Literasi Nusantara
vol.5 no. 2, March 2025 – June 2025
https://journal.citradharma.org/index.php/literasinusantara/index

ISSN 2746 8208 (Online)
ISSN 2746 3575 (Print)

Dissolved Oxygen Control with Variable Aerator based on Fuzzy Type 2 and IoT

Galih Novian Prasetyo*[1], Basuki Rahmat [2], Fetty Tri Anggraeny [3]

[1,2,3] Universitas Pembangunan Nasional Veteran, Jawa Timur, Surabaya, Indonesia
18081010150@student.upnjatim.ac.id* , basukirahmat.if@upnjatim.ac.id ,
fettyanggraeny.if@upnjatim.ac.id

DOI : *https://doi.org/10.56480/jln.v5i2.1570*

Received: April 21, 2025
Revised: May 13, 2025
Accepted: June 04, 2025

Abstract

In the era of rapidly evolving technology, energy efficiency in aquarium systems plays a crucial role in maintaining artificial ecosystem balance while optimizing electricity consumption. This study develops an automated aerator system based on the Internet of Things (IoT) using the Fuzzy Type-2 algorithm, allowing adaptive adjustment of aerator operation duration based on dissolved oxygen levels in water. A Dissolved Oxygen (DO) sensor is utilized to measure oxygen levels, while data is monitored in real-time through Ubidots as an MQTT server. This research aims to evaluate energy efficiency in automated aerator systems compared to conventional methods. Testing was conducted by comparing energy consumption and oxygen stability between IoT-based systems and manual systems. The results indicate that the Fuzzy Type-2 approach enhances energy efficiency, optimizes aerator performance, and maintains oxygen levels within an ideal range for fish survival. With this automated system, aquarium management becomes more energy-efficient and effective while opening broader opportunities for IoT technology integration in data-driven environmental management.

Keywords– *Internet of Things, Dissolved Oxygen, Aerator, Fuzzy Type-2, Ubidots*

1. Introduction

Water quality is an essential factor for the survival of aquatic biota, particularly in aquaculture and aquarium systems, which require careful monitoring of parameters such as temperature, pH, and dissolved oxygen (DO) levels. Fluctuations in these parameters outside the optimal range can cause stress to aquatic organisms, inhibit growth, and even lead to mass mortality. Manual water quality monitoring methods are often reactive, time-consuming, prone to human error, and unable to provide a quick response to sudden changes. This issue is compounded by inefficient energy consumption in efforts to maintain optimal conditions, such as in aeration systems. Therefore, the development of automatic and smart solutions for water quality monitoring and control becomes crucial to improve operational efficiency and the sustainability of aquatic environments.

Various studies have been conducted to address this problem through the implementation of Internet of Things (IoT) technology and intelligent systems. Musfita (2022) designed an IoT-based monitoring and control system for ornamental fish aquarium water quality to facilitate remote monitoring . A focus on specific parameters was also shown by Hanan (2022), who developed DO monitoring and control in aquascapes using IoT . Meanwhile, Wijaya et al. (2022) applied Sugeno Interval Type-2 Fuzzy Logic for water pH control, demonstrating the potential of using fuzzy logic in optimizing water quality parameters . Accurate measurement of dissolved oxygen using DO sensors has been studied by Yuliantari et al. (2021), who emphasized the importance of oxygen saturation . Amin et al. (2023) also analyzed the response of dissolved oxygen quality in smart water systems, highlighting the complexity of parameter interactions . In an effort to increase dissolved oxygen levels, aeration technology development continues, such as the design and construction of a microbubble generator for aquaculture by Zaskia Pratiwi et al. (2022) . Additionally, the application of digital moving average filters to DO sensors has also been explored to improve the accuracy of water quality measurements . Although previous studies have made significant contributions to the automation

Literasi Nusantara. vol.5 no. 2, March – June 2025
ISSN 2746 8208 (Online) and ISSN 2746 3575 (Print)

of monitoring and control, there is still a gap in integrating accurate real-time monitoring with smarter and more efficient adaptive control systems, particularly in optimizing aeration based on multiple water parameters.

