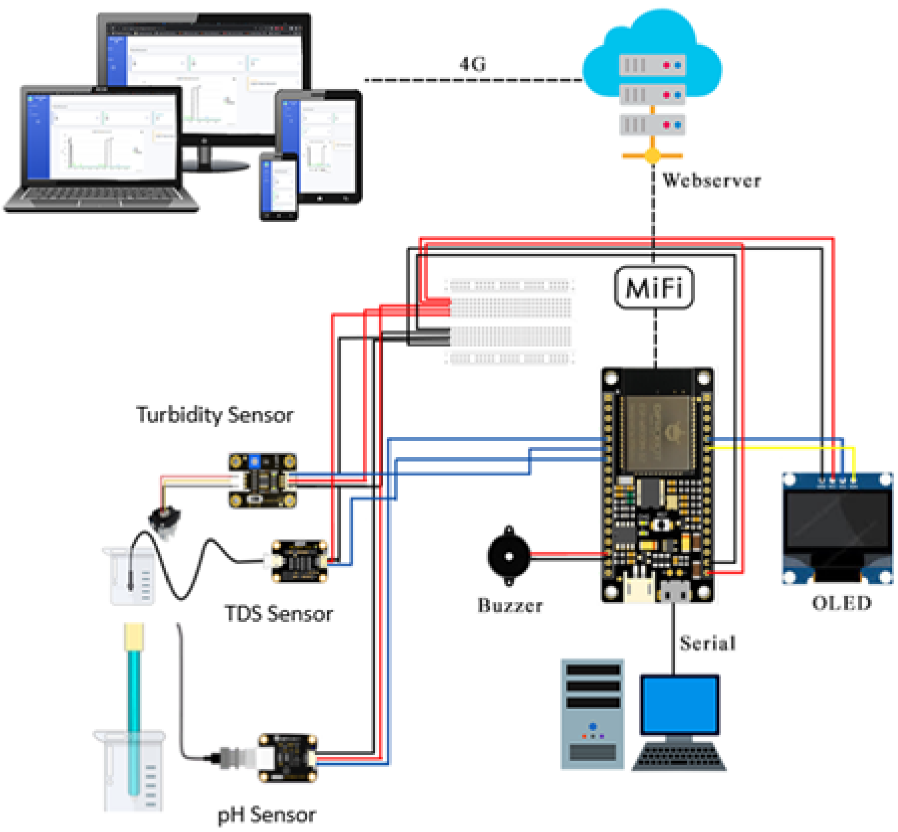


Figure 1. System design of water quality assessment monitoring system

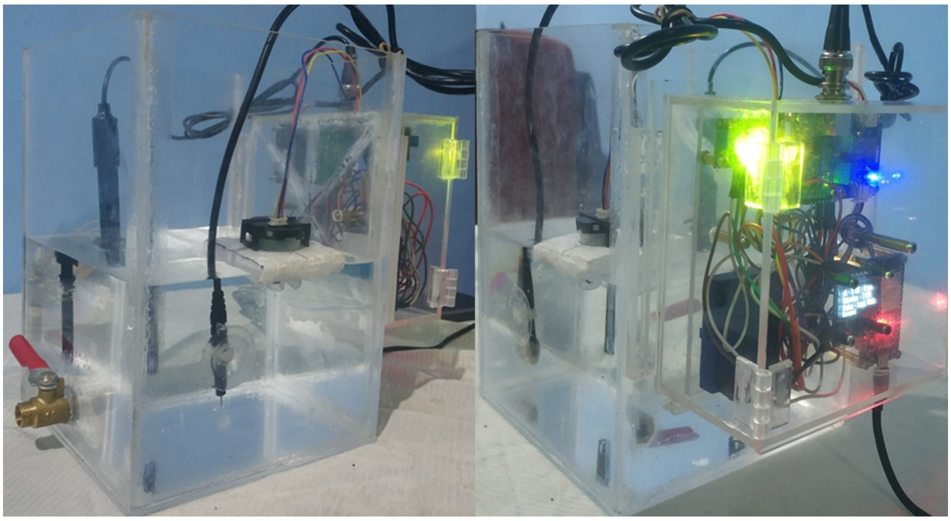


Figure 2. Prototype water quality assessment monitoring system

listed below the class name, while the methods (functions or operations) associated with the class are listed above the class name. Class diagrams are valuable tools for visualizing and designing the structure of a system, helping in communication among stakeholders and guiding the implementation process. They provide a high-level view of the system's architecture, emphasizing the relationships between classes and the behavior of objects within the system [32]. The class diagram in the system design model shown in Figure 4 displays the links between classes and provides a full explanation of each class. It will make the system's class structure easier to visualize. The sensor reads TDS, turbidity, and pH levels. Sensor readings are stored in the microcontroller and can be examined by the user to determine if water is safe to drink.

