Water Quality Monitoring System Using pH and Temperature Sensors

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***Abstract*— AquaNest is an IoT-based water quality monitoring system for ornamental ponds and aquariums, aligned with SDG 14: Life Below Water. It monitors pH, temperature, and dissolved oxygen in real time. If values fall below safe limits, the system activates an aerator automatically. Users can also control the aerator manually via a mobile app. AquaNest helps maintain aquatic health and supports sustainable water ecosystems.**

Keywords—AquaNest, water quality, IoT, automatic aerator, aquarium, pond, SDG 14.

I. INTRODUCTION (*HEADING 1*)

The water quality of the aquatic ecosystem must be monitored to make sure it is sustainable and the organisms inside would be healthy. Some key indicators to see whether the water quality shows any harm to itself and the organisms are the water quality's pH, dissolved oxygen, as well as the temperature [1].

Internet of Things technologies was used for this project as its real-time and automated monitoring systems are more accessible and cost-effective. By having a hardware system that is connected to a mobile application using the Internet, monitoring water quality becomes less time-consuming and prone to human error unlike conventional monitoring techniques [2].

This project utilizes an ESP32 microcontroller, sensors for pH and temperature, and an aerator to control the oxygen level. To detect the oxygen level, instead of using an actual sensor that detects it which would be costly, it is calculated depending on the pH and temperature values. All of the collected data that is continuously being read by the system is transmitted to the Firebase real-time database. The mobile application is developed to view the water quality metrics from the database.

This project presents a low-cost, advanced, real-time controlling system that can improve water quality management. With its remote accessibility, automated response, and efficient data communication, this technology allows the user to monitor water systems without needing to spend more money and time analyzing the quality of that system. This monitoring system serves as a solution for domestic water systems or ecosystems which require minimal user intervention.

II. LITERATURE REVIEW

A. Concepts

a. pH

The pH level is a critical parameter in aquatic environments, representing the concentration of hydrogen ions in water. It is measured on a scale ranging from 0 (most acidic) to 14 (most alkaline), with 7 being neutral [3]. In freshwater aquaculture and aquarium systems, a pH range between 6.5 and 8.5 is generally considered optimal for most species of fish and aquatic plants [4]. Deviations outside this range can lead to physiological stress, inhibit growth, and increase vulnerability to disease. pH fluctuations may result from organic waste accumulation, photosynthetic activity, or the use of certain chemicals or fertilizers.

Studies have shown that maintaining a stable pH is essential for buffering capacity, which helps aquatic systems resist changes in acidity caused by respiration, feeding, or decomposition processes [5]. In unmanaged environments, sudden drops in pH, known as pH crashes, can result in mass fish deaths, especially in closed systems like ornamental ponds and aquariums.

b. Temperature

Temperature is one of the most influential physical parameters in aquatic ecosystems, shaping both the biological and chemical processes within the water. It directly affects the metabolic rates of aquatic organisms—higher temperatures typically increase metabolism, growth rates, and oxygen consumption, while lower temperatures slow these processes. Each aquatic species has a preferred temperature range, and prolonged exposure to temperatures outside this range can lead to stress, weakened immune response, or even death [6].

In natural and artificial aquatic systems, temperature also determines the seasonal behavior of organisms, including spawning, migration, and feeding patterns. Sudden or extreme temperature fluctuations can disrupt these behaviors and destabilize the ecological balance of the system. Furthermore, water temperature influences the rate of biochemical reactions, the solubility of nutrients, and the activity of microbial communities involved in nutrient cycling and organic matter decomposition [6].

Because of its far-reaching effects, maintaining a stable and appropriate temperature is critical, especially in controlled environments like aquaculture systems and ornamental ponds where natural buffering is limited. Regular monitoring of water temperature ensures optimal living conditions and helps prevent stress-related issues among aquatic life [6].

c. Dissolved Oxygen

Dissolved oxygen (DO) is the amount of free, non-compound oxygen present in water and is essential for the respiration of aquatic organisms, including fish, invertebrates, and aerobic bacteria [7]. DO is influenced by various factors such as temperature, atmospheric pressure, salinity, and biological activity. Generally, cold water holds more oxygen than warm water.