Based on the background of the problem and the review of previous research, this study aims to design and implement an automatic IoT-based aquarium water quality monitoring and control system. This system will utilize temperature and Dissolved Oxygen (DO) sensors for real-time data acquisition and apply Fuzzy Type-2 Logic for aeration control optimization, with the ultimate goal of achieving energy efficiency and maintaining stable and optimal aquatic environmental conditions sustainably.

2. Method

This research utilizes fuzzy type 2 and IoT methods as the main approaches in developing an efficient automatic aerator control system. This comprehensive methodology begins with an extensive literature review and needs analysis, followed by the design and assembly of hardware and the development of programs/algorithms. The system then undergoes thorough iterative testing, concluding with the preparation of a report. The flow of this research methodology is illustrated in Figure 1.

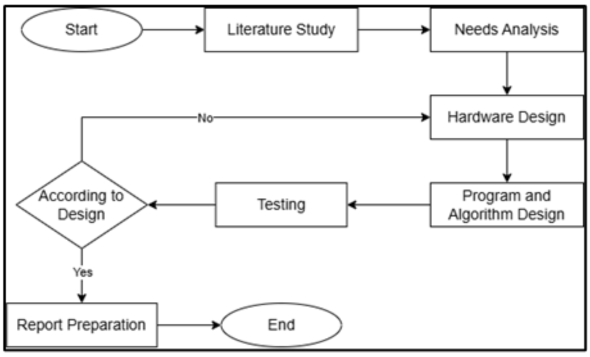

Figure 1 Research Methodology Flow.

Needs Analysis

Needs analysis is a crucial stage in designing an IoT-based automatic aerator control system using the fuzzy type-2 method. This stage aims to identify essential hardware and software to ensure the system can monitor aquarium conditions in real-time, process DO and temperature sensor data, and make automatic decisions using fuzzy logic to control the aerator. Identified hardware includes the aquarium as the primary environment, a microcontroller (ESP32), DO and temperature sensors, an aerator, and supporting components such as a PCB, calibration button, step-down converter, relay, and LCD. The software used includes Arduino IDE for programming, Web MQTT Ubidots for cloud data management, and Microsoft Excel for data analysis.

System Design

The design of this automatic aerator control system is structured to meet the research needs and objectives in maintaining dissolved oxygen (DO) levels and temperature stability in the aquarium. This system design focuses on stable and efficient integration, utilizing a Printed Circuit Board (PCB) as the basis for component unification.

The hardware structure is designed with an ESP32 microcontroller as the main processing unit that executes the fuzzy algorithm. For data sensing, the system uses a DO probe sensor and a temperature sensor directly connected to the ESP32. Additional input in the form of a push button is provided for manual calibration of the DO sensor. Monitoring results are displayed locally via an LCD LCM1602 IIC screen. Aerator control, as the actuator, is performed via an SSR-10DA Solid State Relay (SSR) that receives control signals from the ESP32. All electronic components are stably powered by a buck converter module. The complete system circuit is illustrated in Figure 2.

Literasi Nusantara. vol.5 no. 2, March – June 2025
ISSN 2746 8208 (Online) and ISSN 2746 3575 (Print)

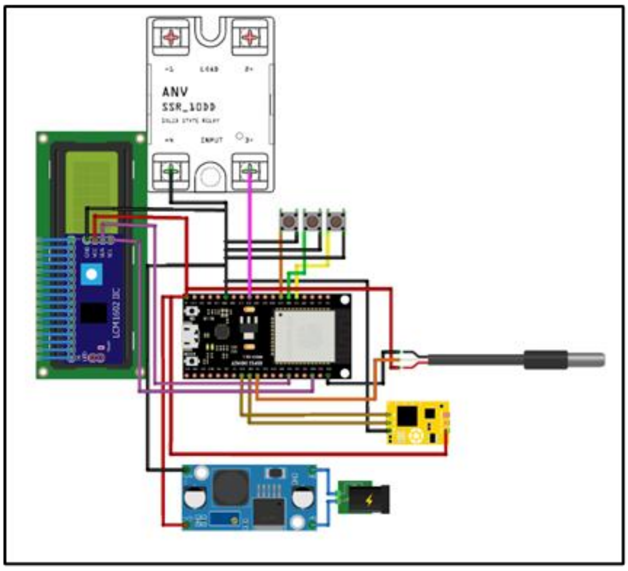

Figure 2 Hardware Structure.