C. Experimental results

1) Development of decision support using Tsukamoto fuzzy

In the fuzzification process, there are several things that must be considered, including fuzzy variables, fuzzy sets, and domains as shown in Figure 5. These can obtain fuzzy membership values for each variable. This study uses 3 input variables and 1 output variable, including the TDS variable (total dissolved substances in water), pH, turbidity, and quality variables. Figure 5 can be explained as follows, the amount of dissolved substances in potable water has a maximum number of 1000 ppm as shown in Figure 5(a). The low membership function of TDS, denoted as $\mu_{\text{Low}}(b)$ in equation (1), and the high membership function of TDS,

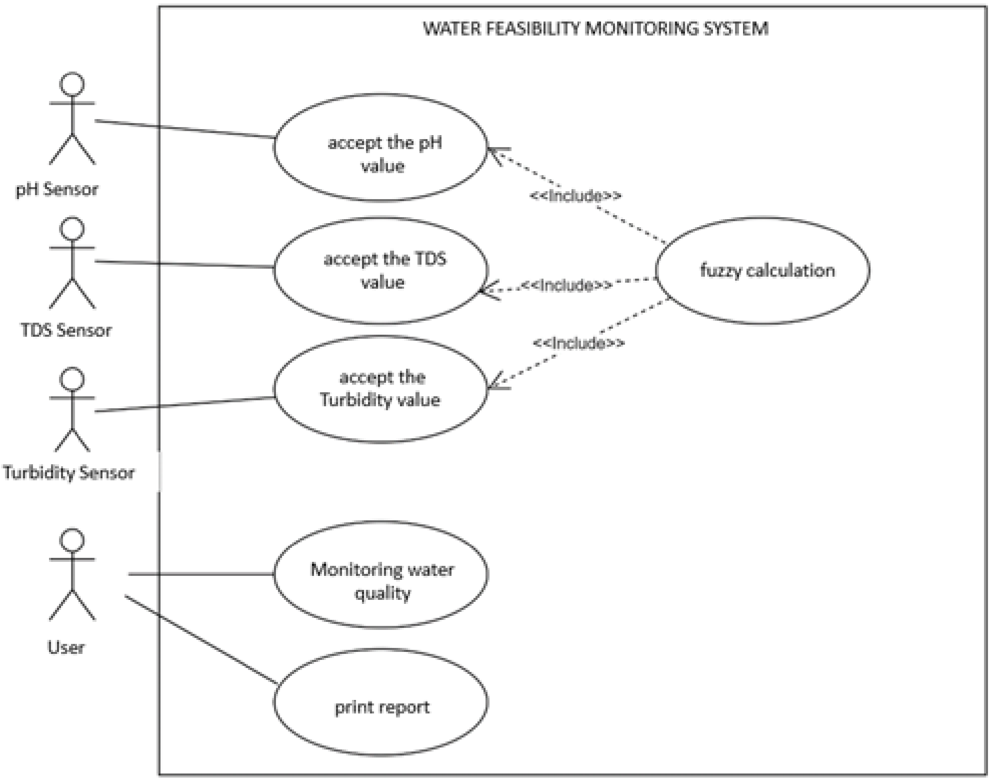


Figure 3. Use case diagram of water quality assessment monitoring system

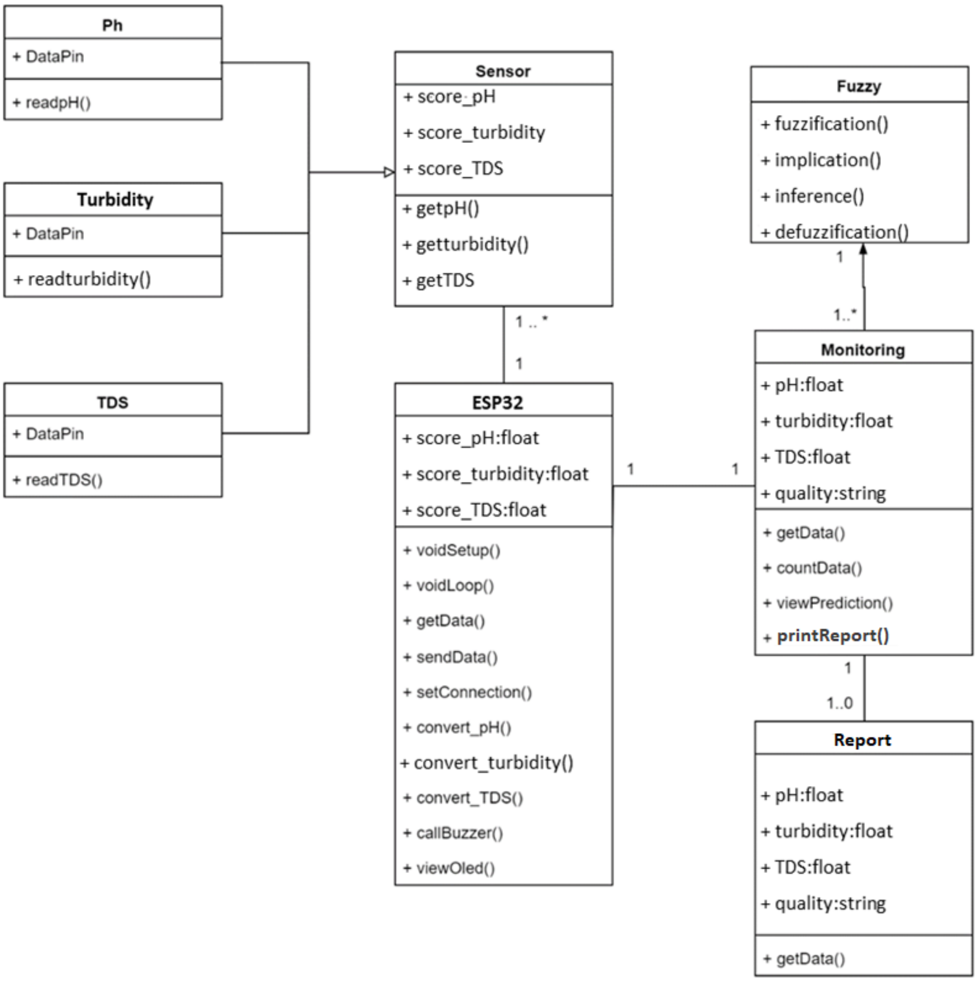


Figure 4. Class diagram of water quality assessment monitoring system

represented as $\mu_{\text{High}}(b)$ in equation (2) as follows,

$$\mu_{\text{Low}}(b) = \begin{cases} 1, & b \leq 500 \text{ ppm} \\ \frac{(1000-b)}{(1000-500)}, & 500 \text{ ppm} < b < 1000 \text{ ppm} \\ 0, & b \geq 1000 \text{ ppm} \end{cases} \quad (1)$$

$$\mu_{\text{High}}(b) = \begin{cases} 0, & b \leq 500 \text{ ppm} \\ \frac{(b-500)}{(1000-500)}, & 500 \text{ ppm} < b < 1000 \text{ ppm} \\ 1, & b \geq 1000 \text{ ppm} \end{cases} \quad (2)$$