DO levels are a key indicator of water quality. According to aquatic environmental guidelines, DO concentrations below 5 mg/L can stress aquatic life, and levels below 2 mg/L are considered hypoxic and potentially lethal [8]. Low DO conditions, known as oxygen depletion, often result from overfeeding, overstocking, algal blooms, or lack of aeration.

Aquatic systems, especially closed ones, require proper aeration to maintain DO levels. Biological oxygen demand (BOD), caused by the decomposition of organic matter, also reduces available oxygen, necessitating the use of aerators or mechanical systems that increase oxygen diffusion into water [7].

d. Relation Between pH, Temperature, and Dissolved Oxygen

The relationship between pH, dissolved oxygen (DO), and temperature is both biochemical and environmental. Photosynthesis and respiration are two major processes that link these parameters [9]. During daylight hours, aquatic plants and algae perform photosynthesis, consuming carbon dioxide (CO_2) and producing oxygen. This increases DO levels and raises pH, as the reduction in CO_2 (which forms carbonic acid in water) makes the water less acidic. At night, photosynthesis ceases, respiration becomes dominant, DO is consumed, and CO_2 accumulates—leading to a decrease in pH [10].

Temperature plays a critical role in this dynamic. Warmer water holds less dissolved oxygen, and high temperatures can accelerate metabolic and microbial activity, increasing oxygen demand and CO_2 production [12]. This can exacerbate declines in DO and pH, particularly during the night. Conversely, cooler water can retain more oxygen and slow down biological activity, helping to stabilize both pH and DO levels.

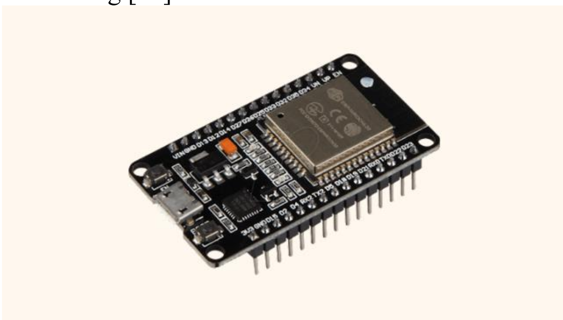
In aquaculture systems, low DO is often associated with more acidic (lower pH) conditions due to the buildup of organic waste and CO_2 [9]. Additionally, elevated temperatures can worsen these conditions by further reducing oxygen availability. Therefore, real-time monitoring of temperature, along with DO and pH, is essential for early detection of unfavorable conditions and maintaining a healthy aquatic environment.

Researchers emphasize that the dynamic interaction among DO, pH, and temperature is especially important in small-scale, closed ecosystems such as ornamental ponds or aquariums, where natural buffering capacity is limited [11]. Neglecting this relationship can lead to poor water quality, increasing the risk of stress, disease, or death among aquatic organisms.

B. Components

a. ESP32

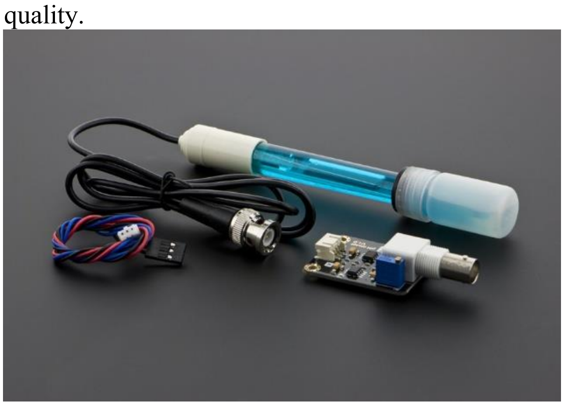
The ESP32 is a low-cost, low-power system on a chip (SoC) with integrated Wi-Fi and Bluetooth capabilities. It is widely used in IoT applications due to its versatility, power efficiency, and support for multiple analog and digital interfaces [13]. In the AquaNest system, ESP32 serves as the central microcontroller, collecting data from sensors, processing it, and communicating with a cloud database (Firebase) as well as local displays (LCD). Its dual-core processor allows for multitasking, such as handling sensor inputs while maintaining network connections, which is crucial for real-time monitoring [13].