Functionally, the system's workflow begins with the microcontroller reading input from the DO sensor and temperature sensor. This data is then processed using the Fuzzy Type-2 Method to generate control decisions. The results of this fuzzy processing will control the aerator's status (on or off) according to the aquarium's environmental conditions. In addition, the processed data is also sent to a broker server for remote real-time monitoring, and displayed on an LCD screen for local monitoring. This data flow and main components are summarized in Figure 3.

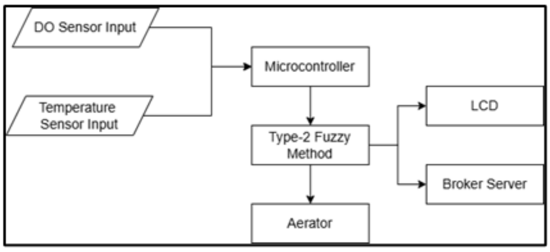

Figure 3 Device Workflow.

The system's algorithm, as depicted in Figure 4, starts with the initialization and real-time data acquisition from the DO (Dissolved Oxygen) and temperature sensors. This data is then processed using the Type-2 Fuzzy method, which allows the system to make adaptive decisions by considering measurement uncertainties. Based on the established fuzzy rules, the algorithm determines the operational conditions of the aerator. Following the control process, the processed data is also transmitted to a server for further monitoring and advanced analysis, ensuring data integrity and real-time availability.

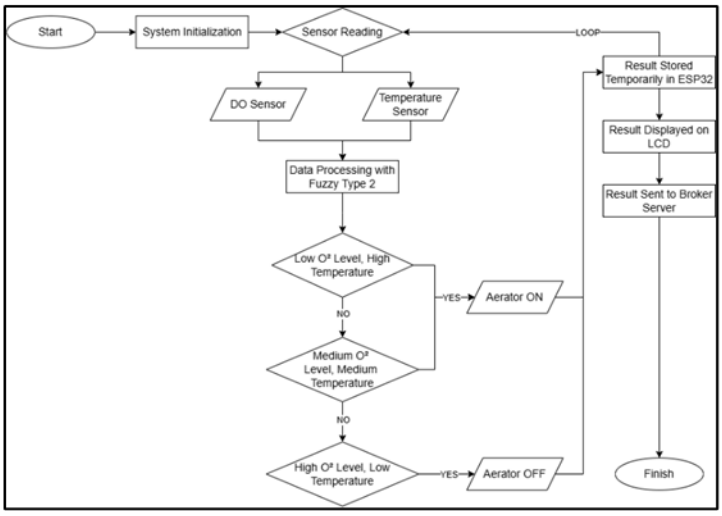

Figure 4 System Workflow.

Type-2 Fuzzy Control System

The Type-2 Fuzzy control system serves as the primary brain in aerator automation, specifically designed to effectively manage the inherent uncertainties in aquarium water quality measurements, such as temperature and dissolved oxygen (DO), to maintain an optimal environmental stability. This control process begins with fuzzification, where crisp values from the temperature sensor (range 21°C–33°C) and DO (range 0–11 mg/L) are converted into Type-2 fuzzy sets. This stage generates an interval of membership degrees (μL and μU) that reflect the Footprint of Uncertainty (FOU), representing uncertainty through mathematically defined linguistic categories. Subsequently, the system utilizes a rule base consisting of nine predefined IF-THEN rules, combining temperature and DO conditions to make decisions. Through fuzzy inference, these rules are evaluated based on the interval membership degrees. Finally, through type reduction and defuzzification, the fuzzy output is converted into a crisp decision to activate or deactivate the aerator, thereby ensuring an adaptive and optimal response to dynamic changes in the aquarium.

Literasi Nusantara. vol.5 no. 2, March – June 2025
ISSN 2746 8208 (Online) and ISSN 2746 3575 (Print)

Fuzzification

The fuzzification stage is the first step in a fuzzy control system that transforms crisp values (precise numerical values, such as sensor readings) into a fuzzy representation. In Type-2 Fuzzy, this process generates an interval of membership degrees [μL, μU], which reflects the uncertainty in a value's membership to a fuzzy set. This interval is formed by the Upper Membership Function (UMF) and Lower Membership Function (LMF), which respectively define the upper and lower bounds of the membership degrees.