The amount of turbidity in potable water has a maximum number of 5 NTU as shown in Figure 5(b) with the low membership function ($\mu_{\text{Low}}(b)$) in equation (3) and high membership function ($\mu_{\text{High}}(b)$) in equation (4) as follows,

$$\mu_{\text{Low}}(b) = \begin{cases} 1, & b \leq 4 \text{ NTU} \\ \frac{(5-b)}{(5-4)}, & 4 \text{ NTU} < b < 5 \text{ NTU} \\ 0, & b \geq 5 \text{ NTU} \end{cases} \quad (3)$$

$$\mu_{\text{High}}(b) = \begin{cases} 0, & b \leq 4 \text{ NTU} \\ \frac{(b-4)}{(5-4)}, & 4 \text{ NTU} < b < 5 \text{ NTU} \\ 1, & b \geq 5 \text{ NTU} \end{cases} \quad (4)$$

In potable water, the pH level ranges from a minimum to a maximum of 6.5 to 8.5, as depicted in Figure 5(c) with the membership functions of acid ($\mu_{\text{Acid}}(a)$) in equation (5), the membership functions of neutral ($\mu_{\text{Neutral}}(a)$) in equation (6), and the membership functions of base ($\mu_{\text{Base}}(a)$) in equation (7) as follows,

$$\mu_{\text{Acid}}(a) = \begin{cases} 1, & a \leq 6.5 \\ \frac{(7-a)}{(7-6.5)}, & 6.5 < a < 7 \\ 0, & a \geq 7 \end{cases} \quad (5)$$

$$\mu_{\text{Neutral}}(a) = \begin{cases} 0, & a \leq 6.5 \\ \frac{(a-6.5)}{(7-6.5)}, & 6.5 < a < 7 \\ \frac{(9.5-a)}{(9.5-7)}, & 7 < a < 8.5 \\ 0, & a \geq 8.5 \end{cases} \quad (6)$$

$$\mu_{\text{Base}}(a) = \begin{cases} 0, & a \leq 7 \\ \frac{(a-7)}{(8.5-7)}, & 7 < a \leq 8.5 \\ 1, & a \geq 8.5 \end{cases} \quad (7)$$