Picture 2.1 ESP32 [14]

b. pH Sensor

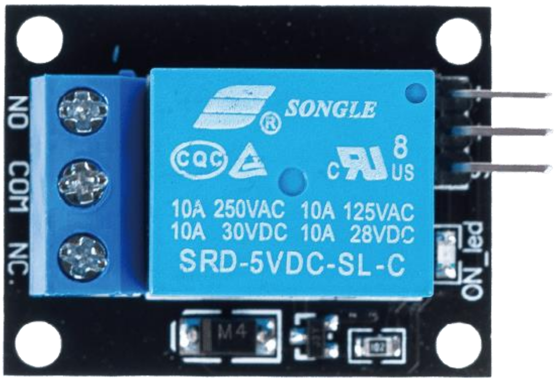
A pH sensor, typically based on a glass electrode and reference system, measures the hydrogen ion activity in water [3]. In AquaNest, it is used to provide continuous and accurate readings of water pH. The sensor interfaces with the ESP32 via an analog-to-digital converter or dedicated signal conditioning board. Regular calibration and maintenance are essential to ensure precision, especially in aquatic environments where biofouling or mineral deposits can affect the sensor's reliability [3]. The temperature sensor communicates with the ESP32 to adjust system responses, such as alerting users if water becomes too warm (which lowers DO levels) or too cold (which may slow fish metabolism). Integrating temperature monitoring with DO and pH offers a more holistic view of water quality.



Picture 2.2 pH Sensor [15]

c. Relay

The relay module acts as a digital switch controlled by the ESP32 to turn high-power devices—such as the aerator—on or off [16]. It is especially useful in cases where automated responses are needed, for example, when DO or pH readings cross predefined safety thresholds. The relay ensures electrical isolation between the microcontroller and high-voltage components, enhancing safety and reliability [16].



Picture 2.3 Relay Module 5V [17]

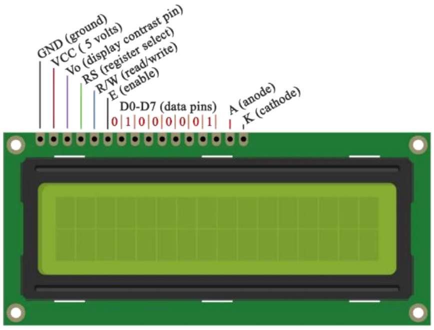
d. Temperature Sensor
Temperature affects both the chemical and biological processes in water, including the solubility of oxygen or pH readings cross predefined safety thresholds [18]. The relay ensures electrical isolation between the microcontroller and high-voltage components, enhancing safety and reliability.

Picture 2.4 Temperature Sensor [19]

e. Aerator
The aerator is a mechanical device used to increase dissolved oxygen levels in water by promoting air-water mixing. It is activated automatically by the relay when the DO or pH values fall below safe levels. By injecting oxygen into the water, it helps stabilize the aquatic environment, particularly during nighttime when DO levels typically drop due to plant respiration [20]. Aerators are critical in preventing hypoxic conditions in densely stocked ponds and aquariums.

Picture 2.5 Aerator [21]

f. LCD
The LCD display provides real-time visual feedback of water parameters such as pH and temperature. It is useful for on-site monitoring, especially when a mobile application is unavailable or disconnected. A 16x2 character LCD connected to the ESP32 via I2C protocol allows compact and energy-efficient data display.