The input variables in the fuzzy control system include Water Temperature (21°C – 33°C) and DO (0 mg/L – 11 mg/L). The membership functions for the Water Temperature and DO input variables, as well as for the Aerator output variable, use a combination of triangular or trapezoidal linear models. The UMF and LMF parameters for each fuzzy set are presented in the following tables. Visualizations of the membership curves for the Temperature and DO variables can be seen in Figure 5.

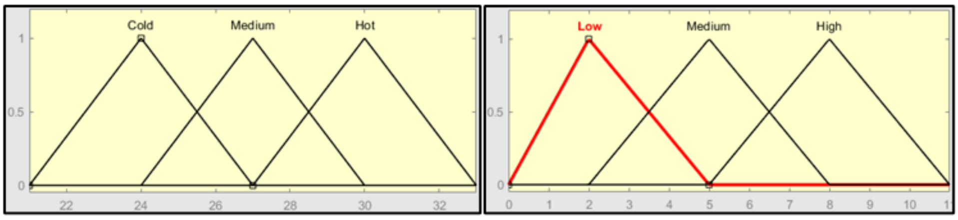

Figure 5 Temperature and DO Variables.

Table 1. Temperature Membership Function Parameters

Fuzzy Set	UMF (a, b, c)	LMF (a, b, c)
Cold	(21, 24, 27)	(22, 24, 26)
Medium	(24, 27, 30)	(25, 27, 29)
Hot	(27, 30, 33)	(28, 30, 32)

Table 2. DO Membership Function Parameters

Fuzzy Set	UMF (a, b, c)	LMF (a, b, c)
Low	(0, 2, 5)	(0.5, 2, 4)
Medium	(2, 5, 8)	(3, 5, 7)
High	(5, 8, 11)	(6, 8, 10)

Table 3. Aerator Membership Function Parameters

Fuzzy Set	UMF (a, b, c, d) or (a, b, c)	LMF (a, b, c, d) or (a, b, c)
Aerator On	(8, 10, 12, 12) (Trapezoid)	(9, 11, 12, 12) (Trapezoid)
Aerator Off	(12, 16, 20) (Triangle)	(13, 16, 19) (Triangle)

Rule Base

At this stage, the system evaluates the input conditions based on a predefined set of IF-THEN rules. These rules form the decision-making logic of the system, connecting the status of temperature and DO with the aerator control actions. Below is a list of the nine basic rules used in this fuzzy control system:

Table 4. Rule Base

No	IF Temperature	AND DO	THEN Aerator
1	Cold	Low	ON
2	Cold	Medium	ON
3	Cold	High	OFF
4	Medium	Low	ON
5	Medium	Medium	ON
6	Medium	High	OFF
7	Hot	Low	ON
8	Hot	Medium	ON
9	Hot	High	OFF

Literasi Nusantara. vol.5 no. 2, March – June 2025
ISSN 2746 8208 (Online) and ISSN 2746 3575 (Print)

Fuzzy Inference

In this inference stage, the fuzzy rules (rule base) are evaluated using the interval membership degrees obtained from the fuzzification process. The objective is to determine the "firing strength" of each rule. For Type-2 Fuzzy, this firing strength is also an interval, which will then be used to truncate the consequent (output) membership function of that rule.

Type Reduction and Defuzzification

Following the inference process, the output of the Type-2 Fuzzy system is still a Type-2 fuzzy set. Therefore, a Type-Reduction stage is required to convert it into a Type-1 fuzzy set. The Type-Reduction method will generate a crisp interval or a Type-1 fuzzy set that represents the collective output of all active rules. Subsequently, the defuzzification process is applied to convert this Type-1 fuzzy set into a single crisp value that can be directly used to control the aerator (e.g., a threshold value determining Aerator ON or OFF). Thus, the system can translate complex fuzzy processing results into clear and adaptive control actions.