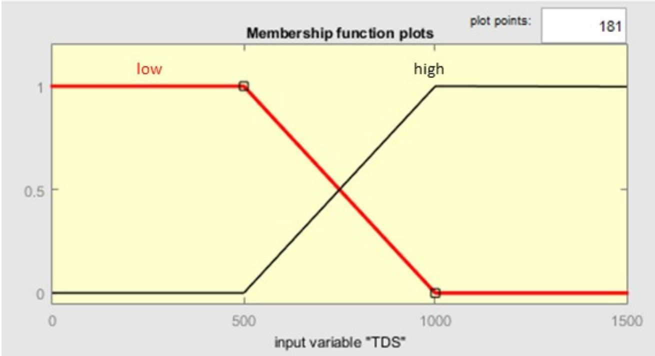
In this output, there are three categories of water: good, moderate, and unhealthy. A moderate category is water that can be used daily but not for foods such as bathing, washing, watering plants, etc. as shown in Table 3.

Table 3.
Membership function of quality membership function representation

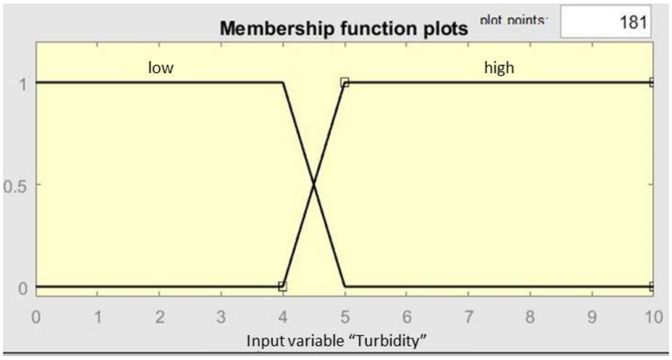
No.	Set	Membership Degree
1.	Good	0 – 5
2.	Moderate	3 – 7
3.	Unhealthy	5 – 10

The water quality membership function is illustrated in Figure 6. Good water quality is represented within the range of 0– 5, moderate water quality is depicted within the range of 3– 7, and unhealthy water quality is demonstrated within the variable range of 5– 10. The membership functions include feasible water ($\mu_{\text{feasible}}(z)$) in equation (8), feasible but not for consumption ($\mu_{\text{feasible not for consumption}}(z)$) in equation (9), and not feasible ($\mu_{\text{not feasible}}(z)$) in equation (10).

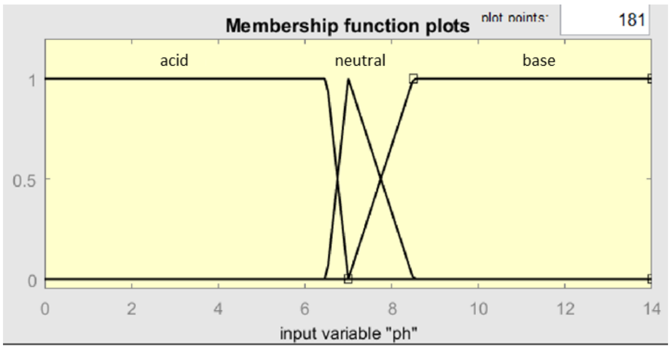
$$\mu_{\text{feasible}}(z) = \begin{cases} 1, & z \le 3 \\ \frac{(5-z)}{(5-3)}, & 3 < z < 5 \\ 0, & z \ge 5 \end{cases} \qquad (8)$$



(a)



(b)



(c)

Figure 5. Membership function of: (a) TDS; (b) turbidity; (c) pH

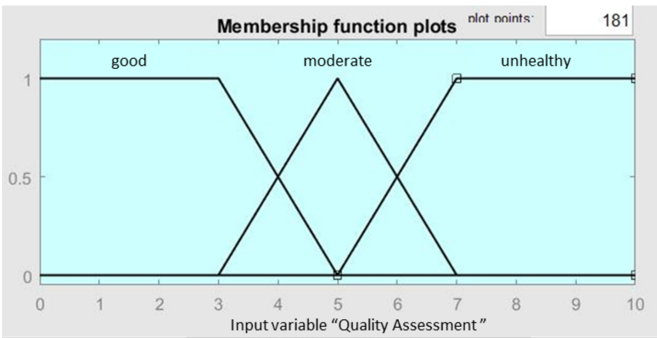


Figure 6. Quality membership function representation

$$\mu_{\substack{\text{feasible} \\ \text{not for consumption}}}(z) = \begin{cases} 0, & z \leq 3 \\ \frac{(z-5)}{(5-3)}, & 3 < z < 5 \\ \frac{(7-z)}{(7-5)}, & 5 < z < 7 \\ 0, & z \geq 7 \end{cases} \quad (9)$$

$$\mu_{\text{not feasible}}(z) = \begin{cases} 0, & z \leq 5 \\ \frac{(z-5)}{(7-5)}, & 5 < z < 7 \\ 1, & z \geq 7 \end{cases} \quad (10)$$