Picture 2.6 LCD [22]
https://howtomechatronics.com/tutorials/arduino/lcd-tutorial/#google_vignette

g. Firebase
Firebase is a cloud-based platform by Google that offers real-time database and cloud storage services. In AquaNest, Firebase is used to store and retrieve sensor data in real time. It enables remote monitoring and logging of water quality metrics, and can also support alert systems and data visualization on the mobile application. Firebase's integration with ESP32 is lightweight, making it ideal for embedded systems.

h. Android Studio
Android Studio is the official IDE for Android app development. It is used to design and build the mobile interface of AquaNest, where users can view live sensor data and manually control the aerator. The app communicates with Firebase to retrieve data and send control commands, creating an interactive user experience that enhances control and awareness of water conditions.

III. Methodology

A. *Hardware Implementation*

The hardware system is built around the ESP32 microcontroller, chosen for its integrated Wi-Fi capabilities suitable for IoT applications. It reads the values at regular intervals. The pH sensor is used to measure water acidity. The temperature sensor is used to check thermal conditions. The LCD is displayed to show real-time readings locally. The aerator, when turned on, is used to increase oxygen in the water. To regulate it's usage and allow it to be switched on or off, a relay module is connected to it.

B. *Data Communication and Cloud Integration*

Firebase Realtime Database is used to store sensor data readings and control commands. The updated pH and temperature values are sent by ESP32 to the Firebase cloud. The status of the Aerator is also synchronized for the communication between the hardware and the mobile application to work.

C. *Mobile Application Development*

An Android application is developed using Android Studio with Kotlin. It retrieves sensor data from Firebase and displays the current pH, temperature, and an inferred oxygen level status. The application offers two control options:

- Manual Mode: Enables users to toggle the aerator on or off directly.
- Auto Mode: When enabled, the system autonomously controls the aerator based on predefined thresholds for pH and temperature.

D. *System Testing*

Both manual and automatic system controls are evaluated in how accurate the sensor readings are and the responsiveness of real-time data in the mobile application. Specifically, the system is analyzed based on it's timing, consistency, and correctness. The aerator's activation is also analyzed based on those aspects on both control mode.

IV. Discussion

A. *Utilization of pH Sensors to Predict Oxygen Content in Solutions*

pH sensors can be used indirectly to estimate oxygen levels in aqueous solutions because dissolved oxygen (DO) affects water's pH through chemical equilibria. Oxygen influences the redox state of the solution and can promote the formation of acidic or basic species. For instance, in natural waters, dissolved oxygen facilitates the oxidation of ammonia to nitrate (nitrification), which produces hydrogen ions:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$$

The production of H^+ lowers the pH, so an increase in DO can correspond to a decrease in pH. Conversely, in low-oxygen (anoxic) conditions, microbial reduction processes consume H^+, raising the pH.

Thus, monitoring pH trends using a pH sensor along with knowledge of the solution's chemistry allows for indirect estimation of oxygen levels, particularly in systems like aquaculture, wastewater, or natural water bodies.

B. *Effect of Temperature on Solubility and Indirect Detection of Dissolved Oxygen (DO) via Temperature Sensor*

The solubility of oxygen in water is a phenomenon that is influenced by temperature. When the water temperature increases, the ability of water to dissolve oxygen (O2) increases. Based on Le Chatelier's principle: 'Increased temperature will shift the balance towards the release of gas into the air phase which reduces solubility. This relationship can be expressed through Henry's solubility formula:

$$\boldsymbol{C = K_h . P_{O2},}$$

C = Dissolved oxygen concentration (mg/L)

K_h = Henry's constant (the higher the temperature, the smaller the value of K_h)

P_{O2} = partial pressure of oxygen

When the K_h value is at a temperature of 15°C, water can dissolve about 10.08 mg/L of oxygen, while at a temperature of 30°C it is only about 7.56 mg/L.