System Testing

System testing is conducted to evaluate the performance, accuracy, and reliability of the fuzzy control system in regulating aquarium aeration based on Water Temperature and DO (Dissolved Oxygen) parameters. This process also analyzes the electrical power consumption generated by the system, aiming to ensure accurate operation under various environmental conditions and to optimize energy usage for maintaining optimal aquarium water quality. The evaluation also focuses on analyzing sensor reading errors and the system's effectiveness in maintaining optimal aquarium environmental conditions.

3. Result and Discussion

This chapter presents the implementation, performance test results of the IoT and Type-2 Fuzzy-based automatic aerator control system, and energy consumption analysis.

System Implementation

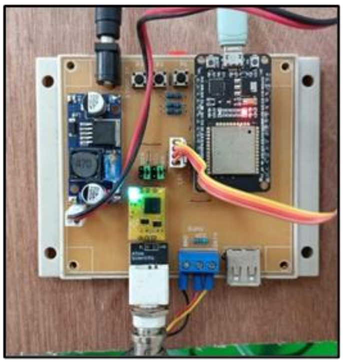

Figure 6. PCB Circuit.

The aerator control system is implemented through hardware assembly on a PCB that includes an ESP32 microcontroller, sensor connections (DO, Temperature), an aerator relay, and a communication module (USB for modem) as shown in Figure 6. The microcontroller is placed above the aquarium and connected in real-time with the sensors and the aerator via the relay, ensuring automatic control and environmental condition monitoring as depicted in the figure 7.

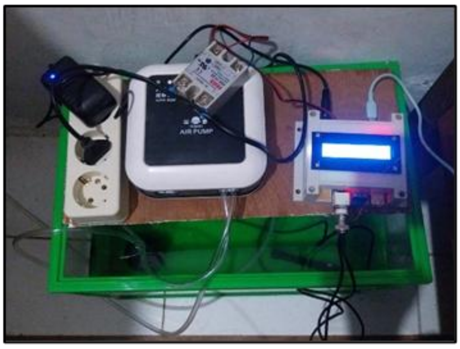

Figure 7. Microcontroller Placement on the Aquarium.

From the software perspective, the system was developed using Arduino IDE on an ESP32, implementing Type-2 fuzzy logic for the fuzzification, inference, and defuzzification processes based on Temperature and DO variables shown in Figure 5, Table 1 (temperature parameters), Table 2 (DO parameters), Table 3 (output parameters), and Table 4 (basic rules). Sensor data and system status are also displayed on an LCD and transmitted to the Ubidots cloud platform for remote monitoring, as shown in Figure 8.

Literasi Nusantara. vol.5 no. 2, March – June 2025
ISSN 2746 8208 (Online) and ISSN 2746 3575 (Print)

Figure 8. Ubidots Dashboard

System Test Results

System testing was conducted by comparing the Type-2 Fuzzy automation method with a conventional method (aerator running 24 hours non-stop), focusing on energy optimization and DO/water temperature stability.

Sensor test results indicated that the DO sensor showed a decrease in accuracy of about 16.8% (data outside the normal range of 0-13 mg/L) due to prolonged use, while the temperature sensor was relatively accurate with only 0.1% data error (outside the range of 21-33°C). Further evaluation of the DO sensor is needed to improve data accuracy.

The fuzzy control system operated according to its rules, with fuzzy values ranging from 10-20 and the aerator activating if the fuzzy value exceeded 12. Although there was approximately 11.7% inconsistent fuzzy data (value of 0) caused by sensor errors, the aerator function continued to maintain aquarium conditions as intended. Detailed monitoring of this can be seen in Figure 8, data on the Ubidots Dashboard.

Electricity consumption analysis showed that the aerator operated for 23.9% of the total time in a single day. With an aerator power of 6 watts, the automation system consumed 0.0344 kWh per day, significantly lower than the conventional method which consumed 0.144 kWh per day. This resulted in energy savings of 76.1%, demonstrating the system's high efficiency in maintaining optimal aquarium oxygen levels.

Discussion

The system successfully demonstrated adaptive performance in maintaining optimal aquarium water quality through Type-2 fuzzy control, showcasing its ability to handle uncertainties and dynamic environmental changes. Despite challenges with dissolved oxygen (DO) sensor accuracy, the system maintained stable water parameters, proving its robustness in real-world conditions. The remarkable energy saving of 76.1% highlights the system's efficiency, making it a cost-effective solution for aquarium maintenance while promoting sustainability. This achievement underscores the potential of intelligent automation in reducing operational expenses and minimizing resource wastage, which is crucial for both small-scale and large-scale aquatic ecosystems.