After the fuzzification process, the next process is the formation of fuzzy rules. These rules are used to express the relationship between input and output along with the number of variables and their sets. To make it easier to determine the amount and output, previously made a matrix for each set of water volumes against pH and turbidity as shown in Table 4. The membership value obtained from each variable is used to determine the implication function using the min method by the equation (11) as follows,

$$a_i = \mu_{A \cap B} = \min(\mu_{Ai}(x), \mu_{Bi}(y)) \quad (11)$$

The fuzzy implication in equation (11) represents the fuzzy intersection of two fuzzy sets A and B. In this equation, $\mu_{Ai}(x), \mu_{Bi}(y)$ are the membership values of the elements x and y in the fuzzy sets A and B, respectively. The min function is applied to these membership values, indicating the minimum membership value between the corresponding elements of A and B.

This equation essentially calculates the degree of membership in the intersection of sets A and B for a given element. It signifies that the membership in the intersection is determined by the minimum membership value of the corresponding elements in the individual sets A and B.

This implication function will be used to find the Z value. The defuzzification value can be obtained by calculating the Z value using the equation (12),

$$Z = \frac{\sum X_i a_i}{\sum a_i}, \; i = 1,2,3, \ldots \quad (12)$$

The defuzzification equation in equation (12) is a method used in fuzzy logic to convert fuzzy sets, which have membership values associated with different linguistic terms, into a crisp (non-fuzzy) value. Z is the crisp output or the defuzzified value. X_i represents i-th the linguistic term or value in the fuzzy set. a_i is the degree of membership associated with the i-th linguistic term. So, the process of defuzzification involves weighing each linguistic term by its degree of membership, summing these weighted values, and then dividing by the sum of the degrees of membership. This results in a single crisp value (Z), which is considered the "center" or representative value of the fuzzy set. To find out the linguistic variable, the output membership function is used and takes the largest value.

Table 4.
Fuzzy Rule of water quality

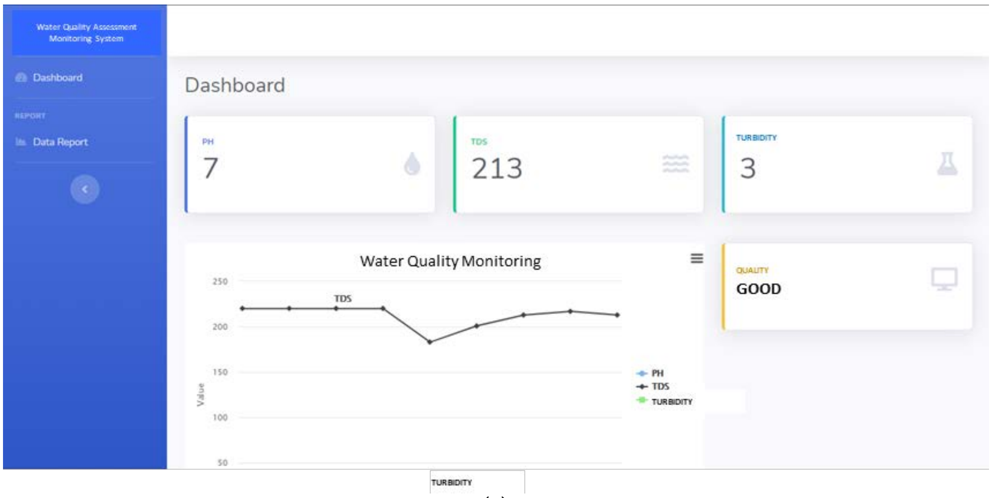
Rule	TDS	pH	Turbidity	Quality
1	Low	Acid	Low	Moderate
2	Low	Acid	High	Unhealthy
3	Low	Neutral	Low	Good
4	Low	Neutral	High	Unhealthy
5	Low	Base	Low	Moderate
6	Low	Base	High	Unhealthy
7	High	Acid	Low	Moderate
8	High	Acid	High	Unhealthy
9	High	Neutral	Low	Moderate
10	High	Neutral	High	Unhealthy
11	High	Base	Low	Moderate
12	High	Base	High	Unhealthy