This relationship can be modeled empirically, with the equation:

$$\boldsymbol{C_{O_2}(T) = C_0 . e^{-kt}}$$

$\boldsymbol{C_{O_2}(T)}$ = Dissolved oxygen content at temperature

$\boldsymbol{C_0}$ = Solubility of oxygen at the reference temperature

K = Constant

T = Temperature

By collecting temperature data using a temperature sensor, the temperature value can be fed into an empirical model to estimate dissolved oxygen levels without the need to use a DO sensor directly. This method is very useful in cost-effective IoT-based environmental monitoring systems or in systems where direct DO measurements are difficult to perform continuously.

C. *The Role of This App in Maintaining Sustainable Water Quality*

This application plays a crucial role in maintaining water quality by utilizing a combination of two environmental sensors temperature and pH to estimate dissolved oxygen (DO) levels indirectly. While DO sensors provide direct measurements, this approach leverages scientifically established correlations between temperature, pH, and oxygen solubility to infer oxygen concentrations in water at a lower cost and with greater energy efficiency.

Rising water temperatures reduce oxygen solubility, while pH levels reflect the biochemical processes that either consume or generate oxygen, such as nitrification and photosynthesis. By continuously monitoring these parameters, the application dynamically calculates an estimated DO value using pre-calibrated models or empirical equations.

This estimated DO value becomes the basis for evaluating whether the aquatic environment such as an aquarium is capable of supporting a healthy ecosystem. Adequate dissolved oxygen is critical for the survival of fish, aquatic plants, and beneficial microorganisms.

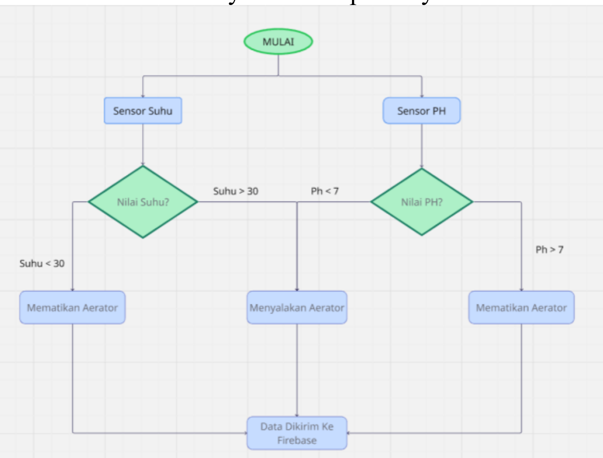
To ensure sustainability, the application includes an automatic aeration control feature. When the estimated DO level drops below a predefined threshold, the system automatically activates the aerator to replenish oxygen levels. Once the oxygen returns to safe levels, the aerator is turned off to conserve energy. This automation allows for real-time response to environmental changes, supporting the long-term balance and health of the aquatic ecosystem without requiring constant user intervention.

D. *How Internet Of Things Devices Work*

This IoT-based device is designed to monitor and maintain water quality by utilizing two main environmental sensors: a pH sensor and a temperature sensor. These sensors are used to indirectly estimate the level of dissolved oxygen (DO) in water, based on the well established correlation between oxygen solubility, pH, and temperature.

When the estimated DO level drops below a critical threshold determined through temperature and pH readings the system automatically activates an aerator to increase oxygen levels in the water. This real-time response mechanism helps prevent hypoxic conditions and supports aquatic life in closed ecosystems, such as aquariums.

The entire system is controlled by an ESP32 microcontroller, which collects sensor data, performs oxygen level estimation, and controls the aerator based on predefined conditions. Additionally, a LCD display is integrated into the device to provide real-time visualization of the water's pH level, temperature, and the current status of the aerator (ON/OFF). This enhances user interaction and system transparency.



E. How The Application Works

The AquaNest application provides users with a seamless interface to control and monitor the water quality management system. The app integrates both automatic and manual control modes for operating the aerator, offering flexibility and user autonomy.