A key limitation of this research lies in the reduced accuracy of the DO sensor, which may compromise the precision of the fuzzy control system's input data. To enhance reliability, future studies could incorporate higher-precision sensors or implement sensor fusion techniques to improve data consistency. Additionally, further development could focus on adaptively optimizing the fuzzy rule base using machine learning algorithms to enhance the system's responsiveness to varying conditions. Long-term testing in diverse aquarium environments would also provide more comprehensive validation of the system's durability and effectiveness, ensuring its applicability across different scenarios. Addressing these limitations could significantly improve the system's performance and broaden its practical implementation in aquaculture and environmental monitoring.

This comparison involved monitoring the operational duration of the aerator, electrical power consumption, and the stability of Dissolved Oxygen (DO) levels in the water during the testing period. This testing aimed to evaluate the extent to which the automation system could optimize energy usage and ensure the aerator functions according to the oxygen requirements in the aquarium. With this approach, the developed IoT system is able to operate more adaptively, providing flexibility in aerator management, and improving efficiency in data-driven environmental condition monitoring.

Literasi Nusantara. vol.5 no. 2, March – June 2025
ISSN 2746 8208 (Online) and ISSN 2746 3575 (Print)

4. Conclusion

Based on the design, implementation, and testing of the IoT and Type-2 Fuzzy-based automatic aerator control system, several key conclusions can be drawn. The system was successfully implemented, demonstrating adaptive control of the aerator by responding to real-time dissolved oxygen (DO) and temperature readings from the aquarium, ensuring optimal water quality. Despite challenges such as a 16.8% data error from the aging DO sensor (Atlas Scientific 2019) and an 11.7% inconsistency in fuzzy data processing, the system maintained stable aquarium conditions, proving its robustness in handling sensor inaccuracies. Notably, the temperature sensor exhibited high precision, with only a 0.1% error, contributing to reliable environmental monitoring. Additionally, the system showcased remarkable energy efficiency, reducing the aerator's operational duration to just 23.9% of the total time, which translated to a 76.1% energy saving. This efficiency was evident in the daily power consumption, which decreased significantly from 0.144 kWh in conventional systems to only 0.0344 kWh, highlighting the system's potential for cost savings and sustainability in aquaculture management. These findings underscore the effectiveness of integrating IoT and Type-2 Fuzzy logic in automating and optimizing aquarium aeration systems while addressing real-world sensor limitations.

Based on the results and limitations of this research, several key recommendations emerge for enhancing the system's performance and expanding its capabilities in future studies. First, integrating more accurate and stable dissolved oxygen (DO) sensors, such as optical or galvanic sensors with built-in temperature compensation, would significantly improve measurement reliability, while implementing dynamic aerator control with variable oxygen output could enable finer adjustments to water conditions, enhancing both precision and energy efficiency. Second, further optimization of the Type-2 fuzzy logic algorithm should be pursued to better handle data anomalies and environmental fluctuations, alongside conducting extended real-world testing over several months to evaluate the system's long-term stability, sensor drift, and adaptive performance under varying conditions. Third, developing a more sophisticated and user-friendly interface such as a mobile or web application with real-time alerts, historical data visualization, and remote control functionality would greatly improve usability, while migrating to a more robust server platform (e.g., cloud-based IoT services with edge computing capabilities) could enhance data processing speed, storage, and security. Additionally, future research could explore integrating multi-sensor fusion techniques, machine learning for predictive maintenance, and expanding the system's application to larger-scale aquaculture environments to further validate its scalability and commercial viability. These improvements would collectively advance the system's reliability, usability, and adaptability for real-world deployment.