2) Sensor calibration

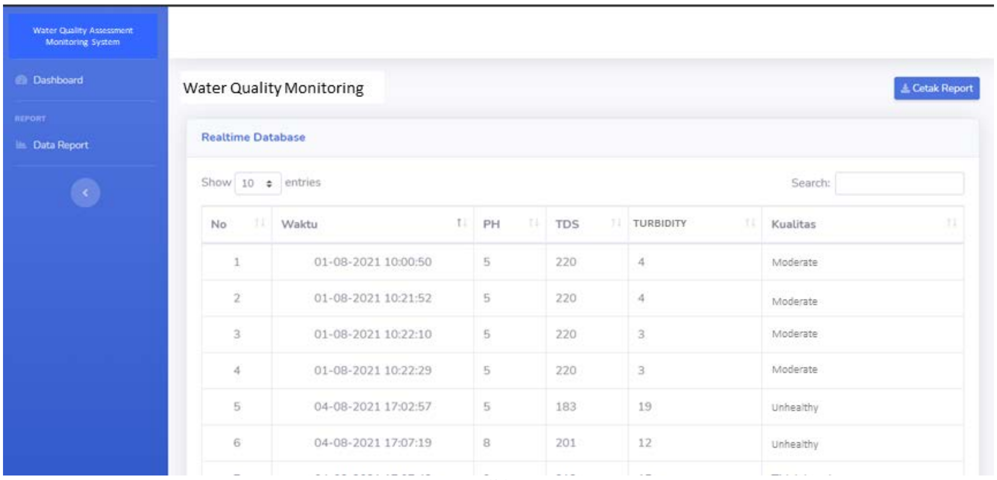
Sensors are essential components used in various fields, such as industrial manufacturing, environmental monitoring, medical devices, and scientific research. Calibration is the process of comparing the output of a sensor to a known reference or standard to ensure its accuracy and reliability. Factors like environmental conditions, aging, wear and tear, or exposure to contaminants can affect sensor performance. Calibration helps determine the sensor's true output by comparing it to a reference, allowing any inaccuracies or deviations to be identified and corrected.

The average error rate of the sensors that were used in this study was calculated by sensor calibration. The sensors evaluated included a temperature sensor, a TDS sensor, a pH sensor, and a turbidity sensor. The sensor reading error rate is the difference between the tool's reading output and the output of the manual measurement instrument. As indicated in Figure 7, manual measuring tools such as a pH meter, TDS meter, and turbidity meter are then utilized. Calibrate the pH sensor using a pH buffer solution with pH values of 6.8 and 4.01, respectively. Following that, the sensor's value is adjusted to the pH meter so that one gets the correct measurement results.

Figure 7. pH sensor calibration



(a)



(b)

Figure 8. (a) Interface: Dashboard; (b) Interface: Water quality monitoring

3) Web interface for water quality monitoring system

The implementation of the interface is a description of the display that is used directly by the user, so that they can interact and monitor the system. There are several parts that must be done, namely from determining the menu structure in the program, displaying input and output for each function that has been determined, that is described in Figure 8. Figure 8(a) is the dashboard of the web interface and Figure 8(b) is the data report. The dashboard provides real-time information about pH, TDS, and turbidity. The latest values for these parameters are displayed numerically, while historical data is presented graphically over a period of time. Additionally, the water quality level is indicated as either good, moderate, or unhealthy based on these values. The data report contains all recorded data, including the timestamp when each measurement was taken. Users can access data and have the option to print the report using the Print Report menu. Component testing on the prototype is carried out functionally and observed on the reaction of the component is, as shown in Table 5.

The sensor reading test is carried out by observing the movement of data changes in the water including TDS, turbidity, and pH which are stored in the database every 5 minutes. Figure 9 is a graphical representation of changes in water quality parameters over a specific period of time. Figure 9

Table 5.
Component test results

No.	Test Function	Way to Test	Expected Result	Result
1.	Connection with Wi-Fi	Restart component	Connected automatically	Valid
2.	Send data to the server	Connected to the internet and sensor reading	The water quality value in the OLED screen is the same as in the web	Valid
3.	Showing water quality data in the OLED screen in real-time	Turn on the component and sensor reading	The value can be seen on the screen in real-time	Valid
4.	Showing water quality data on the web	Make sure data is updated on the web in real-time	Data is updated when connected to the internet	Valid
5.	Report	Showing data from PDF file	Print out the data in PDF form	Valid

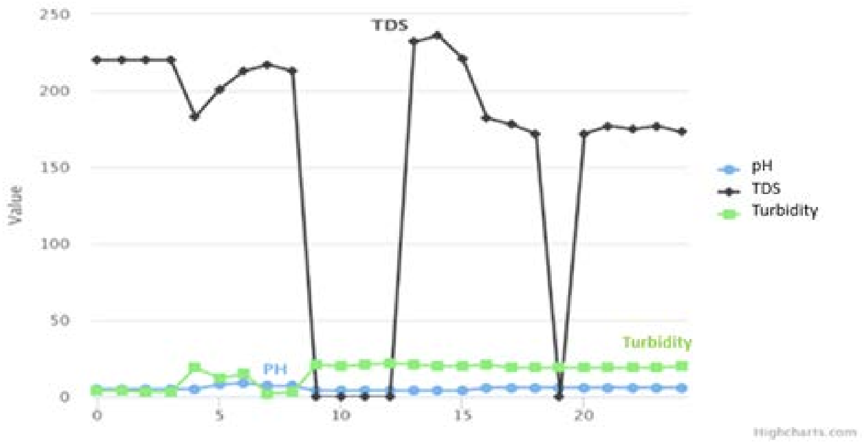


Figure 9. Chart of water quality assessment

uses different colored lines to represent the variations in three key parameters: Black color for TDS, blue for pH, and green for Turbidity. The data is calculated using Tsukamoto fuzzy to determine water quality.