- Automatic Mode:
  When enabled, the system continuously monitors pH and temperature data to estimate dissolved oxygen (DO) levels. Based on predefined thresholds, the aerator activates or deactivates automatically. For example, if the oxygen level is inferred to be too low (Ph < 7 and Temperature > 30), the aerator turns ON to replenish oxygen. Once adequate oxygen conditions are restored, the system turns the aerator OFF, ensuring efficient energy usage and responsive environmental control.
- Manual Mode:
  In this mode, sensor readings are still monitored and displayed, but the aerator does not respond automatically. Instead, users must manually activate or deactivate the aerator using the "Turn On" or "Turn Off" button in the application. This allows users to take direct control when needed, for instance during testing, maintenance, or exceptional conditions not captured by the automatic logic.

V. Conclusion

AquaNest presents an efficient, cost-effective, and sustainable approach to water quality monitoring by utilizing pH and temperature sensors to estimate dissolved oxygen levels indirectly. This IoT-based system eliminates the need for direct DO sensors by leveraging scientifically validated relationships between temperature, pH, and oxygen solubility. Through integration with the ESP32 microcontroller and a mobile application, AquaNest offers both automatic and manual control modes, enabling real-time responses to changing environmental conditions.

The automated aerator control ensures that oxygen levels are maintained within safe limits, supporting aquatic life while optimizing energy usage. Manual override via the application provides additional flexibility for users. By facilitating continuous environmental monitoring and responsive control, AquaNest contributes to the sustainability of aquatic ecosystems and supports the objectives of SDG 14 – Life Below Water, making it a valuable tool for modern aquaculture, aquarium management, and water resource conservation.

References

[1] M. P. Sharma et al., "Water Quality Parameters: A Review," International Journal of Engineering Research and Applications (IJERA), vol. 10, no. 6, pp. 13–17, 2020.

[2] R. Ramya and S. Shanmugasundaram, “Smart water quality monitoring system using IoT environment,” Int. J. Pure Appl. Math., vol. 119, no. 16, pp. 2219–2225, 2018.

[3] Hariyadi, M. Kamil, and P. Ananda, “Sistem pengecekan pH air otomatis menggunakan sensor pH probe berbasis Arduino pada sumur bor,” *RANG TEKNIK Journal*. Available: https://jurnal.umsb.ac.id/index.php/RANGTEKNIKJOURNAL/article/view/1930/1609

[4] D. W. Otterson, “pH Measurement and Control Basics,’ *SAGE journals*. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC4180894/

[5] W. Aoi, Y. Marunaka, “Importance of pH Homeostasis in Metabolic Health and Diseases: Crucial Role of Membrane Proton Transport,” *BioMed Research International.* Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC4180894/

[6] H. Dallas, “The effect of Water Temperature on Aquatic Organisms: A Review of Knowledge and Methods for Assessing Biotic Response to Temperature,” *Water Research Commision*. Available: https://www.researchgate.net/publication/268803537_The_effect_of_water_temperature_on_aquatic_organisms_A_review_of_knowledge_and_methods_for_assessing_biotic_responses_to_temperature

[7] [B. Ali, Anushka, A. Mishra, “Effects of Dissolved Oxygen Concentration on Freshwater Fish,” *International Journal of Fisheries and Aquatic Studies*. Available: https://www.researchgate.net/publication/362634321_Effects_of_dissolved_oxygen_concentration_on_freshwater_fish_A_review

[8] R. V. Sunyer, C. M. Duarte, “Thresholds of Hypoxia for Marine Biodiversity,” *PubMed*. Available: https://www.researchgate.net/publication/23289890_Thresholds_of_hypoxia_for_marine_biodiversity?utm_source=chatgpt.com

[9] R. Nordio, E. Viviano, A. S. Zurano, “Influence of pH and Dissolved Oxygen Control Strategies on The Performance of Pilot-scale Microalgae Raceways Using Fertilizer or Wastewater as the Nutrient Source,” *Journal of Environmental Management.* Available: https://www.sciencedirect.com/science/article/abs/pii/S0301479723016870