References

Amin, C., NP, S.D. and Amaru, K., 2023. Kajian respons kualitas dissolved oxygen pada sistem smart watering dan autopot akibat pengaruh perubahan suhu lingkungan Study of dissolved oxygen quality response in. *Jurnal Agrotek UMMAT*, *10*(2), pp.175-185. https://doi.org/10.31764/jau.v10i2.13347

Bautista, M. G. A. C., Palconit, M. G. B., Rosales, M. A., Concepcion II, R. S., Bandala, A. A., Dadios, E. P., & Duarte, B. (2022). Fuzzy logic-based adaptive aquaculture water monitoring system based on instantaneous limnological parameters. *Journal of Advanced Computational Intelligence and Intelligent Informatics*, *26*(6), 937-943. https://doi.org/10.20965/jaciii.2022.p0937

Dey, I., Pilli, S., & Ambati, S. R. (2024). Design of supervisory fuzzy control for enhanced energy saving in a sequencing batch reactor-based wastewater treatment plant. *Environment, Development and Sustainability*, 1-28. https://doi.org/10.1007/s10668-023-04363-x

Gu, Y., Li, Y., Yuan, F., & Yang, Q. (2023). Optimization and control strategies of aeration in WWTPs: A review. *Journal of Cleaner Production*, *418*, 138008. https://doi.org/10.1016/j.jclepro.2023.138008

Hanan, I. E. (2022). PEMANTAUAN DAN PENGENDALIAN DISSOLVED OXYGEN PADA AQUASCAPE BERBASIS INTERNET OF THINGS (Doctoral dissertation, UPN" VETERAN'JAWA TIMUR).

Li, D., Yang, J., Bai, Y., Du, Z., & Wang, C. (2024). Advances in dissolved oxygen prediction and control methods in aquaculture: a review. *at-*

Automatisierungstechnik, *72*(6), 499-517. https://doi.org/10.1515/auto-2023-0212

Li, D., Zou, M., & Jiang, L. (2022). Dissolved oxygen control strategies for water treatment: a review. *Water Science & Technology*, *86*(6), 1444-1466. https://doi.org/10.2166/wst.2022.281

Musfita. 2022. RANCANG BANGUN SISTEM INFORMASI MONITORING DAN KONTROLING KUALITAS AIR PADA AKUARIUM IKAN HIAS AIR TAWAR MENGGUNAKAN INTERNET OF THINGS. Universitas Hasanuddin.

Rengga Tisna, D., Maharani, T., Komunitas, A., & Pacitan, N. (2022). Penerapan Digital Moving Average Filter pada Sensor Dissolved Oksigen untuk Mengukur Kualitas Air. Journal of Electrical, Electronic, Mechanical, Informatic and Social Applied Science, 1(2), 32–40. https://doi.org/10.58991/EEMISAS.V1I2.13

Shakhray, E. A., Lubentsov, V. F., Lubentsova, E. V., Masyutina, G. V., & Shtyrkhunova, N. A. (2022, June). Automatic Aeration Mode Control System with Fuzzy Correction of the Dissolved Oxygen Concentration Controller. In *International Conference on Applications in Electronics and Computing Systems* (pp. 166-175). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-20631-3_18

Wijaya, D. C. M., Rahmat, B., & Puspaningrum, E. Y. (2022). Sistem Pendukung Keputusan Berbasis Interval Type-2 Fuzzy Sugeno Pada Kendali pH Air. InComTech : Jurnal Telekomunikasi Dan Komputer, 12(3), 226. https://doi.org/10.22441/incomtech.v12i3.15453.

Yuliantari, R., Yuliantari, R. V., Novianto, D., Hartono, M. A., & Widodo, T. R. (2021). Pengukuran Kejenuhan Oksigen Terlarut pada Air menggunakan Dissolved Oxygen Sensor. Jurnal Fisika Flux: Jurnal Ilmiah Fisika FMIPA Universitas Lambung Mangkurat, 18(2), 101–104. https://doi.org/10.20527/flux.v18i2.9997

Zaskia Pratiwi, C., Mawardi, I., Adi Nugroho, F., Studi Mekanisasi Perikanan, P., & Kelautan dan Perikanan Sidoarjo, P. (2022). RANCANG BANGUN MICROBUBBLE GENERATOR (MBG) UNTUK MENINGKATKAN OKSIGEN TERLARUT (DO) PADA BUDIDAYA PERIKANAN. Chanos Chanos, 20(1), 45–50. https://doi.org/10.15578/chanos.v20i1.11160