IV. Conclusion

The design of an IoT-based water monitoring system has been completed by integrating the ESP32 MCU device, pH sensor, TDS sensor, turbidity sensor, OLED screen, buzzer, and the Tsukamoto fuzzy approach based on the results of study and testing. The system produces what is required in the form of water quality ratings of "good", "moderate", and "unhealthy." The results of sensor component testing show that by viewing and monitoring at different locations in real-time, accuracy and processing time may be improved.

Declarations

Author contribution

H. Fakhrurroja: Writing - Original Draft, Writing - Review & Editing, Conceptualization, Formal analysis, Investigation, Visualization, Supervision. E. T. Nuryatno: Review & Editing, Conceptualization, Supervision. A. Munandar: Review & Editing, Formal analysis, Resources, Software, Visualization. M. Fahmi: Writing - Original Draft, Writing - Review & Editing, Conceptualization, Investigation, Validation, Data Curation. N. A. Mahardiono: Formal analysis, Resources, Software, Visualization, Funding acquisition.

Funding statement

This research receive funding from Telkom University that supports the success of this research and development.

Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Additional information

Reprints and permission: information is available at https://mev.brin.go.id/.

Publisher’s Note: National Research and Innovation Agency (BRIN) remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

[1] Howard, G., Bartram, J., Williams, A., Overbo, A., Fuente, D., and Geere, J. A., "*Domestic water quantity, service level and health*," World Health Organization, 2020.

[2] El Gaayda, Jamila, *et al.*, "Optimization of turbidity and dye removal from synthetic wastewater using response surface methodology: Effectiveness of Moringa oleifera seed powder as a green coagulant," *Journal of Environmental Chemical Engineering*, 10(1), pp. 106988, 2022.

[3] Tomperi, J., Isokangas, A., Tuuttila, T., and Paalova, M., "Functionality of turbidity measurement under changing water quality and environmental conditions," *Environmental technology*, 43 (7), pp. 1093-1101, 2022.

[4] Habib, M. A., Rahman, M. T., Ferdous, J., Hoque, M. M., and Rasheduzzaman, M., "Farmers Perception and Salinity Driven Fresh Water Scarcity in Coastal Bangladesh," in *Towards Water Secure Societies: Coping with Water Scarcity and Quality Challenges*, pp. 173-182, 2021.

[5] Nel, T., Hardie, A. G., and Clarke, C. E., "Simple and multivariate linear regression models for pH conversion between measurement techniques," *Communications in Soil Science and Plant Analysis*, 53 (14), pp. 1797-1808, 2022.

[6] H. Fakhrurroja, C. Machbub, A. S. Prihatmanto, and A. Purwarianti, "Multimodal Interaction System for Home Appliances Control," *International Journal of Interactive Mobile Technologies (iJIM)*, 14 (15), 2020.

[7] D. Yadav, S. S. Chouhan, S. K. Vishvakarma, and B. Raj, "Application Specific Microcontroller Design for Internet of Things Based Wireless Sensor Network," *Sensor Letters*, 16 (5), pp. 374–385, 2018.

[8] A. Munandar et al., "Design and development of an IoT-based smart hydroponic system," in *2018 International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)*, pp. 582–586, 2018.

[9] M. Babiuch and J. Postulka, *Smart Home Monitoring System Using ESP32 Microcontrollers*. IntechOpen, pp. 82-101, 2020.

[10] E. Rijanto, E. Adiwiguna, A. P. Sadono, M. H. Nugraha, O. Mahendra, and R. D. Firmansyah, "A new design of embedded monitoring system for maintenance and performance monitoring of a cane harvester tractor," *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, 11(2), pp. 102–110, 2020.

[11] Chin, J., Callaghan, V., and Allouch, S.B., "The Internet-of-Things: Reflections on the past, present and future from a user-centered and smart environment perspective," *Journal of Ambient Intelligence and Smart Environments*, 11 (1), pp. 45-69, 2019.

[12] P. B. Bokingkito and L. T. Caparida, "Using Fuzzy Logic for Real-time Water Quality Assessment Monitoring System," in *Proceedings of the 2018 2nd International Conference on Automation, Control and Robots*, pp. 21–25, 2018.