[10] S. Zainab, N. Handajani, H. Wibisana, “Acidity (pH) and Dissolved Oxygen Levels as Indicators of Water Quality Around the Tuban Coastal Area,” *NST Proceedings.* Available: https://nstproceeding.com/index.php/nuscientech/article/download/768/727/2365

[11] L. Zeng, C. Yan, F. Yang, Z. Zhen, J. Yang, “The Effects and Mechanisms of pH and Dissolved Oxygen Conditions on the Release of Arsenic at the Sediment-Water Interface in Taihu Lake,” *MDPI*. Available: https://www.mdpi.com/2305-6304/11/11/890

[12] F. Febiyanto, “Effects of Temperature and Aeration on The Dissolved Oxygen (DO) Values in Freshwater Using Simple Water Bath Reactor,” Walisongo Journal of Chemistry. Available: https://www.researchgate.net/publication/343665631_Effects_of_Temperature_and_Aeration_on_The_Dissolved_Oxygen_DO_Values_in_Freshwater_Using_Simple_Water_Bath_Reactor_A_Brief_Report

[13] E. W. Pratama, A. Kriswantono, “Electrical Analysis Using ESP-32 Module in Realtime,” Journal of Electrical Engineering and Computer Sciences. Available: https://ejournal.ubhara.ac.id/jeecs/article/download/21/11

[14] Ozami. “Mengenal ESP32, Mikrokontroler IoT”. Availabale: https://ozami.co.id/mengenal-esp32-mikrokontroler-iot/

[15] DigiwareStore. “Gravity: Analog pH Sensor / Meter Kit for Arduino Ver.1”. Available: https://digiwarestore.com/id/sensor-other/gravity-analog-ph-sensor-meter-kit-for-arduino-ver1-296334.html

[16] Y. Tjandi, S. Kasim, “Electric Control Equipment Based on Arduino Relay,” *Journal of Physics Conference Series*. Available: https://www.researchgate.net/publication/334023870_Electric_Control_Equipment_Based_on_Arduino_Relay

[17] SunFounder. “5V Relay Module”. Available: https://docs.sunfounder.com/projects/ultimate-sensor-kit/en/latest/components_basic/25-component_relay.html

[18] V. P. S. Bentulan, “Temperature Sensor Using Arduino,” *Research Gate*. Available: https://www.researchgate.net/publication/361320414_Temperature_Sensor_Using_Arduino

[19] Random Nerd Tutorials. “9 Arduino Compatible Temperature Sensors for Your Electronics Projects”. Available: https://randomnerdtutorials.com/9-arduino-compatible-temperature-sensors-for-your-electronics-projects/

[20] M. A. D. Perin, M. J. Cuaton, A. J. Rapirap, “Automated Aerator System for Controlling Dissolved Oxygen and Monitoring Acidity and Temperature on Aquatic System,” *Research Gate*. Available: https://www.researchgate.net/publication/326129037_AUTOMATED_AERATOR_SYSTEM_FOR_CONTROLLING_DISSOLVED_OXYGEN_AND_MONITORING_ACIDITY_AND_TEMPERATURE_ON_AQUATIC_SYSTEM

[21] “Aerator Portable USB Taffware Fish Tank Aquarium”. Available: https://shopee.co.id/Aerator-Portable-USB-Taffware-Fish-Tank-Aquarium-i.48977535.24300326771

[22] HowToMechatronics. “Arduino 16×2 LCD Tutorial – Everything You Need to Know”. Available: https://howtomechatronics.com/tutorials/arduino/lcd-tutorial/#google_vignette

[23] S. I. Patty, M. P. Rizqi, dan R. Huwae, “Oksigen Terlarut di Perairan Bolaang Mongondow Timur, Sulawesi Utara (Dissolved Oxygen in the East Bolaang Mongondow Waters, North Sulawesi),” *Jurnal Ilmiah Platax*, vol. 10, no. 1, pp. 216, Jan.–Jun. 2022. Available: https://ejournal.unsrat.ac.id/v3/index.php/platax/article/view/40434/36679