[13] M. F. Johan, S. Abdullah, N. S. Mohamad Hadis, S. Omar, and A. Zanal, "Development and Implementation of Water Quality Assessment Monitoring (WQAM) System using the Internet of

Things (IoT) in Water Environment," *Journal of Electronic Voltage and Application (JEVA)*, 2 (2), pp. 1-12, 2021.

[14] Ainannisa, N., Silalahi, D. K., and Pangaribuan, P., Automatic Water Monitoring and Draining System Manufacturing for Aquascape Based on Water Quality Using Fuzzy Logic Method. in: Triwiyanto, T., Rizal, A., and Caesarendra, W., (eds) Proceeding of the 3rd International Conference on Electronics, Biomedical Engineering, and Health Informatics. *Lecture Notes in Electrical Engineering*, vol 1008. Springer, Singapore, 2023.

[15] Abdallah, Emad E., Eleisah, W., and Otoom, A. F., "Intrusion Detection Systems using supervised machine learning techniques: a survey," Procedia Computer Science, 201, pp. 205-212, 2022.

[16] Javaid, M., Haleem, A., Rab, S., Singh, R.P., and Suman, R., "Sensors for daily life: A review," *Sensors International 2*, p.100121, 2021.

[17] Nemčeková, K. and Labuda, J., "Advanced materials-integrated electrochemical sensors as promising medical diagnostics tools: A review," *Materials Science and Engineering*: C 120, p. 111751, 2021.

[18] Boyd, Claude E., *Water quality: an introduction*. Springer Nature, 2019.

[19] Uddin, Md. G., Nash, S., and Olbert, A. I., "A review of water quality index models and their use for assessing surface water quality," *Ecological Indicators*, 122, p. 107218, 2021.

[20] N. H. Omer, "Water quality parameters," *Water quality-science, assessments and policy*, vol. 18, pp. 1–34, 2019.

[21] I. L. Tarigan, "Physical, chemical, and biological analysis of drinking water quality in Tulungagung regency, East Java," *Medical Laboratory Analysis and Sciences Journal*, vol. 2, no. 1, pp. 23–30, 2020.

[22] V. Azteria and E. Rosya, "Drinking Water Quality of Water Refill Station in Gebang Raya Tangerang," *Jurnal Kesehatan Lingkungan (Journal of Environmental Health)*, vol. 15, no. 2, pp. 120-126, 2023.

[23] Kementrian Kesehatan Republik Indonesia, "Peraturan Menteri Kesehatan Nomor 2 Tahun 2023 tentang Peraturan Pelaksanaan Peraturan Pemerintah Nomor 66 Tahun 2014 tentang Kesehatan Lingkungan,".

[24] Oliva, D., et al., "Fuzzy simheuristics: Solving optimization problems under stochastic and uncertainty scenarios," *Mathematics*, 8 (12), p. 2240, 2020.

[25] V. Rexhepi and P. Nakov, "Condition assessment of power transformers status based on moisture level using fuzzy logic techniques," *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, 9 (1), pp. 17–24, 2018.

[26] H. Fakhrurroja, S. A. Mardhotillah, O. Mahendra, A. Munandar, M. I. Rizqyawan, and R. P. Pratama, "Automatic pH and Humidity Control System for Hydroponics Using Fuzzy Logic," in *2019 International Conference on Computer, Control, Informatics and its Applications (IC3INA)*, pp. 156–161, 2019.

[27] Permatasari, Y., Firdaus, M. R., Zuhdi, H., Fakhrurroja, H., and Musnansyah, A., "Development of IoT Control System Prototype for Flood Prevention in Bandung Area," *JOIV: International Journal on Informatics Visualization*, 7(3), pp. 1016-1021, 2023.

[28] Jerry, M. Mendel, *Uncertain rule-based fuzzy systems: Introduction and New Directions*. Springer, 2019.

[29] Höhle, Ulrich, "On the mathematical foundations of fuzzy set theory," *Fuzzy Sets and Systems*, 444, pp. 1-9, 2022.

[30] A. Jain and A. Sharma, "Membership function formulation methods for fuzzy logic systems: A comprehensive review," *Journal of Critical Reviews*, vol. 7, no. 19, pp. 8717–8733, 2020.

[31] Zhang, B., Li, C. -C., Dong, Y., and Pedrycz, W., "A comparative study between analytic hierarchy process and its fuzzy variants: a perspective based on two linguistic models," *IEEE Transactions on Fuzzy Systems*, 29 (11), pp. 3270-3279, 2020.

[32] Rumbaugh, J., Jacobson, I., and Booch, G., "The unified modeling language reference manual," Addison-Wesley, 1999.